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Research Trends in Zoology

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PREFACE

Zoology, the scientific study of animals and their interactions with the environment, continues to evolve with advancements in research methodologies and interdisciplinary approaches. From classical taxonomy and morphology to molecular genetics and ecological conservation, zoological research has expanded its horizons, contributing significantly to our understanding of biodiversity, species adaptation, and ecosystem dynamics. With the growing need to address global challenges such as climate change, habitat loss, and species extinction, the importance of zoological studies has never been more crucial.

Research Trends in Zoology aims to provide a comprehensive insight into the latest developments and emerging trends in this ever-expanding field. This volume brings together contributions from researchers and scholars worldwide, highlighting novel discoveries and innovative methodologies in various branches of zoology.

One of the key aspects of modern zoological research is its interdisciplinary nature. The integration of genetics, biotechnology, bioinformatics, and environmental sciences has opened new avenues for understanding complex biological phenomena. Studies on animal physiology and molecular biology are shedding light on fundamental life processes, while advancements in conservation biology are offering sustainable solutions for preserving endangered species. This book emphasizes the importance of such interdisciplinary research and its role in shaping the future of zoological sciences.

The objective of this book is to serve as a valuable resource for students, academicians, and researchers who are keen on exploring the latest research trends in zoology. By presenting a blend of theoretical insights and practical applications, we hope this volume will inspire further studies and foster scientific discussions among scholars.

We extend our sincere gratitude to all the contributors for their dedicated efforts in bringing forth high-quality research. We also appreciate the support and cooperation of the editorial team, whose meticulous work has ensured the successful completion of this volume. It is our belief that Research Trends in Zoology will serve as a significant reference for those passionate about the study of animal life and its ever-evolving dimensions.

- Editors

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DETERMINATION OF PLANKTON POPULATION WITH SPECIAL REFERENCE TO POLLUTION STATUS

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Abstract:

Water proved to be important natural resources in the world, without it life can't exist. Essentially, all life forms depend upon the water for being a major component of living organisms. Any alterations in normal water quality directly relate to survival of aquatic organisms. In aquatic organisms, planktons were most sensitive component of the ecosystem and one of the crucial indicators of environmental disturbances. The composition, distribution and abundance of phytoplankton, in water body were found depend upon the physico-chemical properties of water. The zooplanktons were important as they play role in maintaining food chain. Therefore, it becomes important to gain knowledge and acquire requisite skills to ensure the conservation of water as vital resource. Considering the biological system along with the floral and faunal diversity some standard methodological assessment required. The main objective of this study is to highlight the impact of various water pollutants on aquatic organisms which have rendered the water unsuitable for drinking and other domestic purposes. The composition, distribution and abundance of phytoplankton, in water body were found depend upon the chemical and physical properties of water. Physico-chemical factors influence the biological productivity of the water body.

Keywords: Phytoplankton, Zooplankton, Pollution Status

Introduction:

Life on the earth began in the water, which found to be essential source for existence of life. In the nature, water is not only essential for survival of all living things but, is the important source of economic wealth and creator of wonderful environment. Water serves as essential requirement for every cell of an organism to perform normal functions.

A plenty supply of clean water is essential for survival of human being, plants and animals. The disposal of industrial and agricultural waste directly into the aquatic medium burdens the ecosystem (Nagarathnamma and Ramamurthy, 1983). Phosphate is a nutrient for plant growth and a fundamental element in the metabolic reaction of plants and animals. It controls algal growth and primary productivity. Excess amounts of phosphorus can cause eutrophication leading to excessive algal growth called algal blooms (Gyathri *et al.,* 2013).

Physico-chemical parameters of ground water in relation to health have been studied by number of scientists. But less attention has been found to compare with river, reservoirs, lake and ponds (Vijay kumar, 1996 and Reddy, 2001). Water quality affects the abundance, species, its composition, stability, productivity and physiological conditions of aquatic animals. Therefore the nature and health of aquatic communities is a unique expression of water quality (APHA, 1985). Water pollution has significant effect on human health, balance of aquatic ecosystems, socio-economic development and prosperity (Milovanovic, 2007). Rivers and streams have been used for discharging waste. Most of the civilizations have grown and flourished on the banks of rivers, but unfortunately, growth in turn, it has been responsible for pollution of rivers.

Polluted water is the main cause of a number of diseases. Polluted water not only affects the life of present generation but it also affects the life of upcoming generations because its effect remains for long. In India most of the area is characterized by intensive farming, and urban-industries development. Thus the aquatic environment gathers several elements which affect the quality of the rivers and lakes. The nutrient increase, toxins presence and others xenobiotics input, such as biocide and heavy metals, provoke changes in the normal conditions that according to inflow regime (sewage of various degrees of treatment, thermal regime, weather conditions and land use) affect the quality conditions of the receptors. Some products and household waste, industrial discharges, pesticides or sewage are transformed and degraded through various reactions with other biotic and abiotic components, when they get into the river.

Available literature and information suggest that environmental pollution get intensified now days. The region may be revolution in the industries, agricultural field which release of toxic chemical, gases and other waste into terrestrial and aquatic environment. This release of toxic chemicals and metals causes the health hazardous to flora and fauna depending on it.

Phytoplankton found fundamental component of aquatic ecosystems as they are the major source of food chain. Phytoplankton, being the primary producer, forms the lowest trophic level in the food chain of freshwater ecosystem, moreover, number and species of phytoplankton served for determination of water quality. Distribution of phytoplankton with variation at different zones found influenced by physiochemical parameters of water. Temperature is an important controlling factor for the growth of phytoplankton and zooplankton Phytoplankton study provides a relevant and convenient point in research and in mechanism of eutrophication with its impact on an aquatic eco-system.

Eutrophication can be defined as the sum effects of the excessive growth of phytoplanktons leading to imbalanced primary and secondary productivity and a faster rate of succession from existence to higher serial stage, as caused by nutrient enrichment through runoffs that carry down overused fertilizers from agro-ecosystems and discharged human waste from settlements. Water eutrophication can be greatly accelerated by human activities that increase the rate of nutrient input in a water body, due to rapid urbanization, industrialization and intensifying agricultural production. Zooplankton occupies an intermediate position in the aquatic food web (Altaff, 2004). Different environmental factors that determine the characteristics of water have great importance upon the growth and the abundance of zooplankton (Thirumala *et al.,* 2007). The term water quality defined as those physical, chemical and biological characteristics by which the users evaluate the acceptability of water (Neelima and Kumar, 2005). Therefore the water quality is a major factor in determining the welfare of the society (Dwivedi and Pathak, 2000). It also plays a vital role in governing the production of planktonic biomass.

Obtained data was discussed in relation to pollution status of all study sites which in turns come up with the level to of contamination of the region and its impact over bioresource in the ecosystem.

I) Material and Methods:

1. Study area:

For the present study, freshwater aquatic bodies from Gadhinglaj Tahsil, District Kolhapur, state Maharashtra had been selected.

2. Geographical survey:

Gadhinglaj tahsil is one of the important tahsil of the Maharashtra state, geographically at latitude 16º 13' 26" N and longitude 74º 26' 9" E. Throughout the Tahsil, there are number of small and large water bodies are present along with an important river Hiranyakeshi that is lifeline of the Tahsil. Overall this river has about 140 km distance and finally meets to Ghataprabha River. Major area of the basin of river is under agricultural practice, whereas remaining area is forest covered. Most of the people depend on the river

Hiranyakeshi for their day- today needs as well as for agricultural processes. This region has rich animal biodiversity but the quantity and quality of water from this river is now a days affected by municipal, industrial as well as agricultural discharge.

The present study was carried to reveal the baseline status of freshwater bodies from Gadhinglaj tahsil. The selected sites are mentioned in Plate No. 1.

Plate No. 1

Plate No. 2

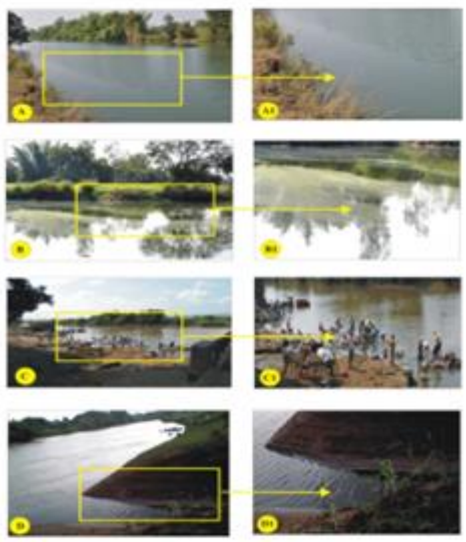


Plate No. 3

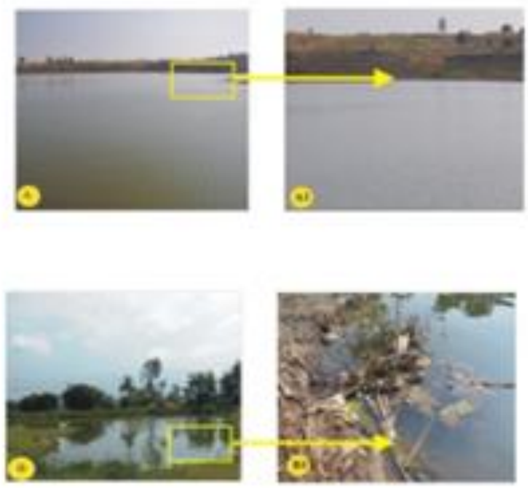


Plate No. 1, 2 and 3: Graphical and pictorial view of Hiranyakeshi River, Gadhinglaj, Kolhapur, Maharashtra representing study sites

a. Lotic system in Gadhinglaj Tahsil:

Lotic system is the running water system. It includes rivers, streams and springs, etc. Hiranyakeshi river is the major lotic system which arises at Amboli in Sindhudurg district.

For the present study we have selected four sites of Hiranyakeshi river, Mahagoan site (N 16°9’54” E 74°19’58”), Harali site (N 16°9’54” E 74°19’58”), Nilgi site (N 16° 14’ 16” E 74° 25’ 41”) and Nangnur site (N 16°14’3” E 74° 29’46”). Most of the sugar industries are located close to the freshwater resources and their effluents are disposed off into the freshwater that creates the problem of ground water as well as soil pollution. With the selected area Harali sugar factory is situated at West zone of Gadhinglaj tahsil and Senkeshwar sugar factory is at East zone of Gadhinglaj tahsil. Organic and inorganic waste of Harli factory is mixed into Hiranyakeshi site at Harli (khurd). Waste of Senkeshwar factory is mixed into Nangnur site (Plate No. 2).

b. Lentic system in Gadhinglaj Tahsil:

Lentic as standing water system includes ponds, lakes, swamps, etc. There are 40 to 45 small or larger water reservoirs distributed in the Gadhinglaj tahsil. Nool reservoir, (N16°12’36” E 74° 25’ 56”) and Yenechwandi reservoir (N 16°10’24” E74°25’46”) are present at the base of Samangad. Nool and Yenechwandi are situated at east zone of Gadhinglaj Tahsil. These are two small freshwater bodies located in Gadhinglaj Tahsil. The local inhabitants depend on these for their daily needs like drinking, cloth washing, cattle washing and agriculture use etc. (Plate No. 3).

4. Laboratory analysis:

Different physico-chemical parameters were analyzed by applying following standard physico-chemical methods as per (APHA, 1985). Heavy metal analysis was carried out by using Atomic Absorption Spectrophotometer (AAS) (Kemito company- 201).

b. Biological parameters:

- **Qualitative and quantitative analysis of phytoplankton and zooplanktons:**

The planktonic samples were collected fortnightly, from sampling sites, by filtering hundred liters water through plankton net made-up of bolting silk No.125. The concentrated samples were preserved by adding 4 % formalin. The phytoplankton and zooplanktons were analyzed on seasonal base, qualitatively and quantititatively by Sedgwick Rafter cell method, (1988).

Results and Discussion:

All physico-chemical parameters from six water bodies higher values in summer. The lotic sites II and IV were polluted due to continuous discharge of distillery effluents indicating high concentration of COD, while lentic site II polluted by domestic pollution. Thus, it can be concluded that these characteristics of water bodies are influenced by seasonal variation. It is recommended that the proper maintaince of the water bodies is necessary. Deterioration of water quality and eutrophication are due to casual attitude of people. Human activities include washing of cloths, vehicles and household utensils, discharge of sewage, industrial and agricultural effluents etc. even though nature has got its own mechanisms to take care of waste when they are in limited quantities. Proper sanitation measures and environmental education to public care essential to keep these water bodies clean and safe.

Planktons form a remarkable bioindicator for water pollution. Various physico-chemical factors like pH, DO, alkalinity, hardness, free CO_2, sodium, potassium were analyzed, increased range of these physico-chemical parameters adversely affect the phytoplankton production. Experimental studies have suggested that a higher assimilation of carbon into organic matter at high CO_2 may increase extracellular organic matter release from phytoplankton cells. Plankton diversity quickly responds to change in the environment of aquatic system, particularly in relation to nutrients.

The healthy aquatic ecosystem depends on the biological diversity and physico-chemical characteristics (Venkatesharaju *et al.,* 2010). Phytoplankton and zooplankton diversity have been made by Rao and Choubey, 1990; Devercelli M., (2006).; Adeyeye E. I. Abulude F.O. (2004), Mishra *et al.,* 2010; and Joseph and Yamakanamardi, 2011). Change in any physico-chemical factor of the water body directly or indirectly causes great variation in phytoplankton species diversity and abundance (Patil *et al.,* 2015).

I. Phytoplankton Analysis:

Present study showed four groups of phytoplankton population as *Cyanophyta, Chlorophyta, Bacillariophyta*, and *Euglenophyta* (Table No.1, Fig: 1 and Plate No. 4, 5, 6). Planktonic quantification from four sites of Hiranyakeshi river, site I, II, III and IV and two stagnant water bodies site V and VI from Gadhinglaj tahsil, were assessed for seasonal variations. Comparatively *Bacillariophyta* was dominating with seventeen species in it. Next to *Bacillariophyta, Chlorophyta*, included ten species whereas, *Cyanophyta* showed five diversified species in study area. *Euglenophyta* showed only one species.

Thus Phytoplankton population in the study area showed order of dominancy among the species with regards to number as follows: Bacillariophyta > Chlorophyta > Cyanophyta > Euglenophyta. On an average the lotic ecosystem representing least phytoplankton population as compare to lentic ecosystem.

II. Zooplankton Analysis:

Zooplanktons are microscopic organisms which include protozoans, microcrustaceans and other micro invertebrates that are planktonic present in water bodies. The freshwater zooplankton comprises protozoa, rotifers, cladocera, copepods, microscopic crustaceans and microinvertibrates suspended in water. Zooplankton found to be major link in energy transfer to the higher trophic level.

Zooplankton is good indicator of the changes in water quality because they are strongly affected by environmental conditions and respond quickly to changes in water quality (Dhembare, 2011). They occupy an intermediate link between phytoplankton and fish. Hence qualitative and quantitative studies of zooplankton are of great importance.

Zooplanktons are minute aquatic animals that are very weak swimmers. They contribute significantly to biological productivity of freshwater ecosystem.

The major group of zooplankton observed during assessment were *Rotifera, Ostracoda, Cladocera, Copepoda and Protozoa* are majority documented (Table No. 2 Fig: 2 and Plate No.7, 8, 9). Quantified data related to species diversity showed nine species of *Rotifera,* four species of *Cladocera,* five species of Protozoa, four species of *Copepoda* and only one species of *Ostracoda.*

Among zooplankton in the study area, the order of dominance in diversified groups was as follows: Rotifera > Copepoda > Cladoecera > Protozoa > Ostracoda.

Thus Copepodans, Cladocerans and Rotiferans were maximum in population as compared to Ostracoda species. Comparatively Ostracoda species minimum at all sites. On an average the lotic ecosystem representing least zooplankton population as compare to lentic ecosystem.

Zooplankton communities found responsive to nutrients levels, temperature and pollution and can be used to determine the health of an ecosystem. Animals were typically tiny animals found near the surface of the aquatic environments. Cyclops found pollution tolerant and was abundantly in nutrient rich environments and thus can be considered eutrophication indicators.

Biodocumentation of planktons indicated that, site V and site VI showed maximum species richness, during summer season as that of in rainy and winter season which may be due to stagnancy, eutrophication and increased CO_2 content as one of the reason of contaminated aquatic bodies.

Table 1: Enumeration of Phytoplanktons from study sites

Sr. No.	Name of species	I	II	III	IV	V	VI
A	**Cyanophyta**						
01	*Ulothrix*	+	+	+	+	+	+
02	*Gomphospheria*	+	+	+	+	+	+
03	*Fragilaria*	+	+	-	-	+	+
04	*Closterium*	+	+	-	+	+	-
05	*Pleurotaenium*	+	+	+	-	-	+
B	**Chlorophyta**						
06	*Pinnularia dolasa v. robusta*	-	-	-	-	+	+
07	*Diacanthos species*	-	-	+	+	-	-
08	*Ankistrodesmus fulcatus*	-	+	-	-	+	-
09	*Pediastrum ovatum*	+	+	-	+	+	+
10	*Pedistrum simplex*	+	+	+	-	-	+
11	*Pedistrum duodenarium*	+	+	-	+	+	+
12	*Cosmarium nastum*	+	+	+	-	-	+
13	*Cosmarium punctulatum*	+	+	-	+	+	+
14	*Pinnularia interrupta*	+	+	-	+	+	+
15	*Spirogyra*	+	+	+	-	-	+
16	*Pediastrum orentale*	+	-	-	+	-	-
17	*Pinnularia arosphaeria v. minor*	-	+	+	-	-	+
18	*Pinnularia dolasa v. tumid*	+	+	-	-	+	-
19	*Spirogyra protensis*	-	+	-	-	+	-
C	**Bacillariophyta**						
20	*Diatoma*	+	+	-	+	+	+
21	*Cyclotella meneghiniana*	+	+	+	-	-	+
22	*Diatoma vulgaris*	+	+	+	+	+	+
23	*Gomphonema parvulum*	-	-	+	-	+	+
24	*Gomphonema sphaerophorum*	-	-	-	-	-	+
25	*Gomphonema intricatum*	-	-	+	-	+	+
26	*Gomphonema subapicatum*	+	+	+	-	+	+
27	*Navicula gregaria*	+	-	-	-	+	-

28	*Navicula mutica*	+	+	+	+	+	+
29	*Navicula protracta*	-	-	+	+	-	+
30	*Navicula rhyncocephala*	-	+	-	-	-	-
31	*Navicula rodisa*	+	-	-	-	+	+
32	*Cymbella turgidula*	+	+	+	-	+	+
33	*Cymbella ventricosa*	+	+	-	+	+	+
34	*Cymbella engalensis*	-	+	+	-	+	+
35	*Stauroneis phoenicenteron*	+	+	+	-	+	-
D	**Euglenophyta**						
37	*Euglena maharashtrensis*	+	+	-	+	+	+
38	*Euglena sociabilis*	+	+	-	-	+	+

(+ indicates present, - indicates absent)

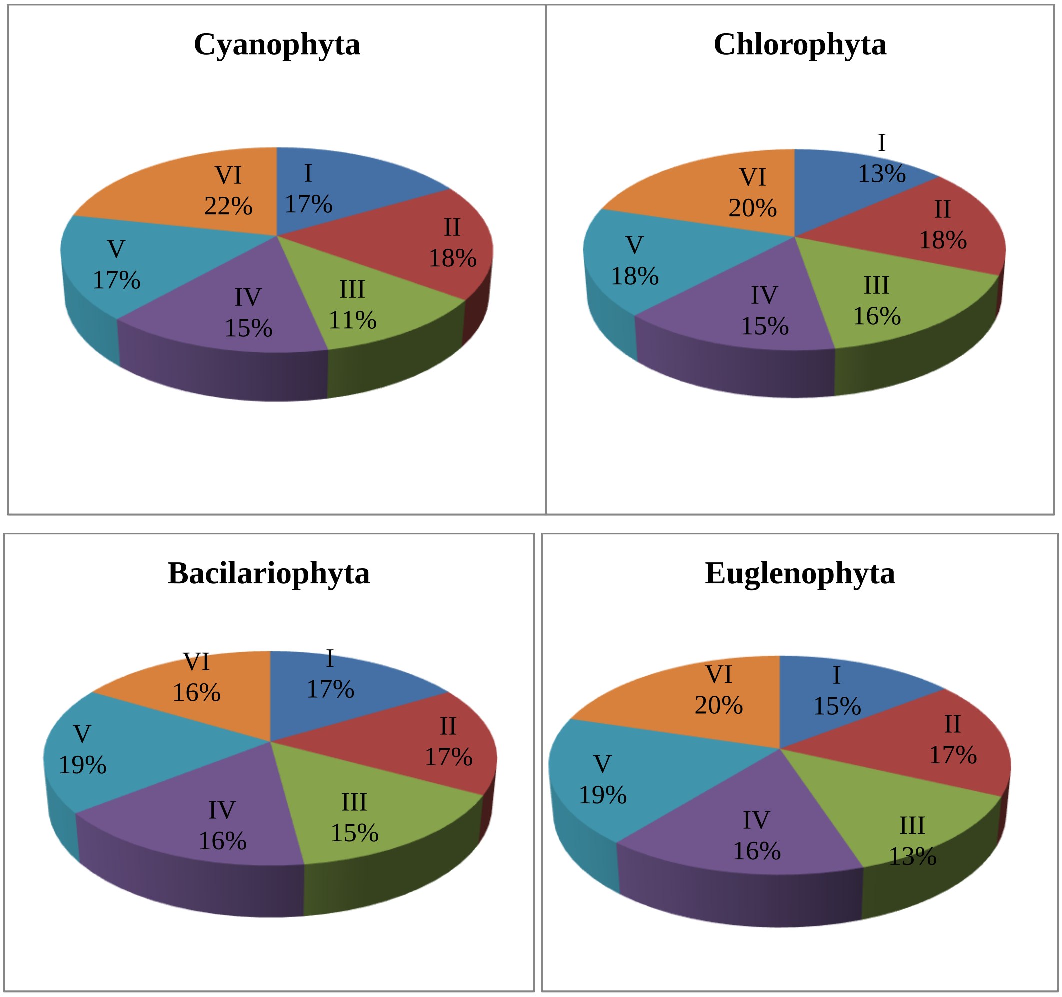


Figure 1: Percent composition of Phytoplankton from study sites

Table 2: Enumeration of Zooplanktons from study sites

Sr. No.	Name of species	I	II	III	IV	V	VI
A	**Rotifera**						
01	*Brachionus calciflorus*	-	+	+	-	+	+
02	*Brachionus angularis*	+	+	+	+	+	+
03	*Brachionus forficula*	+	+	-	-	+	+
04	*Brachionus quadrientata*	+	+	-	+	+	-
05	*Brachionus falcatus*	+	+	+	-	-	+
06	*Brachionus caudatus*	-	-	+	-	+	+
07	*Keretella tropica*	-	-	-	-	+	+
08	*Keretella quadrata*	-	-	+	+	-	-
09	*Tricholera longiseta*	-	+	-	-	+	-
B	**Ostracoda**						
10	*Stenocypris*	+	+	-	+	+	+
11	*Cypris subglobosa*	+	+	+	-	-	+
C	*Copepoda*						
12	*Cyclopoid copepod*	+	+	+	+	+	+
13	*Calanoid copepod*	-	-	+	-	+	+
14	*Mesocyclops sp.*	-	-	-	-	-	+
15	*Paracyclops sp.*	-	-	+	-	+	+
16	*Nauplius sp.*	+	+	+	-	+	+
D	**Cladocera**						
17	*Moina micrura*	+	-	-	-	+	-
18	*Daphnia carinata*	+	+	+	+	+	+
19	*Cerodaphnia reticulate*	-	-	+	+	-	+
20	*Daphanosoma sarsi*	-	+	-	-	-	-
21	*Leptodora kindtii*	+	-	-	-	+	+
E	**Protozoa**						
22	*Paramecium cauuadatum*	+	+	+	-	+	+
23	*Euglina species*	+	+	-	+	+	+
24	*Verticella species*	-	+	+	-	+	+
25	*Metapus species*	+	+	+	-	+	-
26	*Stentor species*	+	+	-	-	+	+
27	*Balantidium species*	-	+	+	-	+	+

