TRANSYLVANIAN REVIEW OF SYSTEMATICAL AND ECOLOGICAL RESEARCH

22.3

The Wetlands Diversity

Editors

Doru Bănăduc & Angela Curtean-Bănăduc

Sibiu – Romania
2020

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"*Lucian Blaga*" University of Sibiu,

Applied Ecology Research Center

International Association for Danube Research

"*Lucian Blaga*" University of Sibiu

Ecotur Sibiu N.G.O.

Applied Ecology Research Center

Broward College, Fort Lauderdale

ESENIAS East and South European network for Invasive Alien Species

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Scientifical Reviewers

IN MEMORIAM

Herbert Spencer
(1820 – 1903)

Herbert Spencer was an English biologist, anthropologist, sociologist, philosopher, and distinguished classical liberal political thinker of the Victorian period.

He was born in Derby, England, on the 27th of April 1820. Spencer's father introduced him to science while the members of the Derby Philosophical Society introduced him to pre-Darwinian ideas of biological evolution, with emphasis on work done by Erasmus Darwin and Jean-Baptiste Lamarck. One of Spencer's uncles taught him mathematics, physics, and Latin but in general he was an autodidact that collected most of his wisdom from readings and conversations.

Spencer found it hard to settle on any scholarly or professional area. He worked as an engineer, as an author, and editor for different journals.

He advanced the exhaustive idea of evolution as the continuous progress of the physical world, biological organisms, the human mind, and culture. As a gifted person, he contributed to a large range of subjects: ethics, religion, anthropology, economics, political theory, philosophy, literature, astronomy, biology, sociology and psychology. Throughout his life Spencer achieved exceptional authority, mainly in the context of the academia.

He was one of the most illustrious European intellectuals in the closing decades of the nineteenth century, but his importance declined after 1900.

He presented his evolutionary viewpoint for the first time in his essay, "Progress: Its Law and Cause" (1857), which formed after the basis of the "First Principles of a New System of Philosophy" (1862). In it he explains the theory of evolution with a generalization of the law of embryological evolution. *Spencer* hypothesized that all structures in the cosmos evolve from an 'uncomplicated, undifferentiated, homogeneity to a complex, differentiated, heterogeneity, while being accompanied by a process of higher integration of the separate elements'. This evolutionary process could be identified at work, *Spencer* concluded, in all of the cosmos. It was a comprehensive law that was relevant to the stars and the galaxies as much as to biological organisms; to human social organisation as much as to the human mind. It contrasts from other scientific theories only by its higher generality.

Spencer is especially known for the remark "survival of the fittest", which he created in Principles of Biology (1864), after reading Charles Darwin's *On the Origin of Species*. This phrase firmly advocates for natural selection, and yet as *Spencer* extended the evolution concept into the realms of sociology and ethics, he also used the Lamarckism.

Spencer, in his book Principles of Biology (1864), proposed a pangenesis theory that included "physiological units" assumed to be analogous to specific body parts and responsible for the transmission of typical features to descendants. These hypothetical hereditary elements were very much alike to Darwin's gemmules.

Spencer's works were translated into many languages and he was offered honours and awards throughout Europe and North America.

He continued formulating questions all his life, trying to give answers, writing, in later years often by dictation, until he succumbed to poor health at the age of 83.

The Editors

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Preface

In a global environment in which the climate changes are observed from few decades no more only through scientific studies but also through day by day life experiences of average people which feel and understand allready the presence of the medium and long-term significant change in the “average weather” all over the world, the most comon key words which reflect the general concern are: heating, desertification, rationalisation and surviwing.

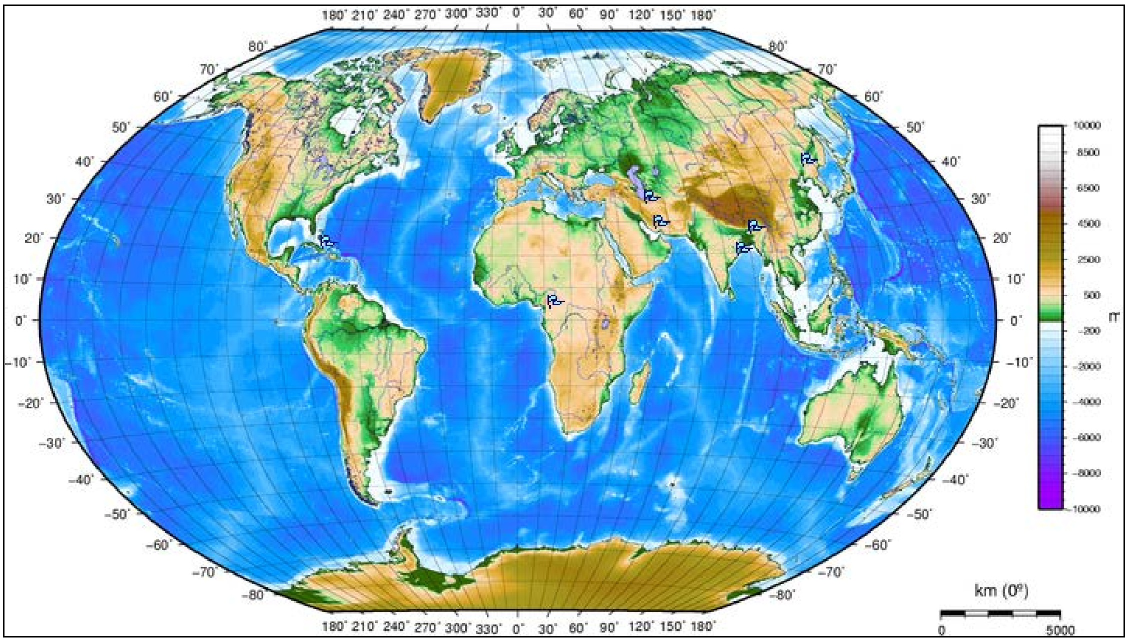
The causes, effects, trends and possibilities of human society to positively intervene to slow down this process or to adapt to it involve a huge variety of aproacess and efforts.

With the fact in mind that these aproaces and efforts shuld be based on genuine scientific understanding, the editors of the *Transylvanian Review of Systematical and Ecological Research* series launch three annual volumes dedicated to the wetlands, volumes resulted mainly as a results of the *Aquatic Biodiversity International Conference*, Sibiu/Romania, 2007-2017.

The therm wetland is used here in the acceptance of the Convention on Wetlands, signed in Ramsar, in 1971, for the conservation and wise use of wetlands and their resources. **Marine/Coastal Wetlands** – Permanent shallow marine waters in most cases less than six metres deep at low tide, includes sea bays and straits; Marine subtidal aquatic beds, includes kelp beds, sea-grass beds, tropical marine meadows; Coral reefs; Rocky marine shores, includes rocky offshore islands, sea cliffs; Sand, shingle or pebble shores, includes sand bars, spits and sandy islets, includes dune systems and humid dune slacks; Estuarine waters, permanent water of estuaries and estuarine systems of deltas; Intertidal