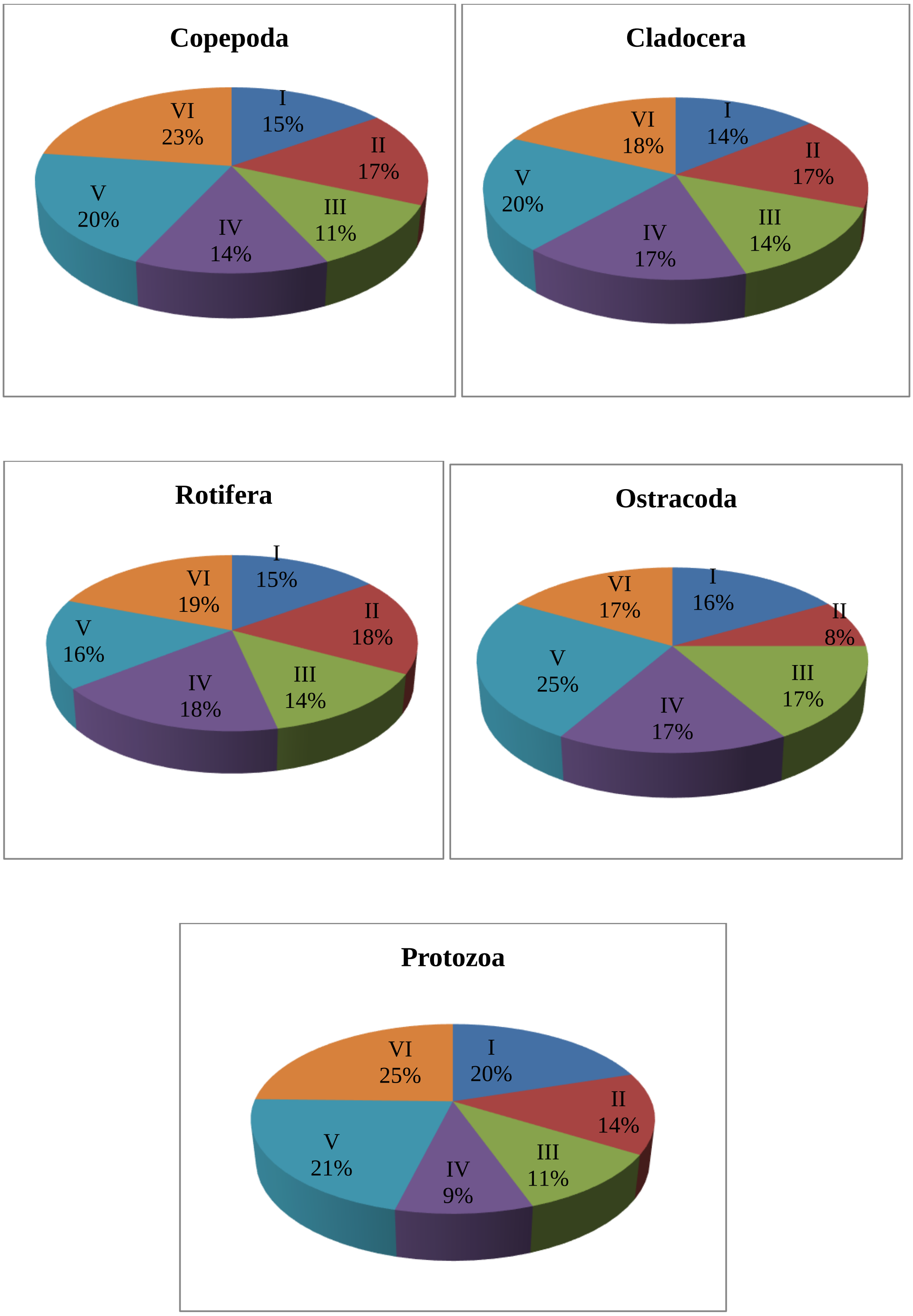


Figure 2: Percent composition of Zooplanktons from study sites

Plate No. 4

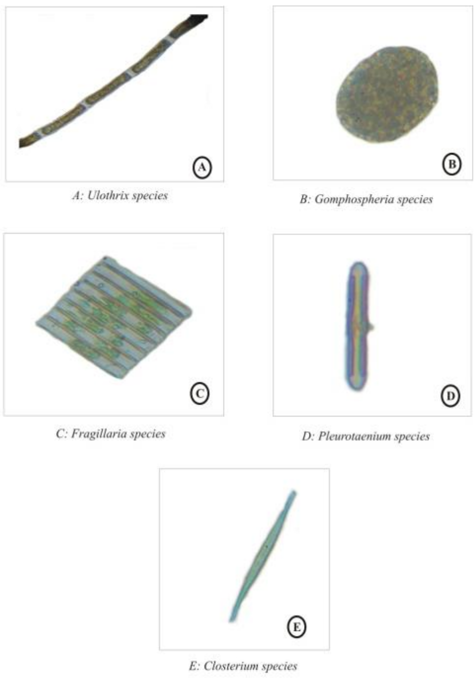


Plate No. 5

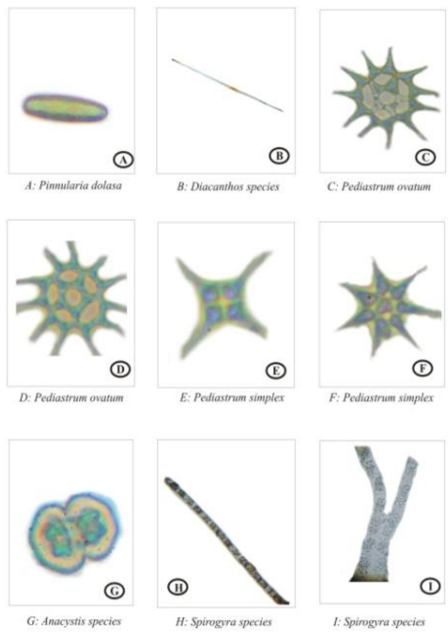


Plate No. 6

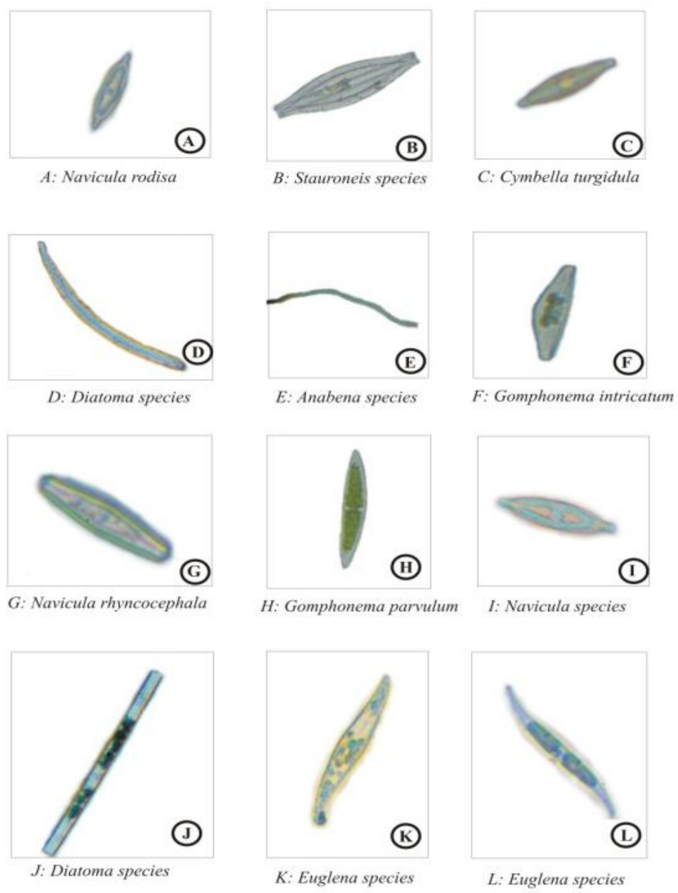
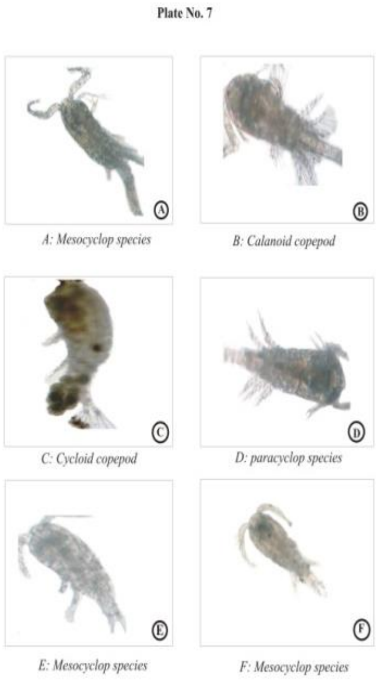
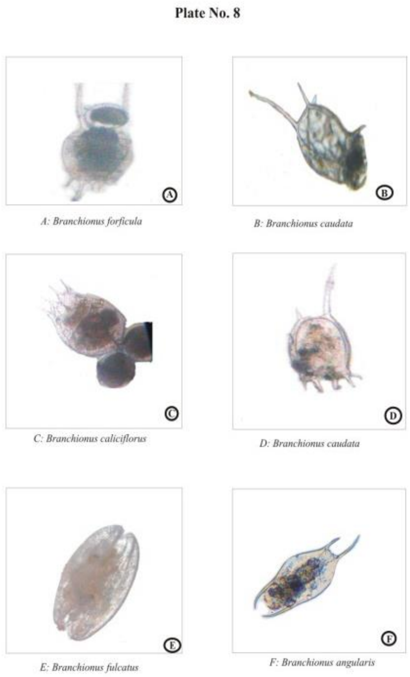


Plate No. 4, 5, and 6: Microscopic images of phytoplankton's





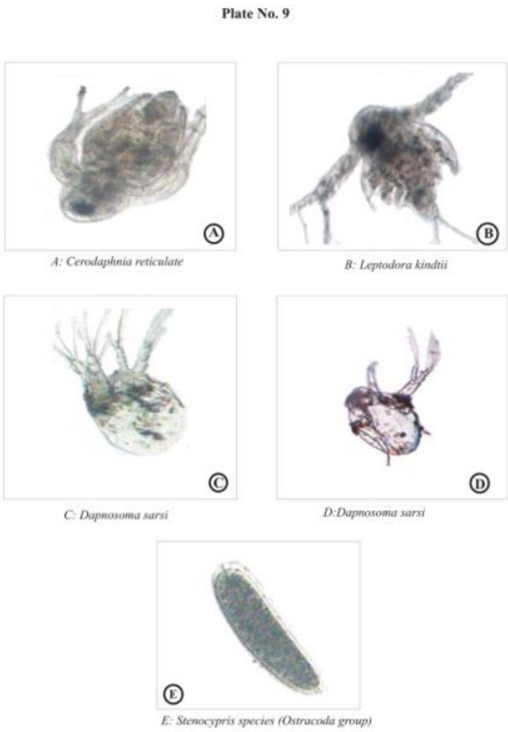


Plate No. 7, 8, and 9: Microscopic images of Zooplanktons.

In the present study lentic sites V and VI showed increased percentage producing the dense mat of vegetation over the waterbodies.

Now a day's aquatic biodiversity is threatened primarily by human misuse and mismanagement of both living resources and the ecosystems which realy support them. Most of the ponds are getting polluted due to domestic waste, sewage, industrial and agricultural effluents. The essentiality of water for development of micro-organisms up to man became serious problem due to unplanned urbanization and industrialization in restricted zones. Water quality assessment generally involves analysis of physico-chemical, biological and microbiological parameters and reflects on abiotic and biotic status of the ecosystem.

Conclusion:

Present study concludes that, seasonal changes showed variation in planktonic population, most of the species were least documented in the period of rainy season. We found that, Phytoplankton population was maximum in summer due to favorable conditions of high level of nutrients with increased photo period of day with high intensity of light. Presence of *Chlorella* under Chlrophyta was found to be dominant species in the assessment indicating that water quality of selected aquatic body is slightly polluted by mixing of organic material thus *Chlorella* indicated contamination of aquatic bodies. In the present investigation *Chlorella species* found only at site II, V and VI indicating organic pollution. Thus, magnitude and dynamics of plankton population becomes an essential tool to assess the general health of an aquatic ecosystem.

In conclusion, overall plankton population of lentic study sites were much more diversified indicating as nutrient rich water body which may undergo the state of eutrophication, if not managed properly. Therefore, the water body has to be preserved for their future use, a sustainable and holistic management planning is necessary for conservation of freshwater bodies.

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ENHANCING FISH SPECIES IDENTIFICATION: INTEGRATING TRADITIONAL AND MODERN METHODS

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Abstract:

Accurate species identification is fundamental to understanding, monitoring, and managing fish biodiversity worldwide. Traditional morphological methods—though long established—face challenges with cryptic species, phenotypic plasticity, and rapid environmental changes. In response, researchers have developed an array of innovative identification tools including computer-assisted image recognition, advanced morphometrics, hydroacoustic techniques, and DNA-based methods such as barcoding and SNP analysis. This chapter reviews the evolution and application of these tools, examines their strengths and limitations, and highlights how their integration can lead to more effective biodiversity assessments and sustainable fisheries management. Through detailed case studies from diverse aquatic ecosystems, we demonstrate that combining traditional and modern techniques enhances species resolution and aids in combating issues such as mislabeling, overexploitation, and the loss of genetic diversity. Finally, we discuss emerging trends and propose future directions for research and policy.

Keywords: Fish Identification, Biodiversity Assessment, DNA Barcoding, Acoustic Surveys, Morphometrics, Image Recognition, Environmental DNA, Fisheries Management.

Introduction:

The world's aquatic ecosystems harbor a staggering diversity of fish—over 32,000 species of finfish are currently recognized, with many more awaiting discovery [1, 9, 14]. Fish biodiversity is not only of intrinsic scientific interest but is also critical for fisheries management, conservation, and sustaining livelihoods. Accurate species identification forms the bedrock of these endeavors, ensuring that stock assessments, conservation measures, and regulatory policies are based on reliable data [1, 47, 50].

Traditional taxonomic approaches—relying on morphological keys, expert judgment, and reference collections—have been the standard for decades [2, 8]. However, these methods are time-consuming and require specialized training, which is not always available in regions of high biodiversity or in rapidly changing environments [2, 5, 8].

Moreover, many fisheries inspectors, data collectors, and even consumers often lack formal taxonomic training, leading to frequent misidentifications that compromise fisheries statistics and conservation outcomes [5, 15].

Recent decades have witnessed a paradigm shift. Advances in molecular biology, computer vision, and acoustic technologies have introduced innovative fish identification tools that are both rapid and robust. DNA barcoding, for example, has revolutionized species authentication by enabling identification from tiny or degraded samples [15, 26]. Similarly, image recognition systems powered by machine learning (e.g. IPOFIS, IPez) now allow even non-specialists to accurately identify fish from digital photographs [2, 8]. Acoustic techniques further complement these methods by providing non-invasive estimates of fish abundance and distribution over large spatial scales [2, 5, 59].

This chapter provides a comprehensive review of the fish identification tools currently available. We discuss traditional morphological methods alongside modern molecular, imaging, and acoustic approaches. We also present case studies from diverse geographic regions and aquatic systems that demonstrate how these methods are applied in biodiversity assessments, fisheries management, and food safety. Finally, we discuss challenges inherent to each approach and propose a framework for integrating multiple techniques to achieve a synergistic and reliable system of fish identification.

2. Background

2.1 The Imperative for Accurate Fish Identification

Accurate identification is essential to all aspects of fish Biodiversity research. Inaccurate or inconsistent species recognition can lead to misreported catch data, misinformed management decisions, and the misallocation of conservation resources [1, 47, 50]. For example, when morphologically similar or cryptic species are confused, fisheries managers may inadvertently overexploit one stock while underestimating the conservation needs of another [47, 55]. In addition, the growing global trade in seafood demands rigorous traceability to ensure food safety and prevent fraudulent practices [15, 21].

Traditional morphological approaches—based on features such as scale counts, fin ray numbers, and body coloration—have long been used to catalog fish diversity [2, 8]. However, these techniques are limited by seasonal variations, ontogenetic changes, and convergent evolution that can mask true genetic relationships [2, 5]. Furthermore, reliance on expert taxonomists is problematic given the worldwide shortage of such specialists [5, 8]. These limitations have spurred the development of alternative tools that can provide rapid, accurate, and reproducible identifications.

2.2 Evolution from Traditional to Modern Approaches

Historically, fish identification relied on dichotomous keys, illustrated field guides, and comparison with museum reference collections [2, 8, 9]. In regions with well-documented faunas—such as Europe and North America—these methods remain effective. However, in biodiversity hotspots where many species are undescribed or exhibit high morphological variability, traditional methods fall short [5, 8, 43].

Modern techniques have introduced new avenues for identification:

Molecular Methods:

DNA barcoding, which typically targets the mitochondrial COI gene, has provided a robust means to identify species from even minute tissue samples [15, 26, 28]. Single nucleotide polymorphism (SNP) analyses further enable population-level discrimination and tracking of genetic stocks [2, 28, 34].

- Image Recognition & Morphometrics: Advances in digital imaging and machine learning have resulted in tools like IPOFIS and IPez that can rapidly analyze fish images, extract morphometric data, and provide automated identifications [2, 8, 32]. Such systems reduce the need for specialized taxonomic expertise and can be deployed on mobile devices for field applications [32, 33].
- Acoustic Methods: Hydroacoustic surveys utilize sound scattering properties to estimate fish densities and, increasingly, to infer species composition through multi-frequency analysis [2, 5, 59]. Although these methods require substantial investment and expertise, they offer non-invasive means to monitor fish populations over large areas [59].

Integration of these techniques offers a promising strategy for achieving high accuracy, rapid response times, and cost-effectiveness—factors essential for effective biodiversity assessments in today's dynamic aquatic environments [15, 26, 34].

3. Overview of Fish Identification Tools

In this section, we review the principal categories of fish identification tools. Each tool is evaluated in terms of methodology, advantages, limitations, and field applicability. (In-text citations refer to the final References section.)

3.1 Traditional Morphological Methods

For decades, traditional morphology-based identification has been the foundation of ichthyology [2, 8, 9]. Experts use keys based on characters such as body shape, fin morphology, scale counts, and coloration to distinguish among species [2, 8]. Illustrated field guides and reference collections (e.g., FishBase [8, 9] and the Catalog of Fishes [14]) provide critical resources for this work.

Advantages:

- High taxonomic resolution when performed by experts [2, 8]
- Extensive historical data available for comparison [9, 14]

Limitations:

- Subjectivity in character interpretation [5, 15]
- Time-intensive and requires extensive training [5, 8]
- Morphological plasticity and cryptic species may lead to misidentification [5, 43]

3.2 Image Recognition Systems and Morphometric Software-

Recent advances in computer vision have led to the development of image recognition systems (IRS) that utilize deep learning to identify fish from photographs [2, 32]. Systems such as the Integrated Photo-based Online Fish-Identification System (IPOFIS) integrate large digital libraries with interactive dichotomous keys [2, 32]. In parallel, morphometric software such as IPez uses quantitative shape analysis—often combined with machine learning—to distinguish species based on subtle differences in morphology [32, 33].

Advantages:

- Rapid and non-invasive identification [32]
- Reduces reliance on specialist taxonomists [32, 33]
- Can be deployed on mobile devices for field use [32]

Limitations:

- Dependent on image quality and proper calibration [32]
- Regional variation in species appearance may reduce transferability [33]
- Requires substantial baseline data for training algorithms [33]

3.3 Molecular Identification Techniques

Molecular methods have transformed species identification. DNA barcoding employs a short standardized region of DNA (commonly the mitochondrial COI gene) to provide rapid, reliable identification [15, 26, 28]. In cases where morphological differences are slight or absent, molecular markers offer a powerful alternative [15, 26]. SNP analyses can further delineate population structure and are increasingly used for stock identification [2, 28, 34].

Advantages:

- High accuracy and reproducibility, even from degraded tissue [15, 26]
- Effective for cryptic and juvenile stages [15, 28]
- Enables forensic applications and traceability in seafood markets [15, 21]

Limitations:

- Requires laboratory facilities and technical expertise [15, 26]
- Higher per-sample cost compared to field-based techniques [15, 26]
- Reference databases (e.g., FISH-BOL) are still incomplete for some taxa [26, 27]

3.4 Acoustic Techniques

Acoustic identification leverages sound to detect and characterize fish schools. Multi-frequency echosounders analyze the backscattering properties of fish bodies, particularly their swim bladders, to estimate abundance and—when combined with advanced algorithms—even to infer species composition [2, 5, 59]. These methods are particularly useful in large-scale marine surveys.

Advantages:

- Non-invasive and suitable for monitoring vast areas [59]
- Provides real-time data on fish density and distribution [59]
- Can be integrated with trawl sampling for ground-truthing [2, 5]

Limitations:

- High capital and operational costs [59]
- Requires specialized training for data interpretation [59]
- Resolution may be insufficient to reliably distinguish closely related species without supplementary data [5, 59]

3.5 Integrated Web-Based Databases and Resources-

The emergence of online databases such as FishBase [8, 9], SeaLifeBase [11], the Catalog of Fishes [14], and ITIS [12] has revolutionized access to taxonomic data. These platforms aggregate morphological, molecular, ecological, and distributional data, enabling users to cross-reference and verify species identities [8, 9, 11, 12, 14].

Advantages:

- Broad accessibility and up-to-date taxonomic information [8, 9, 11, 12, 14]

– Facilitates collaborative research and data sharing [8, 11]
– Integrates various identification tools and data types [8, 12]

Limitations:

– Quality depends on data curation and periodic updates [8, 11]
– May exhibit regional biases in species coverage [12]
– Requires reliable internet connectivity for field applications [8, 11]

4. Molecular Methods

4.1 DNA Barcoding Protocols-

DNA barcoding typically targets a standardized region of the mitochondrial cytochrome c oxidase subunit I (COI) gene. The general protocol involves:

Sample Collection and Preservation: Tissue samples (fin clips, muscle, scales) are collected under sterile conditions and preserved in 95% ethanol to prevent degradation [15, 26].

- DNA Extraction: Standard extraction protocols (e.g., using commercial kits) are applied. Quality control is essential, as even degraded tissue can yield amplifiable DNA if handled properly [15, 26].
- PCR Amplification: Universal primers (such as FishF1/FishR1) amplify the ~650-bp COI region. Optimized thermal cycles are employed to maximize yield and minimize nonspecific products [15, 26].
- Sequencing and Data Analysis: Sanger sequencing or next-generation sequencing (NGS) is performed. Sequences are then compared against reference databases such as BOLD or FISH-BOL [15, 26, 28].

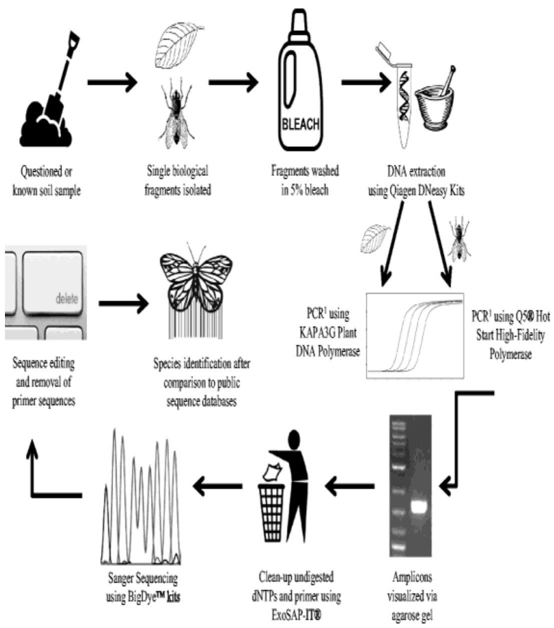

Photo 1: DNA barcoding protocol developed for processing biological material

Studies have shown that DNA barcoding can accurately distinguish species even when morphological characters are ambiguous [15, 26, 28]. In addition, metabarcoding protocols have been developed to analyze environmental DNA (eDNA) samples from water, providing non-invasive snapshots of community composition [17, 29].

4.2. SNP and Metabarcoding Approaches-

Beyond the COI barcode, SNP panels are now used for fine-scale population discrimination. The methodology involves:

- Baseline SNP Discovery: Using high-throughput sequencing, researchers identify single nucleotide polymorphisms that are diagnostic for particular populations or species [2, 28, 34].
- Genotyping: Platforms such as SNP arrays or targeted sequencing enable rapid genotyping of large sample sets [2, 28, 34].
- Data Integration: Genetic data are combined with morphological and acoustic data to produce integrated stock assessments [2, 28, 34].

These approaches are especially valuable when assessing fisheries management scenarios where stock identity and origin are critical for regulatory compliance [20, 28].

5. Image Recognition and Morphometric Analysis

5.1 Automated Image Recognition Systems- Recent advances in deep learning have led to the development of computer vision algorithms capable of identifying fish species from digital photographs. Typical steps include:

Image Acquisition: High-resolution images are obtained from field photography, underwater videography, or museum collections. Consistent lighting and standardized backgrounds improve algorithm performance [32, 33].

Preprocessing and Feature Extraction: Images are cropped, normalized, and processed to extract key features such as body shape, coloration patterns, and fin morphology. Convolutional Neural Networks (CNNs), often adapted from models like MobileNet, are employed to learn discriminative features automatically [32, 33].

Classification and Validation: The model is trained on annotated datasets, achieving high classification accuracy (often >90% under controlled conditions). Cross-validation and testing against independent datasets ensure robustness [32, 33].

For instance, systems like IPOFIS and IPez have demonstrated reliable performance when integrated with smartphone applications for on-site identification [32, 33].

5.2. Digital Morphometrics

Morphometric software such as IPez uses landmark-based analyses to quantify shape differences among species. The process includes:

- Landmark Identification: Key anatomical landmarks are marked manually or automatically on fish images [32, 33].
- Statistical Analysis: Procrustes analysis and multivariate statistics (e.g., Principal Component Analysis) assess shape variation and distinguish between species or populations [32, 33].
- Integration with Machine Learning: The quantitative data serve as inputs for machine learning classifiers, further enhancing identification accuracy [32, 33].

This approach is particularly useful when subtle morphological differences are present, allowing identification at both the species and population levels [32, 33].

5.3 Acoustic Survey Techniques

Acoustic methods provide a non-invasive means to assess fish abundance and distribution:

- Data Collection: Multi-frequency echosounders emit sound pulses and record echoes reflected by fish. These surveys are typically conducted from research vessels or fixed platforms [2, 5, 59].
- Signal Processing: Echo signals are processed using algorithms that analyze backscattering strength across different frequencies. This helps to distinguish fish groups based on body composition and swim bladder characteristics [2, 5, 59].
- Species Inference: While acoustic data alone may not always resolve species-level identity, integration with trawl sampling and reference acoustic signatures allows for probabilistic species assignments [2, 5, 59].

Recent studies have improved classification accuracy using machine learning models trained on labeled acoustic datasets, which then complement traditional fisheries assessments [59].

6. Case Studies and Applications

This section presents case studies demonstrating the application of the above methodologies in various geographic and ecological contexts.

Recent studies in India have demonstrated the value of integrating traditional morphological methods with modern molecular techniques and image recognition systems for robust fish biodiversity assessment. For example, researchers working in the Brahmaputra River basin and the Western Ghats region have applied morphological keys in tandem with DNA barcoding (targeting the mitochondrial COI gene) to resolve species identities and uncover cryptic diversity [59,61]. These approaches have revealed a higher-than-expected number of species, including several cryptic taxa that were not discernible through morphology alone. Additionally, the implementation of image recognition systems has streamlined the identification process in field surveys, making it accessible to non-specialists. Such integrative studies not only enhance taxonomic resolution but also contribute critical data for conservation planning and sustainable fisheries management in India [61,62].

6.2 Biodiversity Monitoring in Tropical Freshwaters. –

In a tropical freshwater ecosystem in the Amazon basin, researchers used eDNA metabarcoding to detect rare and cryptic fish species that were missed by conventional netting methods [17, 29].

- Methodology: Water samples were collected from multiple sites and filtered. DNA was extracted and amplified using primers targeting the 12S rRNA gene, and the resulting sequences were compared with reference databases [17, 29].
- Outcome: The approach revealed a higher species richness than traditional surveys, uncovering several rare species and providing critical data for conservation planning [17, 29].

6.3 Traceability and Food Safety in Global Seafood Markets

Accurate species identification is essential in preventing seafood fraud. In a study conducted in New York supermarkets, DNA barcoding was applied to fillet samples to verify species labels [15, 21].

- Methodology: Tissue samples were subjected to DNA extraction and COI sequencing, and the sequences were compared against the Barcode of Life Database [15, 21].
- Outcome: A significant percentage of samples were mislabelled, prompting regulatory agencies to adopt stricter traceability measures and raising consumer awareness regarding seafood authenticity [15, 21].

6.4 Conservation of Endangered Species in Remote Marine Ecosystems

A recent expedition to the Gorringe Ridge—an underwater mountain in the Atlantic—integrated multiple identification tools to document its unique fish biodiversity [35].

- Methodology: Researchers deployed acoustic surveys to estimate fish densities, used underwater cameras for image-based identification, and collected tissue samples for DNA barcoding. This multi-pronged approach allowed the team to capture both large pelagic species and small, cryptic organisms [35].

- Outcome: The expedition provided robust evidence of the region's rich biodiversity, supporting proposals to upgrade its protection status within marine conservation frameworks [35].

7. Data Integration and Discussion

7.1 Synergistic Use of Multiple Tools

The integration of traditional and modern identification techniques creates a robust framework for fish biodiversity assessment. For example, combining eDNA metabarcoding with acoustic surveys provides complementary data: molecular techniques capture species presence, while acoustics supply real-time abundance and distribution information [15, 29, 59]. Likewise, image recognition systems—when paired with expert-verified reference databases such as FishBase and the Catalog of Fishes—enable rapid, in situ identifications that bridge the gap between laboratory analyses and field observations [8, 9, 14, 32].

7.2 Challenges and Limitations

Despite the progress made, several challenges remain:

- Data Quality and Completeness: Molecular and image-based methods are only as reliable as their reference libraries. Gaps in databases (e.g., for cryptic species or regional variants) can reduce accuracy [26, 27].
- Standardization of Protocols: Variability in sampling, extraction, and amplification protocols for eDNA can lead to inconsistent results. Continued efforts toward standardization are needed [15, 29].
- Cost and Accessibility: While some modern tools are becoming increasingly affordable, high-end acoustic systems and next-generation sequencing facilities remain costly and may not be readily accessible in developing regions [15, 26, 59].
- Integration of Multimodal Data: Effective decision-making requires seamless integration of data from multiple sources. Developing user-friendly platforms for merging molecular, morphological, and acoustic data is an ongoing area of research [2, 28, 32].

Conclusions:

The rapid evolution of fish identification tools—from traditional morphological approaches to advanced molecular, imaging, and acoustic techniques—represents a paradigm shift in biodiversity assessment and fisheries management. Our review has demonstrated that while classical taxonomic methods remain valuable, their limitations in speed, scalability, and sensitivity to cryptic diversity have spurred the development of modern tools that are more rapid, accurate, and accessible. DNA barcoding and SNP-based analyses have proved particularly transformative in resolving species boundaries and verifying product labels in seafood markets [15, 26, 28]. Similarly, deep-learning–based image recognition systems and digital morphometrics have enabled non-specialists to achieve high identification accuracy in the field [32, 33]. Acoustic techniques, despite their high cost and complexity, offer non-invasive means to monitor large-scale fish abundance and distribution [2, 5, 59].

The integration of these diverse methodologies—coupled with robust online databases such as FishBase, SeaLifeBase, ITIS, and the Catalog of Fishes—provides a synergistic framework for comprehensive fish biodiversity assessments. This multimodal approach not only increases identification accuracy but also enhances our ability to monitor ecosystem health, enforce fisheries regulations, and combat seafood fraud [8, 9, 11, 14, 15]. Nevertheless, challenges remain. Incomplete reference libraries, variability in field protocols, and the high capital investment required for certain methods (e.g., acoustic surveys) are issues that must be addressed through further research and international collaboration [15, 29, 59].

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CONSERVATION AQUACULTURE: A SUSTAINABLE APPROACH TO AQUATIC ECOSYSTEMS

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Abstract:

In the 21st century, aquaculture is generally characterized as a foe to conservation efforts. A variety of conservation and restoration tools are essential to protect the structure and function of aquatic ecosystems. While aquaculture the farming of aquatic organisms often contributes to the pressures these ecosystems face, it also has the potential to provide ecological benefits. The analysis identified 12 ecological benefits that aquaculture can deliver: species recovery, habitat restoration, habitat rehabilitation, habitat protection, bioremediation, assisted evolution, climate change mitigation, replacement of wild harvests, coastal defense, control of overabundant species, biological control and ex situ conservation. However, good intentions alone do not ensure positive ecological outcomes. Therefore, it is vital to assess aquaculture activities using clear, measurable success indicators to prevent misuse. As the fastest-growing food industry globally, it is crucial to align aquaculture practices with conservation goals to ensure that this expansion supports conservation efforts in the most effective and sustainable manner. Establishing consensus on goals, terminology, and metrics is critical to aligning aquaculture-environment interactions with standards in conservation and restoration ecology. Such alignment will also facilitate the development of certification schemes for ecologically beneficial aquaculture in the future.

Introduction:

Aquaculture is rapidly evolving into a key sector in the agricultural economy, propelled by the growing need for affordable, high-quality animal protein, particularly as the global population continues to rise (Rathore & Swain, 2024). Aquaculture, the cultivation of aquatic organisms, is a vital component of global food production and security, with an estimated production of 185 million tonnes in 2022 (FAO, 2024). This sector continues to grow as one of the fastest-expanding food industries globally, offering significant opportunities to align its development with sustainable practices. Conservation aquaculture, a sub-discipline of aquaculture, focuses on leveraging aquaculture methodologies to preserve biodiversity, restore ecosystems, and mitigate environmental degradation. Aquaculture has evolved beyond the farming of aquatic species to encompass habitat restoration and the protection of vital species and ecosystems. Conservation-focused aquaculture is not merely a theoretical idea; it is actively being implemented worldwide. These efforts are primarily at the local scale but sometimes extend to broader, regional initiatives to improve the health and status of species and ecosystems.

Conservation aquaculture is not merely a production system but a strategic approach to managing natural resources. It integrates principles of conservation to protect endangered species, restore habitats, and address biodiversity challenges. This chapter explores the key dimensions of conservation aquaculture, its goals, outcomes, and its role in tackling the challenges faced by modern aquaculture. Furthermore, aquaculture has been, and is expected to continue to be, one of the fastest growing food sectors in the world (FAO, 2016). Conservationists have the opportunity to steer that growth in the industry toward sustainable practices that can benefit conservation objectives.

Present Scenario of Aquaculture

The blue revolution in India demonstrated the importance of fisheries and aquaculture to the development of sector. Aquaculture is one of the fastest-growing sectors within India's fisheries industry, with an annual growth rate exceeding 7%. Globally, aquaculture production reached 94.4 million tonnes in 2022, with a per capita consumption rate of 20.7 kilograms. Despite its growth, the aquaculture industry faces significant challenges, including environmental pollution, overexploitation of natural resources, habitat degradation, and biodiversity loss. These challenges highlight the need for a sustainable approach, where conservation aquaculture emerges as a solution.

Conservation Aquaculture: Definition and Goals

According to Froehlich *et al.* (2017), “The use of human cultivation of an aquatic organism for the planned management and protection of a natural resource” it encompasses techniques aimed at preserving endangered fish populations and their gene pools while restoring their habitats. It integrates ecosystem-level benefits through aquaculture-based services, reducing the environmental footprint, including greenhouse gas emissions.

Goals of Conservation Aquaculture:

Conservation aquaculture ultimately needs to support the sustainable use (or recovery) of natural resources, whether through mitigation, prevention, or restoration measures. How best to achieve goal requires explicit consideration of the scale at which conservation aquaculture is being pursued. In particular, we explore how conservation aquaculture can protect,

1. Preservation of specific wild species through hatcheries and habitat restoration.
2. Larger system-level implications through aquaculture-based ecosystem services and reduction in overall environmental footprint (e.g., greenhouse gas (GHG) emissions)

Scales of Conservation Aquaculture

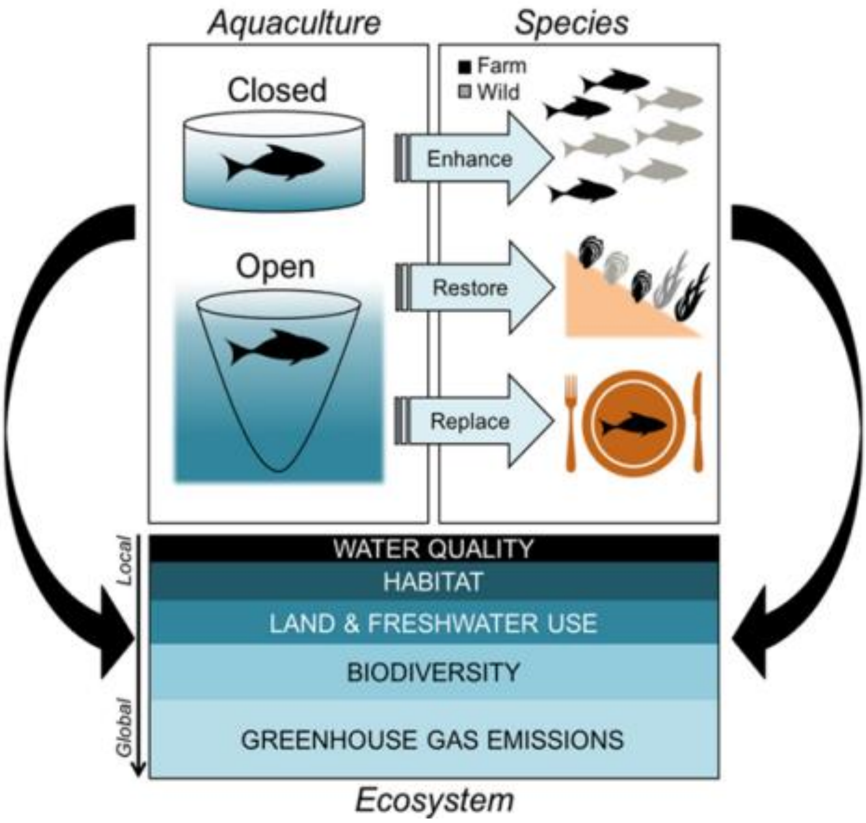

Figure 1: Conceptual framework of how aquaculture is or can be used for conservation at a species and ecosystem scale

Conservation aquaculture operates on two primary scales:

1. **Species-Level Conservation**: Focuses on reducing pressure on wild populations, enhancing at-risk species, and restoring critical habitats.
2. **Ecosystem-Level Conservation**: Aims to restore ecosystems by cultivating species that provide structural or functional benefits to degraded habitats.

Beneficial Outcomes of Conservation Aquaculture

There are 12 distinct ecologically beneficial outcomes that can be achieved through aquaculture (Figure 1; Table 1). The outcomes below are also not mutually exclusive; a single aquaculture activity may deliver several. For example, native shellfish farms operating in an area where wild counter parts have undergone historical declines may deliver positive outcomes for species recovery and habitat restoration, especially if the farmed shellfish carry locally adapted wild-type genes (e.g., Norrie *et al.,* 2020).

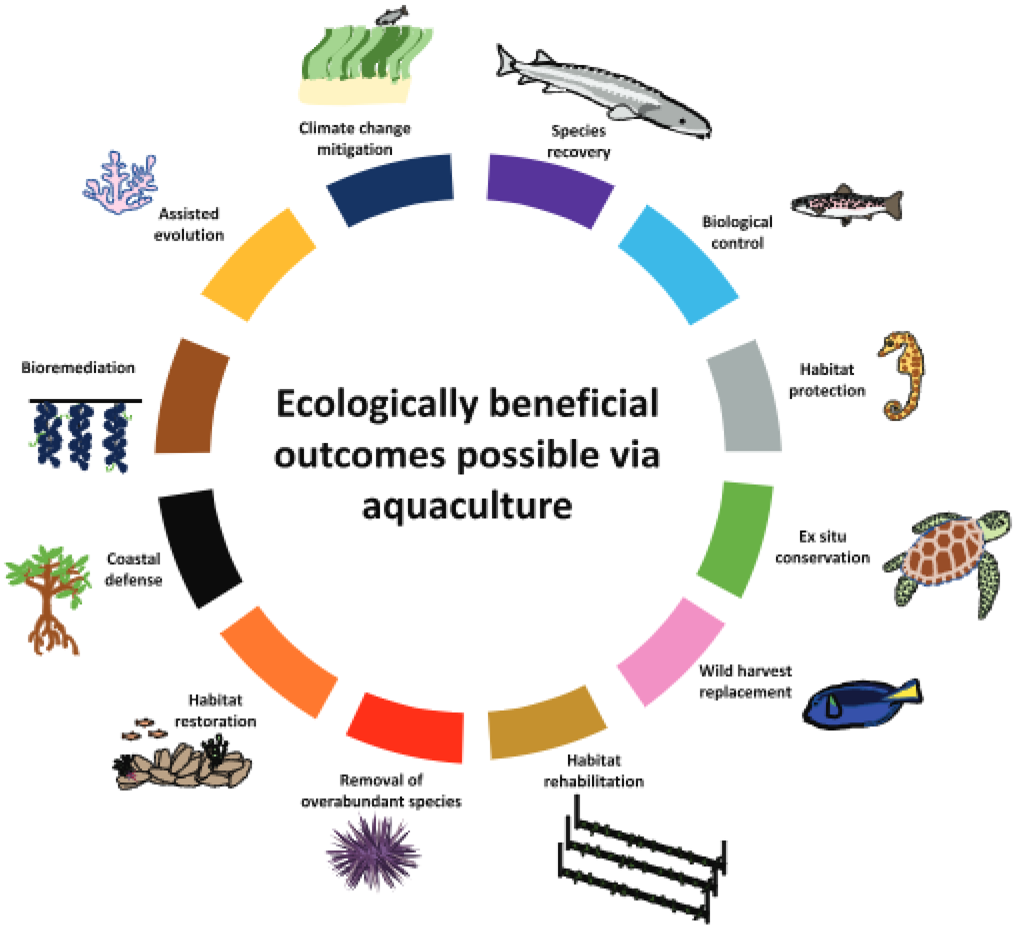

Figure 2: Beneficial outcomes that can be achieved through aquaculture

Further, if the area is eutrophic or turbid, filtering and nutrient assimilation by farmed shellfish can also provide a bioremediation outcome (e.g., Petersen *et al.,* 2014). Finally, if the shellfish is farmed in an area facing habitat loss due to coastal erosion, wave attenuation or sediment stabilization is likely to deliver habitat protection and coastal defense (e.g., Plew *et al.,* 2005). Although this example shows how multiple positive outcomes can be achieved. Therefore, evaluation of the net benefit of an aquaculture activity is required.

Table 1: Summary of the 12 outcomes that can be achieved through ecologically beneficial aquaculture

Beneficial outcomes	**Outcome description**	**Aquaculture activities that can deliver the outcome**
Species recovery	Targeted release of a cultivated aquatic organism of conservation concern to recover a lost local population.	Use of commercial or conservation hatcheries or nurseries to produce or raise biomass or stock to be released or reintroduced to a target area,
Habitat restoration	Use of cultivated aquatic species to substantially or fully restore structure and function of a degraded, damaged, or destroyed habitat	Reintroduction of a native cultivated species (hatchery-, nursery-, or research facility-produced stock) to an area where habitat is degraded, damaged, or previously loss.
Habitat rehabilitation	Use of native or non-native cultured organisms to reinstate structure or function of an ecosystem to achieve partial recovery, rather than attempting to recreate the biodiversity.	Reconciliation ecology techniques, such as introducing cultured species on existing artificial structures that provide partial recovery of ecosystem structure or function.
Habitat protection	Culture of an aquatic organism that results direct or indirect protection of a species or the structure of an existing habitat of conservation concern.	Aquaculture and associated structures that prevent degradation or protect an existing habitat or species of conservation concern.
Bioremediation	Use of cultivated aquatic organisms to improve or restore the quality of a degraded or destroyed ecosystem.	Biological process that uses microorganisms to eliminate the contamination from aquaculture waste without the use of harmful chemicals.

Assisted evolution	Use of a selectively bred aquatic organism of conservation concern with a phenotypic trait that has been selectively bred to improve the ability to adapt to a specified stressor.	Selective breeding programs that can include intraspecific or interspecific hybridization between different populations to increase tolerance or resistance to a pathogen or changing environmental conditions
Biological control	Release of cultivated aquatic organism into a habitat or ecosystem to control an undesirable (pest) species that has degraded or damaged an ecosystem	release of cultured predator or natural enemy to control a target pest that has cascading trophic effects (biomanipulation). Release of a cultured vector to enhance virus or pathogen spread to an invasive or target species.
Removal of overabundant species	Direct removal of an overabundant species from an ecosystem where it is then cultured and subsequently harvested that removes pressure on a degraded, damaged, or previously lost ecosystem.	Removal of an overabundant species to a level that facilitates return to a previous state as the system demonstrates hysteresis.
Ex situ conservation	Culturing of an aquatic organism outside of its natural range or habitat where biotic stressors, abiotic stressors, or both are reduced or eliminated	Captive breeding programs in predator free environments. Insurance population's zoos, botanical gardens, and aquariums.
Coastal defense	Use or culture of an aquatic organism that directly or indirectly protects coastal habitats of conservation concern by reducing abiotic stressors.	Aquaculture activity (including associated structures; e.g. Shellfish cultured on long lines or in baskets) that reduces abiotic stressors (e.g., wave attenuation) and reduces or prevents coastal erosion.

Climate-change mitigation	Use of cultivated aquatic organisms in an ecosystem that can contribute to local, regional, or global mitigation of climate change impacts.	Use of aquaculture biomass to restore aquatic vegetative habitats (e.g., mangrove forests, saltmarshes, sea grass meadows) that function as carbon sinks and enable subsequent carbon storage.
Wild harvest replacement	Culture of an aquatic organism that entirely replaces wild harvest and does not rely on wild stock for continued culture	Wild harvest replaced by culturing an aquatic species

Species-Level Conservation in Aquaculture

For a single species, conservation aquaculture can mean protecting wild stocks from overexploitation, bolstering populations of animals that are vulnerable, or re-establishing vital habitat. The primary cause of the concurrent rise in the exploitation and harvest of wild and farmed species for food has been the expansion in human population, wealth and seafood consumption (FAO, 2016).

Stock enhancement, are among the most prevalent instances of potential conservation aquaculture (Costa-Pierce, 2008). Many species have been raised in hatcheries, with the "success" of those species relying on the goals of their initial management. There is undoubtedly a limit to population supplementation, one that may even cause unfavourable management effects like overcompensation (Foss-Grant *et al.,* 2016). Indeed, if management of fishing effort and habitat for wild populations is disregarded, hatcheries alone will not suffice. In fact, recent studies indicate that hatcheries may be crucial to improving stocks when paired with habitat restoration (Taylor *et al.,* 2017).

Key Methods of Species-Level Conservation

1. Captive Breeding and Stock Enhancement

- Aquaculture facilities play a vital role in breeding endangered species in controlled environments.
- The goal is to maximize genetic diversity, ensuring the resilience of populations against environmental stressors.

- For example, programs for the Kootenai River white sturgeon (*Acipenser transmontanus*) use hatcheries to raise juveniles for release into the wild, combining environmental management and harvest regulation.

2. Headstarting Programs

- Subsequent release of captive-raised hatchlings and yearlings had some success; survival to adulthood was recorded (Bell *et al.,* 2005).
- For instance, green turtles (*Chelonia mydas*) are reared in hatcheries before release to mitigate the threats they face, such as predation or habitat loss.

3. Targeted Species Reintroduction

- Species cultivated in hatcheries or nurseries are reintroduced into areas where their populations have been depleted.
- These efforts often coincide with habitat restoration to ensure the long-term success of reintroduced populations.

4. Selective Breeding and Assisted Evolution

- Genetic enhancement programs focus on developing traits like disease resistance, tolerance to environmental stressors, and adaptability to changing climates.
- For example, hybridization between different populations can produce offspring better equipped to survive in degraded ecosystems.

5. Biological Control and Pest Management

- Cultured species can be released to control invasive or overabundant species that threaten native biodiversity.
- For example, introducing predators or natural enemies into an ecosystem helps restore balance without harming native species.

Benefits of Species-Level Conservation

1. **Reduction of Pressure on Wild Populations** By cultivating aquatic organisms, aquaculture decreases reliance on wild stocks, allowing these populations to recover naturally.
2. **Preservation of Genetic Diversity** Captive breeding programs maintain diverse gene pools, which are critical for the long-term survival of species in the wild.
3. **Support for Endangered Species** Programs targeting critically endangered species, such as the white sturgeon or green turtles; have shown success in stabilizing their numbers.

4. **Prevention of Extinction** Species-level conservation initiatives directly contribute to preventing the extinction of vulnerable populations through planned interventions.

Case Studies

1. **Green Turtle (*Chelonia mydas*)** Conservation programs in the Cayman Islands involve the collection of eggs, raising hatchlings in controlled environments, and releasing them into the wild. These efforts have increased survival rates and improved population stability.
2. **Kootenai River White Sturgeon (*Acipenser transmontanus*)** Conservation aquaculture techniques like hatchery rearing and habitat restoration have been pivotal in recovering this endangered population (Schreier *et al.,* 2012).

Challenges in Species-Level Conservation

1. Balancing conservation goals with aquaculture production objectives.
2. Managing the risk of genetic homogenization due to captive breeding.
3. Ensuring that reintroduced species adapt successfully to their natural habitats.
4. Addressing ecological impacts, such as competition with native populations or the spread of diseases.

Ecosystem-Level Conservation in Aquaculture

Ecosystem-level conservation focuses on restoring, preserving, and enhancing entire ecosystems to ensure their functionality and resilience. The restoration of native biogenic habitat through conservation-focused farming is becoming more popular as a means of achieving advantages at the ecosystem level. Even yet, it might be difficult to quantify the ecosystem benefits that restoration brings. The enhancement of water quality, coastal defence, carbon sequestration and vital habitat for wild species can all be achieved by the cultivation and growth of specific oyster, seaweed, sea grass, and mangrove species.

Key Components of Ecosystem-Level Conservation

1. Habitat Restoration

- Aquaculture aids in rehabilitating habitats like coral reefs, mangroves, seagrass beds, and oyster reefs, which are vital for biodiversity and ecosystem stability.
- Coral gardening, for instance, involves cultivating coral fragments that are later transplanted to degraded reefs. This practice enhances reef resilience and supports marine life.

2. Bioremediation

- Aquatic organisms such as bivalves, algae, and plants are used to remove pollutants, excess nutrients, and contaminants from water bodies.
- Phytoremediation (using algae) and mycoremediation (using fungi) are commonly employed to clean degraded aquatic environments.

4. Assisted Ecosystem Functioning

- Aquaculture can reintroduce species that perform critical ecological functions, even if they are non-native; to restore balance in degraded ecosystems.
- Example: Oyster reef restoration projects improve water quality and provide habitat for other marine organisms.

5. Reconciliation Ecology

- Man-made structures like artificial reefs and aquaculture facilities mimic natural habitats to enhance biodiversity.
- These structures support ecosystem functions, such as providing shelter, breeding grounds, and feeding areas for aquatic species.

6. Coastal defense

- Cultured organisms can be used to restore or create ecosystems for the purpose of coastal defense, which are known as living shorelines or nature based coastal defense (Zhu *et al.,* 2020)
- Target ecosystems that can provide coastal defense or protection include seagrasses, mangroves, saltmarshes, coral reefs, kelp beds, and shellfish reefs (Morris *et al.,* 2018).

7. Carbon Sequestration

- Oceans absorb a significant amount of carbon dioxide (CO_2) from the atmosphere, acting as a vital carbon sink.
- Phytoplankton, marine plants, and other organisms play a crucial role in this process through photosynthesis, where they absorb CO_2 and release oxygen.
- Tang *et al.* (2011) estimate that marine culture of harvested molluscs and seaweed in China remove 0.34–0.88 million tonnes of carbon per year

Benefits of Ecosystem-Level Conservation

1. **An enhanced Biodiversity Restoring ecosystem ensures** a diverse range of species can coexist, contributing to ecological stability.
2. **Improved Ecosystem Services** Healthy ecosystems provide vital services like nutrient cycling, carbon sequestration, and water purification.

3. **Climate Change Mitigation** Restored habitats like mangroves and sea grass beds act as carbon sinks, helping reduce atmospheric CO2 levels.
4. **Protection against Coastal Erosion** Aquaculture activities like cultivating shellfish reduce wave energy and prevent erosion, protecting coastlines and human settlements.

Case Studies

1. **Coral Reef Restoration** Coral gardening projects worldwide have successfully used aquaculture to rehabilitate degraded coral ecosystems, supporting marine biodiversity and fisheries.
2. **Oyster Reef Recovery** Hatchery-reared oysters have been used to restore reefs, improving water quality, enhancing biodiversity, and mitigating biological stressors.
3. **Mangrove Rehabilitation** Integrated aquaculture-mangrove systems have been implemented to protect shorelines, support fish populations, and sequester carbon.

Challenges in Ecosystem-Level Conservation

1. High costs and long timelines for ecosystem restoration.
2. Risks of introducing non-native species that may disrupt ecosystems.
3. Need for multidisciplinary approaches involving ecology, engineering, and socio-economic factors.
4. Monitoring and measuring the success of restoration efforts over time.

Future Use of Aquaculture as a Conservation Tool

Aquaculture holds immense potential as a conservation tool, enabling the sustainable management of aquatic resources while addressing environmental challenges. As global biodiversity faces increasing threats from habitat degradation, overexploitation, and climate change, aquaculture offers innovative solutions to mitigate these impacts and support the recovery of ecosystems. Below are some key future directions where aquaculture can play a significant role in conservation.

1. **Sustainable Practices**: The future of conservation aquaculture relies on ensuring minimal ecological footprints and avoiding harmful practices like introducing invasive species or causing genetic homogenization.
2. **Policy Integration**: Regulations must promote aquaculture systems that align with conservation goals.
3. **Collaboration and Innovation**: Scientists, policymakers, and industry stakeholders must collaborate to develop sustainable technologies and approaches.

4. **Monitoring and Evaluation**: Continuous assessment of conservation aquaculture projects is essential to measure success and address emerging challenges.
5. **Smart planning**: Aquaculture is certainly not a remedy for all environmental issues, but with smart planning alongside sustainable measures and regulations, aquaculture could play a larger role in the future of conservation.
6. **Mitigation:** Aquaculture will most likely not receive the benefit of the doubt when it comes to mitigating, instead of causing, impacts. Through collaboration, strategic planning, and monitoring practices, aquaculture can be used in the service of conservation, so we can have our aquatic resources and protect the planet too.
7. **Carbon sequestration**: Integrating aquaculture into climate change mitigation through carbon sequestration by cultivated algae and mollusks.

Conclusion:

Aquaculture is not a universal solution to environmental challenges, but with smart planning, it can serve as a powerful tool for conservation. Its future lies in balancing ecological preservation with sustainable food production. By addressing key conservation goals such as restoring habitats, protecting biodiversity and mitigating climate change conservation aquaculture can ensure a harmonious coexistence between human activities and the natural environment. The rapid expansion of aquaculture has positioned it as a critical player in global food security and economic development. However, the industry's challenges necessitate the adoption of conservation aquaculture to ensure sustainable growth. By leveraging aquaculture's potential to restore habitats, conserve species and mitigate environmental impacts, we can align this sector with broader conservation objectives, ensuring the sustainable use and recovery of aquatic resources.

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STREPTOCOCCUS TOXIC SHOCK SYNDROME

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"Streptococcus Toxic Shock Syndrome"

An unparalleled number of cases of Streptococcus toxic shock syndrome [STSS] in Japan is bringing attention to this mysterious behavior of 'Strep A bacteria'. This year the strep A bacteria has crossed all the unusual levels by causing the life-threatening fatal infections at very high levels.

According to preliminary data from "Center for disease control [CDC]", U.S also faced the number of serious Group A strep infections -including STSS by reaching a 20 year high in 2023. This year U.S has recorded 395 cases of STSS, exceeding or surpassing the last year's total of 390. Not only U.S but in late 2022, at least five European nations i.e. U.K, Netherlands, France, Ireland and Sweden reported an increase number of cases of invasive group A strep infection cases to world health organization [WHO].

Streptococcus toxic shock syndrome [STSS] is rare, life-threatening and fatal bacterial infection caused by the same bacteria which also causes mild infections like "strep throat" and "scarlet fever" commonly in children's. Streptococcus toxic shock syndrome the name itself indicates is toxin mediated disease which is usually caused by "Streptococcus pyogenes" also known as Group A bacteria [GAS]. The bacterium causes the disease by releasing super antigenic toxins in blood streams or deep tissues which leads to the shock. It is a Gram-positive bacterium which is well characterized by the beta-hemolytic activity (Complete hemolysis in blood agar culture. Centers of disease control (CDC) in 2010 coined the definition of STSS as a severe life-threatening condition which is associated with invasive infections by mainly Group A Streptococcus (S. pyogenes) and less frequently due to other streptococcal species. GAS has the capacity to penetrate through intact membranes but they are believed to access into deeper tissues and bloodstream by rupture of an epithelial tissue.

Occurrence:

This infection can occur to all types of age groups but individuals with higher age group, the ones having medical conditions like Cancer, diabetes, alcohol disorder, the individuals that recently had surgery, cuts or wounds on the body are more susceptible to this infection. It is also to be believed that individuals who recently suffered from viral infections like chicken pox or shingles are more susceptible as sores from chickenpox or shingles contract it and also viruses may make people more vulnerable to infection by damaging their airways or weakening their immune system. Earlier the women's using tampons during their menstrual phase were at the higher risk but now as tampon manufacturers have made changes in their products which are now Safer to use, the risk now has reduced.

Epidemiology:

The Group A strep bacteria enter the body through cut or wounds or from the sores of chickenpox or shingles. But if a patient comes with group A strep in blood, unless they have wound, we can't determine how the bacterium entered the body. However, the infection is not an "airborne" disease unlike the COVID -19, tuberculosis etc. so it cannot be transmitted by contact, but the infected person can transmit the bacteria causing the disease through respiratory droplets by coughing, sneezing or even while taking.

Experts think that the surge of this infection is the post pandemic rebound of the bacterial and viral infections. During pandemic as the person-to-person interaction were avoided, we wore Masks, made use of sanitizers and took so much of precautions that the bacteria and virus had very fewer opportunities to spread and cause infections, but now as the socializing has resumed individuals are more susceptible to the infections. Studies also suggest that the main surge of this current STSS can be the rise of certain more virulent strains of strep A. Furthermore, due to quarantine, we stayed at home and were not in contact to any of the bacteria, so our immunity has lost the ability to respond and has become weak. As we boost our immunity, with more exposure to the bacteria. i.e. during pandemic we didn't build up partial protection against bad strep A infections which comes from repeated exposure.

This year atleast 1019 cases in Japan of STSS have been recorded already surpassing the last year's total 941 which is an alarming clock to other countries. Now the question arises why only Japan is facing such infections at very high levels. The answer suggests that the reason may be due weak immune system in Japanese people or the hygiene importance must have been neglected in Japanese society after strict preventive measures of pandemic have ended.

Pathogenesis or Pathophysiology

The pathophysiology of STSS is nothing but a complex interplay between host immune system and pathogen virulence. The two most common genera which are known to produce superantigens are Streptococci and staphylococcus. Among Streptococci, *Streptococcus pyogenes* (Group A Streptococcus), *S. dysgalactiae* (Group C Streptococcus) and *S. equis* (Group G Streptococcus) can produce exotoxins with super-antigen activity. Super-antigens are the proteins that have the ability to trigger excessive and non-specific T cell activation which results in the massive secretion of pro-inflammatory cytokines occurs. The arterial hypotension in patients is observed due to secretion of other mediators that produces capillary leak. The first streptococcal pyrogenic toxin which appeared to have super-antigenic activity was described in 1924.

S. pyogenes have been identified to have eleven different Streptococcal Super-antigens which are also known as Streptococcal pyrogenic enterotoxins, SPE's. All the eleven different SPE'S produces same biological effects though they have different protein amino acid sequence and structure. They are single-chain proteins expressed as precursor molecules which are then cleaved to release the functional extra cellular toxins. The main characteristics of super-antigens is their ability to bind to the Major histocompatibility (MHC) class 2 molecules which are present outside the antigen presenting cell (APC) and to VB region of the T cell receptor cross-linking those two receptors, bypassing the conventional mechanism of MHC limited antigen cell activation, monoclonal lymphocyte activation and triggers the non-specific, polyclonal lymphocyte activation which results in pro-inflammatory activity, arterial hypotension and organ dysfunction due to shock in patients. Upto 25% of lymphocyte activation is led by the cross linking of receptors by super-antigens. Along with super-antigens, S. pyogenes also produces and secretes a wide variety of exotoxins and enzymes such as hyaluronidase, streptolysins, streptokinase and DNase such as streptodornase and chemokine protease also toxin molecules that play an important role in pathogenicity in necrotizing fasciitis and STSS.

Clinical Presentation

Clinical presentation for STSS is described in three phases:

1. 1.The first phase involves the onset of severe hypotension in 24-48 hrs., with a severe fever, chills, headache, just influenza-like illness. Non-specific digestive symptoms like nausea, diarrhea, vomiting also may be present in initial phase. Roughly half of the patient's involve the alternation of central nervous. Patients in the initial clinical examination are looked up for the tenderness, swelling, redness, arthritis etc. during the follow-up which is done for four times a day. Classical symptoms of STSS i.e. Palmar and plantar desquamation usually occurs after few days of initial symptoms

but does not occur in all patients. Clinician gets alert for the possibility of STSS when there's a variance between the intensity of pain reported by the patient and a normal or quasi-normal clinical examination. The clinical evidence becomes more obvious as the illness progresses and when the localization of symptoms is frequently observed.

2. In second phase Patients are thoroughly searched for a Skin lesion which suggest the entry of GAS, which may be visible in early development of invasive GAS infection, however in half of the severe infections with STSS, such skin lesions are not found. Patients have been reported with the pain in the limb, abdomen or the Thorax which is disproportionate compared to the clinical findings even with deep invasive infections such as necrotizing fasciitis. At this stage to differentiate between the skin infection and fasciitis, Computed tomography (CT) or Magnetic resonance imaging are considered to be very useful.
3. The third phase of clinical presentation is characterized by circulatory shock that can be sudden and is accompanied by multiple organ failure. Many of the patient's die within 24-48 hours of hospitalization despite of aggressive therapy.

Treatment and Prophylaxis:

Treatment includes high dose of intravenous antibiotics like penicillin, amoxicillin etc., IV fluids, dialysis in case of kidney failure, equipment's like oxygen cylinder to assist proper breathing, medications to raise blood pressure and reduce swelling if in case. Also, as chickenpox and influenza are risk factors, so staying up to date with vaccinations against varicella zoster virus and influenza can reduce the risk of severe infection. However early detection can prevent the disease from becoming life threatening. So a very useful step for primary patient consultations can be done by detection of streptococcus pyogenes from oropharyngeal swabs which hardly requires 10 minutes also known as Simple strep A rapid test.

Till now a proper vaccination against STSS has not been introduced but many are in process. But proper precautions or preventive measures can be taken to reduce the risk of infection to a greater extent.

Preventive measures include maintaining proper hand hygiene by using proper effective handwash for washing hands after using washrooms. As Kikuchi a professor in Japan suggested that many people may carry GAS in their intestine without showing symptoms and can contaminate their hands through feces and can enter the body while having food so before and after meals also washing hands appropriately with liquid soap and water for at least 20 seconds is necessary or else if washing facilities are not available at that time washing hands with alcohol is must. Furthermore, while sneezing, coughing both mouth and nose should be covered with clean napkin or tissue paper every time. Wound and cuts on the body if can be treated at home should be washed regularly at home with medications prescribed by doctors and should be covered with waterproof adhesive dressing unless totally healed or else consulting your nearest doctor for wound treatment must be done. Maintaining proper effective hygiene is the most essential preventive measure. Replacing tampons or menstrual cups with sanitary napkins can also be preventive measure for women's. Also avoiding the use of items such as eating utensils, and towels or napkins, cloths of the infected person.

But the story doesn't end here. Just as every coin has two sides, every problem has a solution. Recently, a new antibiotic called as GMCIDES has been developed to combat the infection and can provide better treatment.

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IMPACT OF PLANKTONIC POPULATION ON WETLAND ECOSYTEMS OF GONDIA, DIST. GONDIA (M.S.)

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Abstract:

Studies on the wetlands were made on species composition of phytoplanktons, zooplanktons of water body from June 2006 to May 2007. Among phytoplanktons, members of Myxophyceae have shown the dominance over Chlorophyceae and Bacillariophyceae followed by Euglenophyceae. Among the zooplanktons, rotifers are formed the dominant on copepods, cladocerans and ostracodes. The plankton has shown more abundance during summer season and monsoon while least number was recorded during winter season. The pond water is getting polluted due to inflow of domestic effluents, apart from pollution, resulting from washing of clothes, vehicles, cattle, immersion of Idols during certain festivals etc. All these activities are deteriorating the quality of the water in the lake resulting in the accumulation of the toxic chemicals and other sludge leading to ecological imbalance. However there is an urgent need of an action for conservation to reduce pollution level, to avoid ill effects on human and animal health before it becomes unmanageable.

Plankton:

Plankton have universal occurrence in natural water and play a significant role in the aquatic ecosystem. The plankton community consists of aquatic organisms those have little or no resistance to current, living free, floating and suspended in the open or pelagic waters (Raymond, 1983). Planktons constitute a vital link in the aquatic food chains. While phytoplankton plays a phenomenal role in the biosynthesis of organic material, zooplankton, an important component of secondary production, provides a link between the producers and secondary consumers.

Phytoplankton:

Phytoplankton plays a vital role in nutritional cycle of an aquatic ecosystem. The maintenance of a healthy aquatic ecosystem depends on the abiotic properties of water and the biological diversity of the ecosystem. The planktonic study is a very useful tool in understanding the basic nature and general economy of the lake. (Pawar, et. al, 2006).

In the present study, Myxophyceae followed by Chlorophyceae followed by Bacillariophyceae and Euglenophyceae. Sakhare (2006) has reported the abundance of Chlorophyceae in May with the density of 2008/litre. Myxophyceae Bacillariophyceae have shown the dominance over Chlorophyceae, Bacillariophyceae and followed by Euglenophyceae during the summer season. While during winter Chlorophyceae and Myxophyceae have shown the maximum number and Bacillariophyceae and Euglenophyceae were recorded minimum in number. Seasonal studies on phytoplankton by (Kadam *et al.,* 2006) in Masoli reservoir, Parbhani have also recorded maximum phytoplankton during summer.

Poor plankton population is due to the utilization of the nutrients by the dense macrophytes. (Sharma *et al.,* 2007) in urban lake system, Udaipur stated that there is an alarming increase in nitrate and phosphate and phytoplanktons during summer which is mainly due to release of domestic sewage in lake Pichhola. Among biotic communities phytoplankton constitute the first stage in tropic level by virtue of their capacity to convert radiant energy into the biological energy through photosynthesis. Also referred to as primary productivity, the magnitude of photosynthetic energy fixation depends primarily on diversity and biomass of phytoplankton. The planktonic photosynthesis plays a key role in conditioning the microclimate as it helps in regulating the atmospheric level of oxygen and carbon dioxide.

Apart from primary production, phytoplankton also plays an important role as food for herbivorous animals. They are also considered as biological indicators of water quality in pollution studies. To summarize, because of their definite role in cycling of energy and matter in an ecosystem, evaluation of phytoplankton population in term of their diversity, density, biomass, spatial and temporal distribution, periodicity and productivity and population turnover, is of vital significance in the management of an ecosystem. Fishes consume the phytoplankton, which is found abundantly in ponds, lakes and reservoirs.

Phytoplankton also gives green colour to the water. It is due to the presence of chlorophyll. Growth and multiplication of phytoplankton is mainly dependent on temperature, solar illumination and the availability of certain essential nutrient such as nitrates, silicates and phosphate.

Zooplanktons:

Water bodies which are rich in phytoplankton are also rich in zooplankton diversity and biomass. (Vijaykumar, 1992) stated that in an aquatic ecosystem, zooplanktons play an important role not only in converting plant food into animal food but also provide an important food source for other higher organisms including fish. The zooplankton because of their short life period respond quickly, but also because of their small size and often their great numbers are also useful in determining the origin or recent history of given water mass. (APHA, 1980). The physical and chemical factors play important role, which for the most part is responsible for the distribution of the animal life in fresh water habitat. The seasonal cycle of zooplankton is affected by the size, distribution of algae, bacterial prey and pressure of predatory fishes. (Kalff, 2002; Chavan *et al.,* 2006).

Zooplankton diversity is one of the most important ecological parameters in water quality assessment. The zooplankton study has been a fascinating subject for a long time. Water bodies rich in phytoplankton are also rich in zooplankton diversity and biomass. Vijaykumar (1999) stated that in an aquatic ecosystem, zooplanktons play an important role not only in converting plant food into animal food but also provide an important food source for other higher organisms including fish.

The Zooplankton was represented Rotifera, Cladocera, Copepoda and Ostracoda in the pond. It was recorded as Rotifera > Copepoda > Cladocera > Ostracoda during study. (Khare, 2005) in Jagat Sagar Pond, Chhatarpur, has reported the total zooplankton showed a single peak in the month of April. While lowest during monsoon season. The important zooplankton recorded were- Brachionus spp., Keratella spp., Daphnia spp., Moina spp., Cyclops spp., and Asplanachna spp., etc. He also stated that the population of Rotifers showed a peak in April. Patil *et al.* (2008) has reported minimum Cladocerans during monsoon months and attributed to the low water temperature, dissolved oxygen, turbidity and transparency play an important role in controlling the diversity and density of Cladocera. In the present study, the entire three ecosystems have recorded the lowest number of Ostracodes during the monsoon season and maximum in summer followed by winter season. These results are supported by Ansari *et al.* (2007) has reported least number of total zooplankton.

During summer season high density of rotifers might be due to high temperature which is suitable for their growth, reproduction and development and availability of nutrients due to bacterial decomposition. During monsoon season low density of rotifers may be attributed to dilution effect, cloudy weather and low temperature while during winter season, it may coincide with a substantial decrease in temperature in the pond. (Jorge, *et al.,* 2009) reported highest density and diversity of Rotifers during summer months in Valle de Bravo reservoir, Mexico, due to increase in temperature.

Summary:

During the study, the results revealed well defined seasonal variations. Physico-chemical parameters such as temperature, dissolved oxygen, total alkalinity and nutrients are very much favourable for flora and fauna. The plankton consisted of phytoplankters and zooplankters. 43 species of phytoplanktons and 24 species of zooplanktons were recorded. Among the phytoplanktons, the order of dominance is Myxophyceae > Chlorophyceae > Bacillariophyceae > Euglenophyceae. While among the zooplankton the order of dominance is Rotifera > Copepoda > Cladocera > Ostracoda.

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REVOLUTIONIZING THE FIELD OF ZOOLOGY BY ARTIFICIAL INTELLIGENCE

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Abstract:

The application of artificial intelligence (AI) to zoology has led to revolutionary developments that are revolutionizing our knowledge of, approach to studying, and conservation of the animal kingdom. AI-powered tools have greatly improved wildlife research data gathering, analysis, and interpretation in recent years. Researchers can now track animal populations, monitor ecosystems, and more accurately predict ecological changes thanks to machine learning algorithms that can interpret massive volumes of data from sources like camera traps, drones, and satellites. AI is also transforming our knowledge of animal behavior by enabling real-time, human-free study of interactions, movements, and communication patterns. Furthermore, new discoveries in genetic diversity, species conservation, and evolutionary biology are being made possible by developments in AI-driven genomic research. Scientists and environmentalists are able to monitor biodiversity on a never-before-seen scale thanks to the automation of species identification through picture recognition and sound analysis. AI will be a vital tool in zoology in the future due to its capacity to reveal hitherto unnoticed patterns, enhance conservation tactics, and provide answers to the loss of biodiversity.

Keywords: Zoology, Artificial Intelligence, Wildlife, Behavior, Species, Biodiversity

Introduction:

AI is assisting zoologists in gaining new insights that were previously hard or impossible to obtain, from behavioral research and wildlife conservation to genetic analysis and species identification [1]. AI-powered cameras and sensors, for example, are making it possible to track animal movements over large, remote areas without human intervention. Researchers can now make more precise predictions about animal populations, behaviors, and ecosystems thanks to machine learning algorithms that are evaluating enormous datasets, including genetic sequences and environmental variables

[2]. By giving scientists access to strong tools that enable them to investigate the intricacy of the animal kingdom in previously unthinkable ways, artificial intelligence is transforming zoology. AI has the potential to improve our knowledge of animals and provide fresh answers to problems pertaining to biodiversity preservation and wildlife conservation as it develops [2].

Zoological research is quickly changing as a result of the incorporation of AI, which presents previously unheard-of opportunities to tackle persistent problems. Numerous zoological fields have advanced significantly as a result of AI's vastly superior capacity to process enormous volumes of data and spot patterns [3]. This covers, among other things, population estimation, behavior analysis, and species classification. For example, enormous datasets collected from animal tracking are being successfully analyzed by AI-led technology, supporting conservation efforts. This proof-of-concept informs next conservation biology applications and shows how machine learning may be used to analyze complex ecological data [4].

Although AI has several advantages for zoological study, its capacity to automate work raises questions about the future of professions in animal science. The article examines the ways in which AI may supplant certain conventional occupations and offers solutions for professionals to adjust to this changing environment [5]. The ability to analyze data, plan studies, and synthesize findings is still distinctively human and irreplaceable, even when AI can automate some parts of the process. Additionally, the creation and use of AI tools in zoology need the knowledge of qualified zoologists, opening up new career paths in data science and AI development within the discipline [5].

AI is transforming research methodologies and simultaneously providing novel approaches to engage the public with zoological collections and knowledge. Recent projects illustrate the application of AI in developing interactive experiences, enabling visitors to "converse" with museum specimens [6]. These initiatives utilize AI's natural language processing abilities to facilitate informative and captivating interactions, thereby rendering intricate zoological information more accessible to a broader audience [6]. This strategy for public engagement holds the promise of cultivating a greater appreciation for zoology and its critical role in conservation initiatives. The utilization of AI transcends mere species identification and population assessment [6]. It is increasingly employed to elucidate intricate biological mechanisms within animal models, which is particularly significant in domains such as drug discovery, where these models play a vital role in pre-clinical investigations. By scrutinizing complex biological datasets, AI can aid researchers in formulating more effective therapeutic strategies for a range of diseases. Moreover, the application of AI encompasses various sub-disciplines of zoology, including entomology, thereby underscoring its extensive relevance within the field [7]. Research institutions are actively investigating the transformative potential of AI in enhancing their research methodologies and collections. The successful implementation of AI in zoological studies requires a robust interdisciplinary framework. It is imperative for zoologists, computer scientists, and data analysts to collaborate in the design, execution, and interpretation of AI-enhanced research [8]. Educational institutions are increasingly acknowledging this necessity by embedding AI into their zoology and related academic programs. For instance, universities are integrating AI into their curricula for animal science and biology, reflecting the escalating significance of this technology in the discipline. The incorporation of AI into zoology represents not merely a technological progression but a profound transformation in research practices and the dissemination of knowledge [9].

Wildlife Conservation and AI:

AI is significantly reshaping the field of wildlife conservation by providing advanced solutions to the challenges associated with monitoring and safeguarding animal species. Conventional conservation techniques typically require extensive fieldwork, including the manual tracking of animal movements and population counts, which can be both labor-intensive and challenging in expansive or remote areas [10]. In contrast, AI enhances these efforts through the deployment of camera traps, drones, and remote sensors that utilize machine learning algorithms. These technologies facilitate the automatic identification and tracking of animals, the analysis of their behaviors, and the real-time detection of threats such as poaching and habitat loss. For instance, AI-driven image recognition systems can efficiently process thousands of images captured by camera traps to identify various species, enabling researchers to monitor population dynamics without causing disturbances to wildlife [11]. Furthermore, AI is instrumental in forecasting animal migration patterns and evaluating the effects of climate change, thereby empowering conservationists to take proactive measures in protecting ecosystems. By leveraging AI, wildlife conservation initiatives are becoming increasingly efficient, precise, and scalable, ultimately aiding in the global effort to preserve biodiversity [11].

Animal Behavior Studies and AI:

The utilization of AI transcends mere species identification and population assessment. It is increasingly employed to elucidate intricate biological mechanisms within animal models, which is particularly significant in domains such as drug discovery, where these models play a vital role in pre-clinical investigations [12]. By scrutinizing complex biological datasets, AI can aid researchers in formulating more effective therapeutic strategies for a range of diseases. Moreover, the application of AI encompasses various sub-disciplines of zoology, including entomology, thereby underscoring its extensive relevance within the field. Research institutions are actively investigating the transformative potential of AI in enhancing their research methodologies and collections. The successful implementation of AI in zoological studies requires a robust interdisciplinary framework [13]. It is imperative for zoologists, computer scientists, and data analysts to collaborate in the design, execution, and interpretation of AI-enhanced research. Educational institutions are increasingly acknowledging this necessity by embedding AI into their zoology and related academic programs. For instance, universities are integrating AI into their curricula for animal science and biology, reflecting the escalating significance of this technology in the discipline. The incorporation of AI into zoology represents not merely a technological progression but a profound transformation in research practices and the dissemination of knowledge [14].

Genetic Research and AI:

AI is making remarkable progress in the field of genetic research, equipping scientists with advanced tools to analyze intricate genetic data with unmatched speed and accuracy. In the realm of zoology, comprehending the genetic composition of various animal species is essential for investigating evolution, biodiversity, and conservation efforts. Machine learning algorithms, a subset of AI, are capable of processing extensive genetic datasets to uncover patterns and relationships that may otherwise remain hidden [15]. For example, AI is employed to analyze the genomes of endangered species, enabling researchers to assess genetic diversity, identify mutations, and pinpoint essential survival traits. In the context of conservation, AI-based tools can facilitate the development of breeding programs aimed at preserving genetic diversity, thereby mitigating the risks associated with inbreeding and promoting healthier populations. Furthermore, AI enhances our understanding of evolutionary connections by comparing genetic sequences across different species, providing valuable insights into their common ancestry and adaptive characteristics [16]. By streamlining and enhancing the analysis of genetic information, AI is not only expediting genetic research but also playing a crucial role in the conservation of species and their long-term viability in a rapidly changing environment [17].

Predicting Ecological Changes and AI:

AI is increasingly recognized as a crucial instrument for forecasting ecological transformations, enabling researchers to gain deeper insights into and prepare for alterations in ecosystems driven by factors such as climate change, habitat loss, and species migration [18]. Through the analysis of extensive datasets—including meteorological patterns, environmental parameters, and species behavioral data—AI models can predict potential ecological disturbances with enhanced precision and efficiency compared to conventional approaches. Machine learning techniques are adept at processing intricate, multi-dimensional data to uncover latent patterns and trends, such as shifts in species distributions or the effects of temperature variations on flora and fauna [19]. These predictive frameworks empower conservationists to make strategic decisions regarding their initiatives, such as prioritizing the protection of at-risk habitats or identifying regions likely to become susceptible to invasive species. Additionally, AI can model various environmental scenarios, offering critical insights into the potential evolution of ecosystems over time under differing conditions. By leveraging AI for ecological predictions, researchers and conservationists are better positioned to alleviate adverse effects and promote the preservation of biodiversity in an era of rapid environmental change [20].

Robotics and Biomechanics and AI:

AI is significantly contributing to the fields of robotics and biomechanics, particularly by taking cues from the animal kingdom. Researchers are examining the movement patterns and environmental interactions of various animals to develop robots that replicate these biological systems, thereby enhancing their operational efficiency and functionality [21]. AI algorithms facilitate the analysis of animal biomechanics—such as the flight of birds, the swimming of fish, and the running of cheetahs—allowing for the application of these insights in the design of robots that exhibit improved agility, stability, and energy efficiency. For example, by emulating the swift and adaptable movements of a cheetah, AI-enhanced robots can reach high velocities while preserving balance and navigating obstacles effectively [22]. Furthermore, AI plays a crucial role in refining the design of prosthetics and exoskeletons by studying how animals adjust to their physical surroundings, leading to more natural and effective solutions for individuals and animals facing mobility challenges. Through these advancements, AI is not only deepening our understanding of animal locomotion but also expanding the potential of robotic technologies, resulting in innovations that are more adaptive and inspired by biological principles [22].

Species Identification and AI:

AI is transforming the field of species identification by equipping researchers, conservationists, and citizen scientists with advanced tools that enhance the accuracy of animal recognition and classification. Conventional species identification methods often necessitate specialized knowledge and manual examination, which can be time-consuming and susceptible to inaccuracies [23]. In contrast, AI technologies, including machine learning and computer vision, are streamlining this process. For instance, AI can evaluate images or videos collected in natural settings, identifying distinct characteristics—such as coloration, dimensions, and morphology—to accurately classify various species. This capability is particularly beneficial for biodiversity monitoring, as AI can swiftly analyze extensive datasets obtained from camera traps, smartphones, or drones [24]. Additionally, AI is employed in audio recognition systems, enabling the classification of animal calls or vocalizations to determine species based on auditory signals. This technological advancement not only accelerates the identification process but also enhances accessibility, empowering non-experts to engage in species identification. The improved efficiency in species identification bolsters wildlife conservation initiatives, aids in tracking endangered species, and enriches biodiversity research, ultimately fostering a deeper understanding and safeguarding of the natural environment [25].

Integration of AI into Zoology: Limitations and Challenges

The incorporation of artificial intelligence into the field of zoology opens up a range of promising opportunities; however, it also introduces various limitations and challenges that must be addressed. A significant challenge is the quality and accessibility of data. AI systems depend on extensive and precise datasets to operate effectively, yet in wildlife research, the collection of comprehensive data can be particularly challenging, especially in remote or hard-to-reach environments [26]. Incomplete or biased datasets can result in erroneous predictions, highlighting the necessity for datasets that are both diverse and representative of different species and habitats. Another limitation pertains to the interpretability of numerous AI models. Many algorithms, especially those based on deep learning, function as "black boxes," rendering their decision-making processes opaque [27]. In the context of zoology, comprehending the rationale behind AI predictions is vital for researchers, especially when making critical decisions regarding conservation strategies or species protection. Additionally, bias remains a significant concern, as AI models may mirror the biases present in their training data, which can lead to misidentifications or overlooked patterns in species behavior or distribution. Moreover, the deployment of AI in zoology frequently necessitates considerable technical expertise and computational resources, which may not be readily available to all researchers, particularly in settings with limited resources. Ethical considerations, such as the potential disruption of wildlife habitats due to AI-driven monitoring tools, must also be thoughtfully evaluated. In conclusion, while artificial intelligence holds remarkable potential within zoology, it is imperative to address these limitations and challenges to ensure its responsible and effective use in animal research and conservation efforts [28].

Conclusion and Future Perspective:

The incorporation of artificial intelligence into the field of zoology has already demonstrated significant transformative potential, offering advanced methodologies for wildlife conservation, behavioral analysis, genetic studies, and beyond [29]. By improving the processes of data collection, analysis, and predictive modeling, AI is enabling researchers to gain novel insights into animal behavior and optimize conservation strategies. Nevertheless, issues such as data integrity, the interpretability of models, and ethical implications persist, underscoring the necessity for continuous improvement in the application of AI technologies. Looking ahead, the prospects for AI in zoology are substantial [30]. As machine learning techniques advance and the availability of high-quality datasets expands, AI is poised to enhance capabilities in ecosystem monitoring, the protection of endangered species, and the forecasting of climate change effects. Furthermore, with progress in AI transparency and the establishment of ethical frameworks, scientists will be better prepared to navigate potential challenges. The intersection of zoology and AI holds great promise, presenting opportunities to enrich our comprehension of animal life and bolster global biodiversity conservation efforts. Through sustained research and responsible application, AI is set to play a crucial role in the evolution of zoological studies.

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CLIMATE CHANGE AND ITS IMPACT ON WILDLIFE

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Abstract:

Climate change has become one of the most pressing global environmental challenges, impacting ecosystems and wildlife across the world. Rising temperatures, changing precipitation patterns, habitat destruction, and increasing frequency of extreme weather events threaten biodiversity at an unprecedented scale. This chapter explores the various facets of climate change and its direct and indirect effects on wildlife, focusing on global and Indian contexts. Case studies illustrate the severity of impacts, and potential strategies for mitigation and adaptation are discussed.

Keywords: Climate Change, Biodiversity Loss, Wildlife Conservation, Habitat Destruction, Adaptation Strategies, Mitigation Measures, Global Warming, India, Ecosystem Resilience.

Introduction:

Climate change refers to long-term alterations in temperature, precipitation, wind patterns, and other elements of the Earth's climate system. These changes can occur naturally or be driven by human activities, primarily through the release of greenhouse gases (GHGs). These changes disrupt ecological balance, posing significant threats to wildlife by altering their habitats, food sources, and migration patterns. This chapter aims to examine how climate change affects wildlife globally and within India, highlighting case studies and exploring effective management strategies to mitigate its impacts.

Causes of Climate Change

Climate change is driven by both natural and anthropogenic (human-induced) factors.

A. Natural Causes:

1. Volcanic Activity: Volcanic activity refers to the eruption of molten rock (lava), gases, and ash from beneath the Earth's crust. It has significant effects on the environment, including wildlife and ecosystems. Large volcanic eruptions release aerosols and carbon dioxide (CO_2) into the atmosphere, temporarily cooling or warming the climate.

2. Solar Radiation Variability: Changes in the sun's energy output can affect Earth's climate, though the impact is relatively minor compared to human-induced changes. However, the effects of solar changes are still significant in certain contexts:

- **Short-Term Variability:** Changes in solar radiation over the 11-year solar cycle can lead to slight temperature fluctuations on Earth. When solar activity is higher, the Earth may experience a small warming, while a solar minimum can cause slight cooling.
- **Long-Term Climate Change:** Over longer periods (centuries to millennia), variations in solar radiation can have a more pronounced effect on Earth's climate. For example, during periods of low solar activity (such as the **Maunder Minimum** between 1645 and 1715), the Earth experienced cooler temperatures, contributing to the **Little Ice Age**.
- **Impact on Weather Patterns:** Variations in solar radiation can also influence weather patterns. For example, increased solar radiation may contribute to shifts in atmospheric circulation, affecting precipitation and storm patterns.

3. Ocean Currents: Variations in oceanic circulation patterns, such as El Niño and La Niña, influence regional and global climates. Ocean currents, such as **El Niño** and **La Niña**, are variations in oceanic circulation that significantly impact global and regional climates.

- **El Niño** refers to a periodic warming of sea surface temperatures in the central and eastern Pacific Ocean, leading to changes in weather patterns like warmer temperatures, droughts, and altered precipitation in various parts of the world.
- **La Niña** is the opposite, characterized by cooler-than-average sea surface temperatures in the Pacific, typically bringing cooler, wetter conditions to certain regions and droughts to others.

Both phenomena disrupt typical ocean circulation and atmospheric patterns, influencing weather, agriculture, and ecosystems globally.

4. Earth's Orbital Changes: Long-term shifts in Earth's orbit and axial tilt, known as Milankovitch cycles, impact climate over thousands of years.

B. Human-Induced Causes:

1. Burning Fossil fuels:

The combustion of coal, oil, and natural gas for energy is a major source of greenhouse gas emissions. When these fuels are burned, carbon dioxide (CO_2) is released into the atmosphere, along with methane (CH_4) from natural gas leaks. Both gases are significant contributors to the greenhouse effect, trapping heat in the atmosphere and leading to global warming.

2. Deforestation:

Cutting down forests for agriculture, urban development, or logging reduces the planet's ability to absorb CO_2. Trees naturally capture carbon through photosynthesis, so when forests are cleared, this carbon is released back into the atmosphere, further increasing the levels of greenhouse gases and accelerating climate change.

3. Industrial Processes:

Manufacturing industries, especially in the chemical, cement, and metal sectors, release various greenhouse gases, including potent fluorinated gases (e.g., hydrofluorocarbons or HFCs). These gases have a much higher global warming potential than CO_2, contributing significantly to global temperature rise. Additionally, processes like cement production release CO_2 directly from raw materials.

4. Agricultural practices:

Agriculture, particularly livestock farming, is a major source of methane emissions. Livestock such as cows produce methane through digestion (enteric fermentation). Furthermore, the use of synthetic fertilizers in crop production leads to the release of nitrous oxide (N_2O), another potent greenhouse gas that can remain in the atmosphere for a long time, trapping heat.

5. Urbanization:

As cities grow, they consume more energy for transportation, heating, and cooling, which often comes from fossil fuels. This increases CO_2 emissions. Urban areas also create localized warming effects, known as the "urban heat island" effect, where cities become significantly warmer than surrounding rural areas due to dense infrastructure and human activity. Additionally, cities tend to produce large amounts of waste, which can release methane when it decomposes in landfills.

The Greenhouse Effect:

The greenhouse effect is a natural phenomenon that makes Earth habitable by trapping heat from the sun within the atmosphere. However, human activities have intensified this effect, leading to an enhanced greenhouse effect, and rising global temperatures. Major greenhouse gases include:

- **Carbon Dioxide (CO_2):** Produced by burning fossil fuels and deforestation.
- **Methane (CH_4):** Released by agriculture, landfill sites, and fossil fuel extraction.

- **Nitrous Oxide (N_2O):** Emitted from fertilizers and industrial activities.
- **Fluorinated Gases:** Industrial by-products with high global warming potential.

Evidence of Climate Change:

1. Rising Global temperatures:

Over the past century, Earth's average surface temperature has risen by approximately 1.1°C (2°F). This rise is primarily due to increased concentrations of greenhouse gases in the atmosphere, which trap heat. This warming is not uniform across the planet, with the most significant increases seen in the polar regions, leading to various environmental changes.

2. Melting Ice Caps and Glaciers:

Arctic sea ice, Antarctic ice sheets, and glaciers around the world are melting at rates faster than ever recorded. The Arctic, in particular, is warming more rapidly than other regions, a phenomenon known as "Arctic amplification." As ice melts, it reduces the Earth's albedo (the ability to reflect sunlight), leading to further warming. This ice loss also contributes to rising sea levels and alters ecosystems dependent on ice-covered environments.

3. Sea Level Rise:

Rising global temperatures contribute to two primary factors driving sea level rise: melting ice and the thermal expansion of seawater. As the planet warms, ice melts into the ocean, adding more water, while seawater expands as it heats up. Since 1880, global sea levels have risen by about 8 inches (20 cm), which threatens low-lying coastal areas and islands, increasing the risk of flooding and erosion.

4. Extreme weather events:

The frequency and severity of extreme weather events, such as hurricanes, heatwaves, droughts, and heavy rainfall, have intensified due to climate change. Warmer air holds more moisture, leading to stronger and more frequent rainfall events, while rising temperatures contribute to more intense heatwaves. These events are now more unpredictable and devastating, impacting ecosystems, agriculture, and human infrastructure.

5. Ocean Acidification:

The oceans absorb about a quarter of the CO_2 emitted into the atmosphere, leading to a chemical reaction that lowers the water's pH, a process known as ocean acidification. This harms marine life, particularly organisms with calcium carbonate shells or skeletons, such as corals, shellfish, and plankton, which are essential parts of marine food webs. As acidity increases, marine ecosystems become less resilient, impacting biodiversity and fisheries.

6. Shifts in Ecosystem:

Climate change has triggered observable shifts in ecosystems across the globe. For example, seasonal patterns are changing, with earlier springs, longer summers, and altered growing seasons. Migratory species are changing their routes or timing, and some animals are moving to higher altitudes or latitudes in search of cooler habitats. These shifts disrupt ecosystems, food chains, and human livelihoods, particularly in agriculture and fishing communities.

Impacts of Climate Change:

The effects of climate change are far-reaching and affect the environment, economy, and society in profound ways:

1. Environmental Impacts:

a. **Loss of Biodiversity:** Ecosystems face stress due to changing temperatures and habitat destruction.
b. **Desertification:** Prolonged droughts are turning fertile lands into deserts, threatening food security.
c. **Oceanic Changes:** Coral bleaching, marine species migration, and altered fish populations are consequences of warming oceans.

2. Economic Impacts:

a. **Agricultural Disruptions:** Changes in growing seasons and crop yields affect food supply chains.
b. **Infrastructure Damage:** Extreme weather events cause costly damages to roads, buildings, and utilities.
c. **Energy Demand:** Rising temperatures increase demand for cooling, straining power grids.

3. Social and Health Impacts:

a. **Climate Refugees:** Rising sea levels and natural disasters force millions to relocate.
b. **Public Health Issues:** Heatwaves, poor air quality, and the spread of vector-borne diseases increase health risks.
c. **Water Scarcity:** Droughts and glacial melt reduce freshwater availability.

Climate Change and Wildlife

Climate change poses significant threats to wildlife by altering habitats, food sources, and migration patterns. Some of the key impacts include:

1. Rising Temperatures

- **Impact on Metabolism, Reproduction, and Survival**: Many species are highly sensitive to temperature changes, which can affect their metabolic processes, reproduction cycles, and overall survival. For example, amphibians, which rely on specific temperature ranges for breeding, may face disruptions in reproductive timing, leading to population declines. Similarly, certain species' growth rates and feeding behaviors may be impacted, reducing their chances of survival.
- **Struggling to Adapt**: Species that are adapted to temperature ranges, such as those in polar regions or high-altitude environments, may find it difficult to survive as temperatures rise. These species might be forced to migrate or face extinction if suitable habitats are no longer available.

2. Changes in Migration Patterns

- **Shifts in Timing and Routes**: Many migratory species, including birds, fish, and mammals, depend on seasonal cues for their migration, breeding, and feeding. As seasonal temperatures change, the timing of migration and food availability are disrupted. For example, birds that migrate in search of food may arrive at their breeding grounds when conditions are no longer suitable.
- **Food Shortages and Population Declines**: Disruptions in migration patterns can lead to mismatches in food availability, which in turn can result in malnutrition, reduced reproductive success, and declining populations. Animals that rely on seasonal food sources may not find enough to sustain themselves or their offspring.

3. Increased Natural Disasters

- **Destruction of Habitats and Food Sources**: Extreme weather events, such as hurricanes, droughts, and wildfires, have become more frequent and intense due to climate change. These events can destroy vital habitats and food sources for wildlife. For example, wildfires can decimate forests, leading to habitat loss for species like deer, birds, and small mammals.
- **Adaptation Challenges**: Wildlife often struggles to adapt to these rapid and extreme environmental changes. Species may not have enough time to relocate or evolve in response to the altered conditions, leaving them vulnerable to extinction.

4. Ocean Acidification

- **Impact on Marine Species**: The ocean absorbs a significant amount of CO_2 from the atmosphere, leading to ocean acidification. This lowers the pH of seawater, which can harm marine organisms, particularly those with calcium carbonate shells or skeletons, such as corals, shellfish, and plankton.
- **Disruption of Marine Ecosystems**: Marine ecosystems rely on coral reefs, shellfish, and plankton as essential parts of the food chain. As ocean acidification damages these organisms, the entire marine food web faces major disruptions, affecting fish populations, seabirds, and even humans who rely on these resources for food.

5. Disease and Pests

- **Expansion of Diseases and Pests**: Warmer climates create more favorable conditions for disease-carrying organisms like mosquitoes and ticks, as well as invasive pests. These can carry new pathogens to wildlife populations, exposing species to diseases they have never encountered before.
- **Vulnerability of Wildlife**: Many wildlife species lack natural immunity to these emerging pathogens, leading to population declines. For instance, diseases such as chytridiomycosis in amphibians and white-nose syndrome in bats have devastated certain species. Additionally, pests like ticks can spread diseases such as Lyme disease to mammals.

6. Invasive Species

- **Opportunities for Invasive Species**: As the climate shifts, ecosystems become more vulnerable to invasive species. These species, which thrive in disturbed or altered environments, can outcompete native wildlife for resources, space, and food. Invasive species like the Burmese python in the Florida Everglades or European red foxes in Australia can severely disrupt local biodiversity.
- **Alteration of Ecosystem Balance**: Invasive species can alter ecosystem dynamics, such as predation and competition, leading to imbalances. Native species that are not adapted to these newcomers may be pushed to extinction or suffer significant population declines.

7. Habitat Loss

- **Shifting Ecosystems**: Rising temperatures and changing precipitation patterns affect ecosystems like forests, wetlands, and coral reefs. As these ecosystems change, wildlife may be forced to relocate or adapt to new environments. Species that cannot migrate or adjust may face extinction. For instance, mountain species might not have higher elevations to move to as temperatures rise.

- **Impact on Biodiversity**: Habitat loss due to climate change not only directly affects species but can also lead to a loss of biodiversity. The shrinking of key habitats like wetlands, forests, and coral reefs can result in the decline of numerous species that rely on these ecosystems for food, shelter, and breeding.

8. Food Chain Disruptions

- **Shifts in Temperature and Precipitation**: Climate change alters the availability of food sources across ecosystems. For example, temperature changes in freshwater habitats can impact the life cycles of aquatic insects, which in turn affects the animals that feed on them. Changes in precipitation patterns can also disrupt the growth of plants, reducing food availability for herbivores.
- **Cascading Effects**: These disruptions can have cascading effects on entire ecosystems. For example, the decline of primary producers like plants and plankton can affect herbivores, which are food for carnivores. This ripple effect can lead to a collapse of local ecosystems and a reduction in biodiversity.

Case Studies:

A. Global Case Studies

1. Polar Bears in the Arctic

- **Impact**: Polar bears rely on sea ice to hunt for seals, their primary food source. Rising global temperatures are causing the Arctic ice to melt at unprecedented rates, leaving polar bears with less access to hunting grounds.
- **Consequences**: As the sea ice melts, polar bears are forced to travel farther to find food, increasing their energy expenditure. Some bears may even have to swim longer distances, putting them at risk of exhaustion or drowning. The lack of food has led to lower birth rates and declining populations, making polar bears a vulnerable species in the face of climate change.

2. Great Barrier Reef (Australia)

- **Impact**: Rising sea temperatures and increased CO_2 levels are causing coral bleaching, a phenomenon where corals expel the algae that provide them with nutrients and color. Without these algae, corals lose their vibrant color and become more susceptible to disease and death.

- **Consequences**: Coral reefs are critical ecosystems that support a vast array of marine species. The bleaching of the Great Barrier Reef leads to the loss of habitats for thousands of marine organisms, including fish, invertebrates, and sea turtles. As the reef deteriorates, marine biodiversity is severely impacted, disrupting food chains and the livelihoods of local communities who depend on the reef for tourism and fishing.

3. Amazon Rainforest (South America)

- **Impact**: Climate change has led to increased frequency and intensity of droughts in the Amazon, as well as more frequent forest fires. The combination of rising temperatures and changing rainfall patterns has made the rainforest more susceptible to fires, which are often exacerbated by human activity.
- **Consequences**: Forest fires and droughts result in large-scale deforestation, damaging critical habitats for countless species, including jaguars, monkeys, and various bird species. As the rainforest is destroyed, biodiversity declines, and the ecosystem's ability to act as a carbon sink (absorbing CO_2 from the atmosphere) is diminished, contributing to further climate change.

4. Monarch Butterflies (North America)

- **Impact**: Monarch butterflies migrate thousands of miles from North America to central Mexico for the winter. Temperature fluctuations and changes in weather patterns have disrupted their migration, particularly through alterations in the timing of seasonal events like the blooming of flowers (their primary food source) and the cooling of habitats in Mexico.
- **Consequences**: These disruptions can lead to reduced survival rates of monarch butterflies. If the timing of migration is misaligned with the availability of food sources or the conditions in their wintering grounds, populations may decline. The monarch butterfly is considered a species at risk due to the combination of habitat loss and climate change impacts.

5. African Savannas (Africa)

- **Impact**: Climate change is altering rainfall patterns in the African savannas, making some regions wetter and others drier. These shifts are affecting the availability of food and water, crucial resources for large herbivores like elephants, giraffes, and zebras, as well as the carnivores like lions that depend on them.

- **Consequences**: A decline in rainfall leads to droughts, which can result in food scarcity for both herbivores and predators. In some areas, waterholes are drying up, exacerbating the difficulty for wildlife to find water. As a result, populations of large mammals are declining, and ecosystems are becoming less stable, threatening the biodiversity of the savanna.

Each of these examples demonstrates how climate change disrupts the delicate balance of ecosystems, affecting not only individual species but entire food webs and habitats. Immediate action to mitigate climate change is crucial to preserving these vital ecosystems and the wildlife that depend on them.

B. Indian Case Studies

1. Himalayan Biodiversity

- **Impact**: The retreat of glaciers in the Himalayas, driven by rising temperatures, affects the availability of freshwater. These glaciers feed major rivers like the Ganges, Indus, and Brahmaputra, which are critical for the region's water supply.
- **Consequences**: Changes in water flow impact local ecosystems, particularly the alpine species that rely on stable water sources. As the glaciers retreat and rivers change their flow patterns, the distribution of these species shifts, disrupting local biodiversity. Some species may struggle to survive if their habitats become drier or more unpredictable, leading to declines in certain populations.

2. Sundarbans Mangroves

- **Impact**: The Sundarbans, a vital mangrove forest region located in India and Bangladesh, is being affected by rising sea levels. This causes coastal erosion and saltwater intrusion, which disrupts the delicate balance of the mangrove ecosystem.
- **Consequences**: The loss of mangrove habitat due to rising seas leads to an increase in human-wildlife conflict, especially in areas where people rely on the land for resources. Additionally, the Sundarbans are home to the endangered Bengal tiger, and the encroachment of human settlements, along with habitat loss, has contributed to a decline in tiger populations. These tigers are now forced into closer contact with humans, often resulting in conflict and further population pressures.

3. Western Ghats

- **Impact**: The Western Ghats, one of the world's most biodiverse regions, is facing rising temperatures due to climate change. This affects the delicate ecosystems and species that are uniquely adapted to the region's specific climate.

- **Consequences**: As temperatures rise, the distribution of many endemic species is shifting. Species that thrive in cooler, higher elevations are being pushed to higher altitudes, while others may struggle to survive as their habitats change. This leads to ecological imbalances, as species that once coexisted in specific niches are now competing for resources in altered environments, putting stress on the ecosystem.

4. Indian Ocean Marine Life

- **Impact**: The Indian Ocean is facing both coral bleaching and ocean acidification due to rising sea temperatures and increased CO_2 absorption. Coral reefs, which are sensitive to temperature changes, are being damaged, leading to widespread bleaching.
- **Consequences**: Coral reefs are vital for marine biodiversity, serving as habitats for fish, invertebrates, and other marine life. The loss of these habitats leads to declines in fish stocks, which many coastal communities depend on for food and income. Additionally, ocean acidification harms marine life that relies on calcium carbonate to form shells, further disrupting marine ecosystems and threatening fish and shellfish populations.

5. Ranthambore Tiger Reserve

- **Impact**: The Ranthambore Tiger Reserve, a key wildlife sanctuary in India, is being affected by shifting rainfall patterns due to climate change. Erratic rainfall can lead to droughts or floods, disrupting the availability of prey species for tigers.
- **Consequences**: As prey populations, such as deer and wild boar, become less predictable or decrease in number, tigers may find it harder to find food. This, in turn, forces tigers into closer proximity to human settlements in search of food, leading to increased human-wildlife conflict. As tigers venture into villages or farms, the risks of poaching and retaliation grow, further endangering their population.

These ecosystems and species are just a few examples of how climate change is not only affecting the environment but also the delicate balance of biodiversity. The consequences of these changes are widespread, from increased human-wildlife conflicts to severe disruptions in food chains, highlighting the urgent need for action to mitigate climate change and protect these vital habitats and species.

Mitigation and Adaptation Strategies

A. Mitigation:

Mitigation efforts aim to slow down global warming by reducing or preventing the emission of greenhouse gases (GHGs) into the atmosphere. These actions focus on addressing the root causes of climate change.

1. Transition to renewable energy:

Moving away from fossil fuels like coal, oil, and natural gas is crucial to reducing carbon emissions. Renewable energy sources such as solar, wind, and hydropower produce electricity without emitting CO_2 or other greenhouse gases. Investing in renewable energy infrastructure is essential for long-term sustainability and reducing dependence on fossil fuels.

2. Energy Efficiency:

Improving energy efficiency means using less energy to perform the same tasks. This can be achieved in transportation, buildings, and industries. For instance, better insulation in buildings reduces the need for heating and cooling, and more efficient engines and vehicles reduce fuel consumption. This not only saves energy but also reduces the environmental impact of energy use.

3. Reforestation and Afforestation:

Forests play a critical role in carbon sequestration, meaning they absorb CO_2 from the atmosphere. Reforestation (restoring forests that were previously cleared) and afforestation (planting new forests in areas where there were none) can significantly increase the global capacity to absorb carbon and help mitigate climate change. These activities also restore habitats for wildlife and improve biodiversity.

4. Carbon Capture and Storage:

CCS is a technology designed to capture carbon dioxide emissions from power plants and other industrial processes before they can enter the atmosphere. The captured CO_2 is then transported and stored underground or in other secure locations. This technology holds great potential for reducing emissions from sectors that are difficult to decarbonize, like heavy industry.

5. Sustainable Transportation:

The transportation sector is a major contributor to greenhouse gas emissions, particularly through the burning of fossil fuels. Moving towards electric vehicles (EVs), promoting public transit, and encouraging non-motorized transport like biking and walking can reduce the demand for fossil fuels and lower emissions. Investing in EV infrastructure and expanding public transit networks are essential for shifting to more sustainable transportation systems.

B. Adaptation: Adjusting to Climate Change Impacts

While mitigation addresses the cause of climate change, adaptation focuses on preparing for and responding to the effects of climate change that are already happening or are inevitable. Adaptation helps reduce vulnerability and increase resilience to climate impacts.

1. Resilient Infrastructure:

As extreme weather events like hurricanes, floods, and heatwaves become more frequent, it is essential to design buildings, transportation systems, and critical infrastructure that can withstand such events. This might include building flood-resistant structures, improving drainage systems, and using materials that can endure higher temperatures. Adaptation in infrastructure ensures communities remain functional and safe in the face of climate extremes.

2. Water Management:

Changes in rainfall patterns, droughts, and floods can strain water resources. Effective water management strategies—such as conservation, efficient irrigation techniques, and rainwater harvesting—can help ensure that water is used efficiently and sustainably. These practices are particularly important in agriculture and urban areas that face water scarcity or floods due to changing climate patterns.

3. Climate- Resilient Agriculture:

Agriculture is highly sensitive to climate change, with shifting weather patterns affecting crop yields. To adapt, it is necessary to develop drought-resistant crops, improve irrigation methods, and adopt sustainable farming practices. This could include rotating crops, using organic fertilizers, or incorporating agroforestry techniques that help conserve soil and water. Climate-resilient agriculture helps ensure food security in the face of changing weather conditions.

4. Disaster Preparedness:

Preparing for extreme weather events and disasters is critical to minimizing their impact. Early warning systems that can predict hurricanes, floods, or heatwaves allow communities to evacuate or take preventive measures in advance. Additionally, having emergency response plans in place ensures that resources can be quickly mobilized to assist affected populations. Disaster preparedness also includes the training of local communities to respond effectively to emergencies and build resilience to future events.

Mitigation and adaptation are complementary strategies that together form a comprehensive approach to addressing climate change. Mitigation efforts work to slow or reverse the rate of climate change by addressing its causes, while adaptation strategies help societies cope with the changes that are already underway or anticipated. Combining both strategies is essential for building a sustainable, resilient future in the face of climate challenges.

Efforts to combat climate change focus on two key strategies: mitigation and adaptation.

International Efforts to Combat Climate Change:

Governments, organizations, and individuals worldwide have taken initiatives to address climate change:

- **Paris Agreement (2015)**: A global commitment to limit temperature rise to well below 2°C, with efforts to keep it to 1.5°C.
- **Kyoto Protocol (1997)**: Set binding targets for industrialized nations to reduce emissions.
- **United Nations Framework Convention on Climate Change (UNFCCC)**: Provides a framework for international cooperation.
- **Sustainable Development Goals (SDG 13):** Calls for urgent action to combat climate change and its impacts.

Role of Individuals in Combating Climate Change:

While governments and industries play a critical role, individuals can also contribute to climate action:

- Reducing energy consumption by using energy-efficient appliances.
- Supporting sustainable products and reducing waste.
- Advocating for climate-friendly policies and awareness.
- Adopting plant-based diets to lower carbon footprints.
- Using public transportation, cycling, or walking to reduce emissions.

Challenges and Future Outlook

Despite global efforts, challenges remain in combating climate change:

- **Political and Economic Barriers:** Resistance from industries and governments prioritizing economic growth over sustainability.

- **Technological Gaps:** Developing affordable and scalable clean technologies.
- **Global Cooperation:** Ensuring all nations, especially developing countries, participate effectively.

If action is not taken promptly, the consequences will be severe, leading to further environmental degradation, economic instability, and social disruptions. However, with decisive action and collective effort, a sustainable future is possible.

Conclusion:

Climate change is a critical global challenge that poses severe threats to wildlife and biodiversity, both globally and in India. Rising temperatures, changing weather patterns, and habitat loss are pushing species to the brink of extinction and disrupting fragile ecosystems. To combat this, urgent and sustained action is needed—through effective conservation strategies, supportive policies, and active community involvement. By embracing a comprehensive approach to wildlife conservation and climate adaptation, we can enhance the resilience of ecosystems and ensure the long-term survival of diverse species. The time to act is now, as every effort counts in safeguarding a balanced and sustainable planet for generations to come.

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EFFECTS OF MICROPLASTIC ON AQUATIC ORGANISMS

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Abstract:

Microplastic pollution has become a severe environmental issue, particularly in aquatic ecosystems. These tiny plastic particles, measuring less than 5 mm, originate from the breakdown of larger plastic waste and microbeads in personal care products. Due to their small size, they are easily ingested by aquatic organisms, causing harmful effects throughout the food chain.

The ingestion of microplastics by marine and freshwater species leads to several health issues, including internal injuries, digestive blockages, and reduced nutrient absorption. Additionally, microplastics can carry toxic pollutants such as heavy metals and persistent organic pollutants (POPs), which accumulate in aquatic organisms and biomagnify up the food chain, ultimately affecting human health. Microplastics have also been shown to disrupt endocrine functions, impair reproduction, and reduce growth rates in fish, shellfish, and other marine life.

To combat microplastic pollution, several measures can be implemented. Firstly, reducing plastic production and consumption is crucial, along with promoting biodegradable alternatives. Improved waste management systems, including better recycling and waste disposal, can prevent plastic from entering water bodies. Additionally, advanced filtration systems in wastewater treatment plants can help capture microplastics before they reach aquatic environments. Public awareness and policy interventions, such as bans on microbeads in cosmetics and restrictions on single-use plastics, are also vital in tackling this issue.

By adopting sustainable practices and enforcing strict regulations, we can mitigate microplastic pollution and protect aquatic organisms from its detrimental effects.

The main aim of this article is to review regarding microplastic, its source, effects on aquatic organisms and remedies.

Keywords: Microplastic, Aquatic Organisms, Sources, Entry into The Environment, Effects on Aquatic Organisms.

Introduction:

Now a days we are facing a problem regarding plastic pollution. According to Ahmed *et al.* (2023) plastic is synthetic organic polymers and derived from coal, natural gas, and crude oil through polymerization or polycondensation processes. Global plastic production increased from 1.7 million tons in the 1950s to 335 million tons in 2016. 8 million metric tons (Mt) of plastic waste entered the marine environment from land sources (Talbot and Chang, 2022). Due to high demand, production trends are expected to quadruple by 2050. Consumption of plastic is increased day by day due to consumer habits, improper disposal of plastic waste, and population demographics. Now a days plastic would become a serious concern (Haque and Fan, 2023). Plastic is not safe for environment as it is non-renewable resource, cannot be replenished naturally, high affinity for persistent organic pollutants (POPs), Durability of plastic makes it highly resistant to degradation, leading to its persistence in the environment (Sahu *et al.,* 2023, Wright *et al.,* 2013).

Microplastic (MPs) refer to inconspicuous plastic particles threaten our environment and health. From the oceans to the food chain, they get into everything and harm wildlife and ecosystems. Sizes of microplastic vary from >1.6 μm, <1 mm, <2 mm, 2–6 mm, <5 mm, and <10 mm (Khoshmanesh *et al.,* 2023; Yu *et al.,* 2022). According to National Oceanic and Atmospheric Administration (NOAA) MPs are tiny, ubiquitous plastic particles with a diameter of <5 mm (Miao *et al.,* 2023; Leal Filho *et al.,* 2019). These tiny pollutants, typically measuring <5 mm, have quietly infiltrated our oceans, rivers, and even the air we breathe (L. Xu *et al.,* 2022; D. Xu *et al.,* 2022; Mahamud *et al.,* 2022). While invisible to the naked eye, the impact of MPs on our ecosystems and human health is far from negligible (Kalčíková, 2023; Ali *et al.,* 2020). Microplastic with different derivatives such as Bisphenol A and Phthalates induces a serious threat for the aquatic ecosystem (Auta *et al.* 2017). Combination of microplastic with organic pollutant affect the immune system and there by decreasing the aquaculture products (El-Sherif *et al.* 2022). Microplastic slow down the growth and survival of aquatic animals and causes serious health effects after consumption of microplastic. Microplastic reduces enzymatic activity, absorption function of digestive system. Human health risk increases day by day by accumulation of organic contaminants, such as antibiotics and microplastic and organic additives. Microplastic along with other organic pollutants causes hazardous effects for human reproduction, teratogenic and mutagenic effects and administration of microplastic causes human intestinal microbiota more resistant to infection (Nunes *et al.,* 2023; L. Yang *et al.,* 2021; Yu *et al.,* 2022; Sheriff *et al.,* 2023). So, working to investigate microplastic pollution is essential for aquatic ecosystem. The main objectives of this review are to investigate regarding sources, effects of microplastics on aquatic organisms.

Sources of Microplastic in the Environment

Microplastic can either enter in the environment at the micro sized scale (Primary microplastic) or fragment from larger, "macro" – sized plastic already in the environment (Secondary Microplastic). The The International Union for Conservation of Nature (IUCN) highlights seven primary sources of microplastics in the marine environment: synthetic textiles, vehicle tyres, road markings, personal care products and cosmetics, plastic pellets, marine coatings, city dust (Jeyavani etal., 2022; Nawaz *et al.,* 2023). Microfibres which shed from textiles are the main contributor to micropollution. Although only synthetic microfibers would be considered microplastics, micro fragments from all types of fibres - including natural ones such as cotton and wool, also contribute to pollution. Vehicle tyres are another source of microplastic pollution. Natural rubber contents in the rubber are 20% and rest include plastic. The total microplastics generated from the wear of automotive tyres in the European Union is around 0.5 million metric tonnes (MMT) per year (Eunomia and ICF; 2018). City dust refers to a wide range of microplastic sources originating from urban areas - artificial turf, building paints, and industrial abrasives constitute the largest and most well-understood sources of city dust. City dust refers to a wide range of microplastic sources originating from urban areas - artificial turf, building paints, and industrial abrasives constitute the largest and most well-understood sources of city dust. Road covers and tyres, road markings wear. Hot-melt paints, which are commonly used for road markings, consist of 15-25% polymer binders, which contribute to microplasitc pollution when worn away. Marine coatings applied to the hulls of marine vessels include polymers such as polyurethane, epoxy coatings, vinyl and/or lacquers, as well as other compounds such as metals, when these coatings are weathered, scraped, sanded, disposed of, or spilt during the application, they contribute to microplastic load in the environment. Personal care products, such as exfoliants contain microbeads, which make up a relatively small but well-recognised facet of microplastic pollution. Plastic resin pellets (also known as 'nibs' or 'nurdles') are used as feedstock for the manufacture of most plastic products (Sundt *et al.* 2014). Polymer-based products potentially containing microplastics have a variety of applications in agriculture, including mulches for temperature and moisture control, silage and fumigation films, and anti-bird and weed protection (Horton *et al.* 2017). Primary microplastics have hundreds of other sources across many sectors:

- Dish detergents can contain microplastics such as polyurethane particles that are used to clean surfaces and are subsequently disposed of in wastewater; (Scudo, 2017).
- Plastic bio-beads used as filter media in wastewater treatment plants (WWTPs) can be unintentionally released due to accidents and leaks at plants;
- Microplastics are used in the healthcare and pharmaceutical sectors, including as vectors for drugs and dentist polish (Sundt, 2014).
- Microplastics are also commonly employed in the oil and gas sector as additives to drilling fluids, although it has proved difficult to estimate precisely the tonnage of microplastics used for this purpose (Scudo, 2017).
- Other common uses for microplastis incude: packaging, textile printing and automotive moulding, biomedical research insulation, furniture, pillows, buoys, 3D printing, ceramics, and adhesives (European Chemicals Agency (ECHA) 2019).
- Sources of secondary microplastics include macro-sized terrestrial and marine-based refuse (e.g. fishing gear and shipping waste and losses).

Entry of Microplastic in the Environment

Since the vast majority of plastic has a terrestrial origin, terrestrial ecosystems and wastewater infrastructure are the major pathways of microplastics into the environment. The main channels by which primary microplastics enter the environment are roadside runoff, wastewater treatment plants, wind transfer, marine activities.

Characteristics of microplastic

MPs come in various forms, including fibers, fragments, films, and microbeads, each possessing unique attributes. Their size is a defining characteristic, allowing them to be easily ingested by a broad range of organisms. Shapes, such as irregular, spherical, or elongated, further influencing their transport and behavior in the environment. Microplastics consist of carbon and hydrogen atoms bound together in polymer chains. Other chemicals, such as phthalates, polybrominated diphenyl ethers (PBDEs), and tetra bromo bisphenol A (TBBPA), are typically also present in microplastics, and many of these chemical additives leach out of the plastics after entering the environment.

Ecological implications of microplastic in aquatic environment

Ecological implications of microplastic in aquatic environment are far-reaching and multifaceted effects which plays a crucial role in various trophic levels and disrupting key ecological processes. Microplastic cause serious effects by altering sediment composition and there by affecting nutrient cycling by accumulation in the sediment (Shukur *et al.* 2023). This type of disruption causes changes in primary production with potential effects on ecosystem. Effects of microplastic is observed for various organisms. Among these, fish are the most commonly studied (25%), followed by molluscs (15%), small crustacea (11%), large crustacea (8%), annelid worms (6%), mammals and echinoderms (both 3%), birds and cnidaria (both 2%), porifera, reptiles and rotifers (<1%) (Carlos *et al.,* 2018).

Effects of Microplastic on Aquatic organisms

Incase of fishes Microplastic causes neurotoxicity ((96 h; 1–5 μm; 0.184 mg L^{-1}) (Oliveira *et al.,* 2012, Oliveira *et al.,* 2013; Luis *et al.,* 2015), reduction of the predatory performance and efficiency in *Pomatoschistus microps* (predatory test; 420–500 μm; 100 particles L^{-1}) (Carlos de Sá *et al.,* 2015). Mazurais *et al.* (2015) reported mortality and induction of the cytochrome P450 (CYP P450) in *Dicentrarchus labrax* (846 h; 10–45 μm; 10–100 particles mg^{-1} of diet). Polyethylene MPs have been shown to affect growth and reproduction of a large freshwater crustacean, the amphipod *Hyalella azteca* (240 h and 1008 h; 10–27 μm; 0–10^8 particles L^{-1}) (Au *et al.,* 2015). Several toxic effects related to immune response, oxidative stress and genotoxicity have been reported in molluscs including a study of the marine mussel *Mytilus galloprovincialis* exposed to Polyethelene MPs (168 h; <100 μm; 20,000 mg L^{-1}) (Avio *et al.,* 2015). Van Cauwenberghe *et al.* (2015) observed an increase of energy consumption by the polychaete *Arenicola marina* when exposed to PE MPs (336 h; <100 μm; 1.1×10^5 particles L^{-1}). In echinoderms, PE MPs (120 h; 10–45 μm; 3×10^5 particles L^{-1}) have been shown to influence larval growth and development of *Tripneustes gratilla* without affecting its survival (Kaposi *et al.,* 2014).

MPs on entering in the gastrointestinal system of fish after consumption, producing obstructions across the digestive tract and limiting feeding owing to appetite (Lusher *et al.,* 2013; Wright *et al.,* 2013) and induce anatomical and functional changes in the digestive tracts, causing dietary and development issues in fish (Huang *et al.,* 2022; Borrelle *et al.,* 2017; Peda *et al.,* 2016). MPs pose a threat to fish, with mortality occurring frequently before they reach maturity due to MPs ingestion. Administration of microplastic on *Danio* *rerio* causes oxidative stress, decreased mobility, gene expression disruption and damage of reproductive organs (Mu *et al.,* 2021; Zhao *et al.,* 2021; Zhang *et al.,* 2022). *Oryzias melastigma* showed physical impairment due to MPs ingestion (Xia *et al.,* 2022). Growth inhibition, dysbiosis of fish gut, reduction of weight, disturbance of anti-oxidative condition of the liver, damaging reproductive organs and growth retardation are visible effects in *Oryzias melastigma* (Wang *et al.,* 2022; Zhang X. *et al.,* 2021; Feng *et al.,* 2021; Li *et al.,* 2021). *Sparus aurata* is affected by MPs ingestion by facing stress, oxidative damage, survival, Behavior changes and damage of immune system's key functions (Espinosa *et al.,* 2017; Pannetier *et al.,* 2020; Jacob *et al.,* 2021; Rios-Fuster *et al.,* 2021; Solomando *et al.,* 2021).

Reduction of plastic pollution

Science from 6,300 million metric tons of plastic waste were generated. Of which about 4,900 million metric tons, ended up in landfills and the environment. Researchers assumed that by 2050 the amount of plastic waste in landfills and the environment would reach 12,000 million metric tons. Plastics pollution, especially pollution from microplastics, remained largely ignored by governments and policy makers.

To help overcome this obstacle, organizations such as the United Nations Expert Panel of the United Nations Environmental Programme engaged more than 100 countries in educational campaigns aimed at raising awareness of plastics pollution and encouraging reuse and recycling of plastics. Other international cooperative programs were established to address marine wastes, including microplastics pollution. In 2015 the United States passed the Microbead-Free Waters Act, which prohibits the manufacture and distribution of rinse-off cosmetics products that contain plastic microbeads. Many other countries also placed bans on microbeads.

Remediation of microplastics by using microorganisms capable of breaking down synthetic microplastic polymers. A number of bacterial and fungal species possess biodegradation capabilities, breaking down chemicals such as polystyrene, polyester polyurethane, and polyethylene. Such microorganisms can potentially be applied to sewage wastewater and other contaminated environments.

Conclusion:

Microplastic pollution poses a significant threat to aquatic ecosystems, affecting the health and survival of marine and freshwater organisms. The ingestion and accumulation of microplastics lead to physiological and toxicological effects, ultimately impacting biodiversity and human health. Addressing this issue requires a multi-faceted approach, including reducing plastic production, enhancing waste management, and implementing effective policies.

In the future, advancements in biodegradable materials and innovative cleanup technologies, such as nanotechnology-based filtration and plastic-eating microbes, may offer promising solutions. Further research is needed to understand the long-term ecological and health impacts of microplastics. Additionally, global cooperation and stricter regulations will play a crucial role in mitigating plastic pollution. By adopting sustainable practices and fostering scientific innovations, we can work towards a cleaner and healthier aquatic environment.

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BIOMODULANT PROPERTIES OF THE MILK WEED, *CALOTROPIS GIGANTEA* (L.) DRYAND.: A REVIEW

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Abstract:

Medicinal plants are frequently used as raw materials for the synthesis of different drugs. *Calotropis gigantea* (L.) Dryand, a perennial shrub is considered to be a weed in arid lands. The medicinal value of the plant had been proved and utilized for the betterment of humans from time immemorial. Studies proved that, the extracts of the plant parts are having anti helminthic, analgesic, antisyphilic, antipyretic, cytotoxic and antimicrobial effects in vertebrates. An ayurvedic preparation of *C. gigantea*, Swarnabhasma, is extensively used for the treatment of diabetes mellitus, bronchial asthma, rheumatoid arthritis and nervous disorder

Keywords: Milkweed, Phytochemicals, Bioactive Compounds, Cytotoxicity.

Introduction:

Plants have been used by human beings for the treatment and prevention of various ailments. *Calotropis gigantea* (L.) Dryand known as 'Milkweed', belongs to the family Asclepiadaceae is used as one of the best medicinal plants in traditional system of medicine. Varieties of bioactive components isolated from the plant have proved remarkable pharmacological effects on living world[1].

Taxonomical position of the title plant

Kingdom	*Plantae*
Class	*Magnoliopsida*
Order	*Gentianales*
Family	*Apocynaceae*
Genus	*Calotropis*
Species	*gigantea*

General Description of the Plant

The plant is a perennial shrub, relatively drought resistant and salt tolerant with oval, light green leaves and milky stem growing upto 4 m (13 ft) tall with waxy flowers consists of five pointed petals and a small, elegant "crown" rising from the centre, which holds the stamens usually grows up to 900 meters with an annual rainfall of 300-400mm throughout the country and is a native of India, China, Malaysia, Bangladesh, Thailand, Pakistan, United Arab Emirates and Sri Lanka[2] .The seeds of the plant are numerous and are freely floated thorough the air and natural regeneration happens.

Remarkable Studies on the Plant

In India, a lot of promising works have been reported using different parts viz., leaves, stem, latex, flower, roots of *Calotropis gigantea* L. Dryand.

Phytochemical Profile

Phytochemicals are the chemicals present in plants. The medicinal value of a plant mostly depends upon the presence of phytochemicals in it. Important constituents of plant include alkaloids, tannins, flavonoids, carbohydrates, terpenoids and steroids. Studies revealed that, the leaves of *C. gigantea* contains phytochemicals especially usharin, gigantin, calcium oxalate, fatty acids (both saturated and unsaturated), alpha and beta-calotropeol, and hydrocarbons[3]. Plant produced cardenolides are a group of remarkable chemical compounds or diverse steroids derived from triterpenoids, which are responsible for the poisoning of livestock and also for the treatment of congestive heart failure. It is noted that several cardenolides were isolated from the plant latex, which includes calactin, calactoxin, calotropagenin, proceroside, uscharidin, syriogenine, Calotropin DI and DII (cysteine proteinases) Calotropain FI and FII (proteinases) and voruscharin[4]. Flavonoids are more popular because of the health promoting effects. Important sources of flavonoids in diet are fruits, tea and soybean. Research suggests that flavonoids (most diverse group of phytochemicals), is responsible for reduced mortality rates, observed in people consuming high levels of plant-based foods. It is noted that, the flowers of *Calotropis* contains flavonoids, sterol, queretin-3-catinoside, calotropagenin, calotropin, polysaccharides with D- arabinose, glucose, glucosamine and L-rhamnose[5] . Many studies on root bark revealed that, it contains phytochemicals such as amyrin, taraxasterol and its isomers, taraxasterol acetate, gigantin and sitosterol. A new pregnanone, Calotropone (I) and a cardioglycoside were isolated from the ethanolic extract of the roots of *Calotropis gigantea* L. Dryand [6].

Pharmacological Profile

Plants are used in the treatment of many diseases. Bioactive compounds in plants are the secondary metabolites, which elicit remarkable effects on biological system. Several studies such as antimicrobial (strains of *S.aureus, B.cereus*, and *E.coli),* anti- fungal (against *Fusarium mangiferae*) and anti-candida activity (against clinical isolates of *Candida albicans*) of aqueous extract of *C. gigantea* leaves were reported[1]. A lot of attention has been focused on the wound healing and anti- inflammatory activites of root bark extracts of *Calotropis* against albino rats [7]. Today, many of the plant parts are used traditionally as hepato- protective, anti- diarrhoeal, analgesic, anti - helminthic and anti- pyretic drugs[8]. Another study reported that, the aqueous extracts of different plant parts of milkweed viz. leaves, flowers, roots and stem were found to be highly effective against ovicidal activity on *Helicoverpa armigera*, a polyphagous pest that infest cotton and tomatoes[9].

ROS are highly reactive molecules that originate mainly from the mitochondrial electron transport chain (ETC). Free radicals and ROS are well known inducers of several human diseases such as heart disease, cancer, inflammatory disorders etc. Studies revealed that, the methanolic extract of *C. gigantea* roots exhibited antioxidant activity[10].

Conclusion:

The milk weed has many useful applications in traditional medicine. The description suggests that a wider lacuna is set yet in the field of research about *C. gigantea*. In this scenario, it can be concluded that, the milk weed, *Calotropis gigantea* is a plant with immense potential, many of which has to be searched out further.

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METHANOLIC EXTRACT OF NEEM (*AZADIRACHTA INDICA* A. JUSS) LEAF - A POTENT ANTIMICROBIAL AGENT

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Abstract:

Azadirachta indica (Neem) plant acts as a medicinal plant have been found effective in the treatment of bacterial, fungal, viral and other diseases. Neem leaf may alleviate eczema, ringworm, acne, and has anti-inflammatory and antihyperglycemic characteristics. It is also useful to repair chronic wounds, diabetic food, and gangrene situations. It is thought to eliminate pollutants, neutralize free radicals, and purify the bloodstream. This study examined the antibacterial effects of methanol extract on *Azadiracta indica* leaf. The extract contains pharmacologically active constituents that may be responsible for its activity against *Salmonella typhi, Klebsiella pneumoniae, Clostridium perfringens, Mycobacterium fortuitum* and *Vibrio cholera*. Therefore, the use of Neem plant for treating various medical ailments, particularly infectious diseases, is highly justified.

Keywords: Antimicrobial, Phytocompounds, Ailments, Bioactive, Antibiotic

Introduction:

Drug resistance is a global issue which brings about challenges for clinicians and the pharmaceutical industry. Herbal medications are being used in the developed world due to their bioactive properties, which can be used in medicine, nutraceuticals, pharmaceutical intermediates, and lead molecules in synthetic drugs (De N *et al.,* 2002; Ncube N S *et al.,* 2008). Identifying active chemicals in medicinal plants can lead to the development of novel antibacterial drugs. Chemical modification of these molecules can lead to new and improved treatments for infectious disorders (Natarajan *et al.,* 2003).

Medicinal plants have been used to combat ailments since the beginning of civilization. *Azadirachta indica* A. Juss (syn. *Melia azadirachta*) has been known in India and its neighboring countries for over 2000 years as one of the most versatile medicinal plants, with a wide range of biological activities. The neem tree's sanskrit name is 'Arishtha', which means 'reliever of sickness', and is thus known as 'Sarbaroganibarini'. In India, the tree is still recognized as a 'village dispensary' (Susmitha *et al.,* 2013). *Azadirachta indica* (Neem) plant acts as a medicinal plant have been found effective in the treatment of bacterial, fungal, viral and other diseases. Due to increasing antibiotic resistance in microorganisms and side effects of synthetic antibiotics neem plant are now growing popularity in the treatment of many infections. Neem plant is considered as clinically effective and safer alternatives to the synthetic antibiotics (Gupta and Mohan, 1990; Kumar, V. S. and Navaratnam *et al.,* 2013). The main aim of this study is to evaluate antimicrobial potential of methanolic extract of *A. indica* leaves on selected microbial strains.

Materials and Methods:

The experiment was performed at the laboratory in the Department of Zoology, Iqbal College, Peringammala, Trivandrum. The healthy and mature leaves of *A. indica* for the proposed study were collected from the nearby areas of Palode. The collected leaves were dried under shade and powdered using an electric blender, and were sieved with a mesh of size 0.5mm. 10 g of the powder was extracted in 100 ml methanol using Soxhlet apparatus. The crude extracts were then kept in oven at 37^{o}C for the solvents to get the residue for further use.

Antibacterial Assay

The antibacterial activity was evaluated using the well diffusion method (NCCLS 1993; Perez *et al.,* 1990). The culture medium employed for bacterial growth was nutrient broth, nutrient agar, and Mueller Hinton agar acquired from Hi Media. The five perilous bacterial strains, *Salmonella typhi, Klebsiella pneumoniae, Clostridium perfringens, Mycobacterium fortuitum* and *Vibrio cholerae* were collected from MTTC in Chandigarh. A Stock solution of 64mg/ml methanolic extract of plant leaves was prepared and diluted to get a series of concentrations ranging from 4 mg/ml to 32mg/ml using DMSO.Petri plates containing 20ml Muller Hinton medium were seeded with 24hr culture of bacterial strains. 6mm wells were cut using well cutter. 50 µl of the plant extracts were added to each well. The plates were then incubated at 37°C for 24 hours. The antibacterial activity was assayed by measuring the diameter of the inhibition zone formed around the well (NCCLS, 1993). Tetracycline was used as positive control and DMSO as negative control.

Results:

The plant extract was proved to be highly susceptible to *M. fortuitum, C. perfringens*, *K. pneumoniae* (gram positive) and *S. typhi*, *V. cholera* (gram negative). The findings of antibacterial activity were depicted in the table given below.

Sl. No.	Test Organisms	Methanol Extract Zone of Inhibition (mm)						
		64 mg/ml	32 mg/ml	16 mg/ml	8 mg/ml	4 mg/ml	PC	NC
1	*Mycobacterium fortuitum*	15	13	10	8	0	29	0
2	*Salmonella typhi*	16	14	13	9	7	27	0
3	*Vibrio cholera*	11	9	8	7	0	24	0
4	*Clostridium perfringens*	12	10	9	8	0	28	0
5	*Klebsiella pneumoniae*	9	8	7	0	0	29	0

Discussion:

The development of plant-based antimicrobial compounds with improved safety and efficacy could help address antibiotic resistance (Srivastava *et al.,* 2000). The Bioactive compounds present in the candidate plant is capable of stimulating antimicrobial properties against disease causing bacterial populations. The presence of these phytochemical components may be responsible for the observed antimicrobial activity of the plant leaf extract. This finding conforms to the report of (Anyanwu and Dawet, 2005) in which similar constituents was found to exhibits antiprotozoal and antibacterial activities. According to Himal Paudel Chhetri *et al.,* 2008), the ethanolic extract of *Azadiracta indica* entire plant primarily contains flavonoids and tannins. *Azadiracta indica* extract effectively inhibits *E. coli* and *Staphylococcus aureus*. A previous study by Srinivasan *et al.,* 2001) found that A. indica has antifungal and antibacterial properties. Natural products are unlikely to cause resistance in bacteria, making them effective therapeutic agents. The plant has the potential to be a cost-effective alternative to traditional medications due to its availability and ease of extraction through exfoliation or infusion.

Conclusion:

Antimicrobial studies provided clear cut evidence to the inhibition of bacterial growth indicating potential effectiveness of the methanolic extracts prepared from *Azadirachta indica* leaf.

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HPV VACCINATION CONTROL CERVICAL CANCER IN INDIA

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Abstract:

Human Papillomavirus infection causes cervical cancer. Second most common cancer in women worldwide and leading cancer in Indian women. To prevention of cervical cancer there are several methods. Most effective option is vaccination, two vaccines available Several studies have been published safety about vaccine's efficacy, regarding mandatory vaccination questions and controversy remain in the Indian context need two booster doses and cost-effectiveness

Keywords: Human Papillomavirus, Vaccine, Cancer, Cervix.

Introduction:

Fifth most common cancer in humans is cervical cancer and second most common cancer in women worldwide and cervical cancer cause of death in the developing countries. Cervical cancer sexually transmitted human papilloma virus (HPV) infection is the most important risk factor for cervical intraepithelial neoplasia. The worldwide incidence of cervical cancer is approximately 510,000 new cases annually, with approximately 288,000 deaths worldwide. Unlike many other cancers, cervical cancer occurs early and strikes at the productive period of a woman's life. The incidence rises in 30–34 years of age and peaks at 55–65 years, with a median age of 38 years (age 21–67 years). Estimates suggest that more than 80% of the sexually active women acquire genital HPV by 50 years of age. Hence, the advent of a vaccine against HPV has stirred much excitement as well as debate.

Indian Scenario of HPV Infection

Most frequent cancer in women in India is cervical cance. Women above 15 years of age, who are at risk of developing cervical cancer. Indian women face a 2.5% cumulative lifetime risk and 1.4% cumulative death risk from cervical cancer. At any given time, about 6.6% of women in the general population are estimated to harbor cervical HPV infection. There are currently several cervical cancer research programmers in India. The National cancer registry programme, established by the Indian council of medical research, acts as a surveillance system for cancer in India. It collects data in an "active" manner, visiting government and private sector hospitals, specialized cancer hospitals and pathology laboratories to get information on the types and magnitude of cancer cases. The cancer registry in India does not cover the entire country actively but collects information only from a few urban and rural registries established in the country.

Preventive methods:

Sexual activity and age influenced by HPV transmission is. Almost 75% of all sexually active adults are likely to be infected with at least one HPV type. However, vast majority of the infections resolve spontaneously and only a minority of the HPV infections progress to cancer. The lifetime risk for genital HPV is 50–80% and genital warts is approximately 5%. In women who undergo routine screening, the risk of having an abnormal Papanicolou However, in women without routine screening, the risk for cervical cancer is up to 4%. The Pap test is used to find cellular abnormalities in cervical tissue, aiding early diagnosis. Majority of the women become infected with HPV at some point in their lives, soon after the onset of sexual activity.

Why vaccination is the best form of prevention

Currently, all genital HPV infections cannot be prevented except by abstinence and lifetime mutual monogamy. There is no clear evidence that barrier methods of contraception, most notably use of condoms, confer a protection against HPV infection. Secondly, except for genital warts, the infection is asymptomatic. Adherence to routine screening by the susceptible female population through periodic Pap smears even in developed countries has been unsatisfactory, whereas in developing countries like India, large-scale routine screening is difficult to achieve.

Types of HPV Vaccine

Two vaccines licensed globally are available in India; a quadrivalent vaccine (Gardasil) and a bivalent vaccine (Cervarix). Both vaccines are manufactured by recombinant DNA technology that produces non-infectious VLPs comprising of the HPV L1 protein. Clinical trials with both vaccines have used efficacy against CIN-2/3 and adenocarcinoma *in situ* (AIS) caused by HPV strains contained in the concerned vaccine as primary end points. Both the vaccines have also looked at cross-protection against HPV strains not contained in the concerned vaccine. These vaccines do not protect against the serotype with which infection has already occurred before vaccination. Gardasil™ is a mixture of L1 proteins of HPV serotypes 16, 18, 6 and 11 with aluminum-containing adjuvant. Cervarix is a mixture of L1 proteins of HPV serotypes 16 and 18 with AS04 as an adjuvant.

Dosage and Schedule

The vaccine dose is 0.5 mL given intramuscularly, either in the deltoid muscle or in the antero-lateral thigh. It is available as a sterile suspension for injection in a single-dose vial or a prefilled syringe, which should be shaken well before use. Manufacturer's instructions for storage and administration of vaccines should be followed.

The recommended age for initiation of vaccination is 9–12 years. Catch-up vaccination is permitted up to the age of 26 years. A total of three doses at 0, 2 and 6 months are recommended with Gardasil or 0, 1 and 6 months with Cervarix (minimum interval of 4 weeks between the first and the second dose, 12 weeks between the second and third dose and 24 weeks between the first and third dose). HPV vaccines can be given simultaneously with other vaccines such as Hepatitis B and Tdap. At present, there is no data to support the use of boosters.

If the HPV vaccine schedule is interrupted, the vaccine series need not to be restarted. If the series is interrupted after the first dose, the second dose should be administered as soon as possible, with an interval of at least 12 weeks between the second and third doses. If only the third dose is delayed, it should be administered as soon as possible.

Side-Effects and Contradictions

The most common adverse reactions are local reactions like pain (mild to moderate) in 83%, swelling with erythema in 25% and systemic adverse effects such as fever in 4% of the vaccinees. No serious vaccine-related adverse events have been reported. The HPV vaccine is currently not licensed for use in female patients younger than 9 years or older than 26 years or for use in male patients. It is contraindicated in people with a history of immediate hypersensitivity to yeast or to any vaccine component. The vaccine should be deferred in patients with moderate or severe acute illnesses. The vaccine may be administered in a sitting or lying down position and the patient should be observed for 15 min post-vaccination for syncope.

The vaccine is not recommended for use in pregnant women. Although it has not been causally associated with adverse outcomes of pregnancy, data are limited. Any exposure to the vaccine during pregnancy must be immediately reported. Lactating women and immunosuppressed female patients can receive the vaccine. The efficacy and the degree of immune response could be poor in the latter group.

Conclusion:

HPV vaccination is for primary prevention (serotype-specific with limited cross-protection) of carcinoma cervix. A cost-effective second-generation HPV vaccine is needed for developing countries to address various issues specific to the region. However, till such time, secondary prevention through periodic cervical cancer screening should be in place to use the existing infrastructure and cost-effective screening methods such as Pap smear and HPV DNA tests. There is no risk of getting an HPV infection from the vaccine as the vaccine does not contain live virus. HPV vaccination and regular cervical screening is the most effective way to prevent cervical cancer.

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RESEARCH TRENDS IN ZOOLOGY

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Abstract:

Zoology is the branch of biology dedicated to the study of animals, including their structure, function, behaviour, distribution, and evolution across diverse ecosystems.

Understanding animal biology is crucial for conservation efforts, managing wildlife populations, addressing human health concerns related to zoonotic diseases, and gaining insights into fundamental biological processes.

Research trends in zoology currently focus heavily on integrating molecular and genetic approaches to understand animal behaviour, evolution, and ecology, with a particular emphasis on conservation biology, climate change impacts on animal populations, and the application of advanced technologies like genomics, bioinformatics, and remote sensing to study animal behaviour and physiology in natural environments; this allows for a deeper understanding of animal diversity, adaptation mechanisms, and the complex interactions within ecosystems.

Key points to include in an introduction to research trends in zoology

Evolutionary Biology:

Studying the genetic basis of adaptation and speciation using comparative genomics, particularly in the context of climate change and environmental pressures. Examining how changing environmental conditions affect animal distribution, behaviour, and physiology.

Some research trends in evolutionary biology include:

1. Genome evolution

Genome evolution refers to the changes in the structure and organization of an organism's genome over generations. New genomic technologies allow researchers to study how evolution is reflected in the genome.

Gene Duplication:

The creation of extra copies of genes, which can lead to new functions or specialization.

Mutation:

Random changes in DNA sequences, which can be beneficial, harmful, or neutral, and are the raw material for evolution.

Selection:

The process by which organisms with certain traits are more likely to survive and reproduce, leading to the spread of those traits in a population.

Examples of Research Areas:

- **Evolution of specific genes or gene families:** Studying the evolution of genes involved in adaptation to specific environments or behaviors.
- **Evolution of genome structure:** Investigating how genome size, organization, and the presence of repetitive DNA elements change over time.
- **Evolution of developmental processes:** Understanding how changes in the genome lead to changes in animal development and morphology.
- **Evolution of complex traits:** Studying the genetic basis of complex traits like coloration, behavior, and immunity.

2. Machine learning

Machine learning can analyze genomic data, differentiate cells, and detect disease indicators.

3. Big data

Big data sources include medical records, imaging data, and network-based information.

4. Bioinformatics

Bioinformatics and other technologies have improved the efficiency of biological assays.

5. Developmental biology

Evolutionary developmental biology is a technological and conceptual advance that is moving the field of evolutionary biology forward.

6. Experimental evolution

Experimental evolution is a research approach that is used to study adaptation, estimate evolutionary parameters, and test evolutionary hypotheses.

Explanation

Evolutionary biology is the study of evolutionary processes that have produced the diversity of life on Earth. Evolutionary trends are identifiable patterns in which a trait evolves in a given direction over a prolonged period of time.

- **Behavioural Ecology:**

Investigating animal behaviour through field studies, incorporating advanced tracking technologies like GPS and radio telemetry to understand decision-making, foraging strategies, and social dynamics.

Applying genetic analysis to inform conservation efforts by identifying population bottlenecks, genetic diversity, and potential impacts of inbreeding. Investigating the impacts of human activities on animal populations, developing strategies for species protection, and studying habitat restoration. Exploring the ecological factors influencing animal behavior, including social interactions and foraging strategies.

- **Animal Physiology and Genomics:**

Utilizing genomic tools to explore the physiological mechanisms underlying adaptation in extreme environments, including thermal tolerance and stress responses.

- **Biodiversity and Systematics:**

Utilizing molecular data to refine taxonomic classifications and understand the evolutionary relationships between species, especially in poorly studied regions.

- **Emerging Technologies:**

Incorporating new technologies like drones, underwater robotics, and high-throughput sequencing to access previously inaccessible environments and study animal behavior with greater detail.

- **Animal Genomics and Molecular Biology:**

Utilizing genomic tools to study animal evolution, adaptation, and disease susceptibility.

- **Wildlife Disease Ecology:**

Investigating the dynamics of infectious diseases in wildlife populations and their potential transmission to humans.

Technological Advancements:

- **Biotelemetry:** Using electronic devices to track animal movements and behaviour in real-time
- **Next-generation sequencing:** High-throughput DNA sequencing for population genetics and evolutionary studies

- **Citizen Science:** Engaging the public in data collection and monitoring animal populations.

Technological advancements are crucial in zoological research, enabling scientists to study animals and their ecosystems more efficiently and effectively, leading to better conservation strategies and a deeper understanding of the animal kingdom

Conclusion:

Current research trends in zoology are heavily focused on understanding animal behaviour and ecology in the context of rapidly changing environments, utilizing advanced technologies like genomics and molecular biology to investigate evolutionary relationships and adaptations, prioritizing conservation efforts through detailed studies of threatened species, and exploring the complex interactions within ecosystems, with a strong emphasis on addressing global challenges like climate change and biodiversity loss.

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AN OVERVIEW ON THE STATUS OF EARTHWORMS IN KARNATAKA, INDIA

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Soil organisms as an inhabitant of the soil, play an important role in agricultural practices, forest activities as well as in many other ecosystem functions, there by modify the physico-chemical and biological properties of the soil. At different spatio-temporal scales they improve the soil fertility and land productivity through perturbation and the production of biogenic structures (Lavelle and Spain, 2001; Jouquet *et al.,* 2006; Kanianska *et al.,* 2016). These organisms are mainly supported by the plants for their resources and even to occupy their own niche in a particular habitat (Puga-Freitas and Blouin, 2015). Interactions of the soil macrofauna with other soil biota and microorganisms are important in the soil processes and development of faunal community (Seastedt, 1984; Visser, 1985). Many investigators have reported the role of soil organisms in soil fertility (Edwards and Lofty, 1977; Marinissen and Dereitur, 1993). In terrestrial ecosystem, plant leaf litter inputs are the main energy source in the soil for diverse group of organisms. The soil microorganisms are the key drivers for energy nutrient cycles and macro-biotas are the decomposers and energy transformers. Recently, soil biodiversity has received considerable attention due to the greater recognition of soil animals and their interactions in many soil processes (Wall and Moore, 1999). Alterations in the ecosystem structure and functions leads to the change in biodiversity, because it depends on the presence of specific number of functional group (Ehrlich and Ehrlich, 1981).

Earthworms belonging to the *Phylum*: Annelida; *Class*: Oligochaeta, account for the highest biomass among the soil macro fauna comprising about 80-90 % of total biomass of the soil invertebrates (Didden *et al.,* 1994). They are the first group of multicellular invertebrate animal, which have successfully invaded the terrestrial habitat. There are two groups of Oligochaetes i.e. *megadriles* (terrestrial and semi-aquatic earthworms) and *microdriles* (only aquatic earthworms). Among the soil organisms, earthworms, termites, ants, centipedes, millipedes, woodlice and slugs are important in the soil humification (Ashwini and Sridhar, 2006). Earthworms present in wide range of soil types and play an important role in maintaining the soil fertility and nutrient cycling through fragmentation, mixing of the decomposed organic matters and aeration in the soil (Lee, 1985; Edwards and Bohlen, 1996).

Earthworms are reported to be originated in equatorial region of West Africa and currently distributed in tropical, sub-tropical and temperate regions of the world. Of the 36 families in Oligochaetes, two-third families include aquatic Oligochaetes and rest of the families are terrestrial earthworms (Bohlen *et al.,* 2004). Approximately of the 6200 earthworm species known to exist in the world, the taxonomic status is given only for about 4400 species of earthworms (Csuzdi, 2012; Reynolds and Wetzel, 2018). Of these, about 150 species are considered as peregrine on a global scale (Blakemore, 2012). The earthworm taxonomic work was started by Carolus Linnaeus (1758) with the description of two annelid species *i.e. Lumbricus terrestris* (Oligochaete) and *Lumbricus marinus* (Polychaete) in the 10th edition of his famous book entitled '*Systema Naturae'*. Later, nearly 30 species of lumbricids were described by Savigny (1826). *Glossoscolex giganteus* was described by Leuckart from Brazil and South America during 1850s. New generation zoologists started exploring these soil organisms in 1860s. Therefore, during the first century of earthworm taxonomy (1758–1865), nearly 70 species of earthworms were described. Later, taxonomists have contributed to the earthworm study from different parts of the world including India. The first report on the earthworms of Indian subcontinent was given by Templeton (1844). Subsequently, several species of earthworms were reported from different parts of the country including Karnataka state.

Studies on earthworms of Karnataka was started by Kale and Krishnamoorthy (1978). Later, the biological and ecological aspects of certain Indian earthworms were reported by Rao (1979). Krishnamurthy and Ramachandra (1988) studied the population structure of earthworms in woodlands of Karnataka. Blanchart and Julka (1997) studied the influence of forest disturbance on the earthworm communities in Sagar forest range, Western Ghats of Karnataka. Julka *et al.* (2004) reported few species of octochaetidae earthworms from Western Ghats of Karnataka. Earthworms from Dakshina Kannada district of Karnataka was studied by Siddaraju *et al.* (2010, 2013). Aquatic earthworms have also been reported for the first time from Dakshina Kannada district in Karnataka (Siddaraju, 2011; Hegde and Sreepada, 2015). Earthworm taxonomy from north Karnataka regions of Gulbarga district was reported by Hatti (2013), Padashetty and Jadesh (2014); Harish *et al.,* 2018a & b). *Amynthas alexandri* a new addition to the earthworm fauna of Karnataka State, Southern India reported by Hasyagar *et al.* (2021). The existence of *Eudichogaster indicus* and *E. poonensis* is the new record from Hyderabad-Karnataka region is the second arid region after parts of Rajasthan in India (Mubeen and Hatti, 2022). Range extension of earthworm *Drawida impertusa* in Karnataka (Hasyagar *et al.,* 2022). At present, nearly 505 species of earthworms have been reported from India (Julka, 2014; Ahmed and Julka, 2017). Many scientists have studied the earthworm species diversity and distribution in different regions of Karnataka state. Still, many earthworm species are yet to be surveyed in different types of habitats.

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Research Trends in Zoology

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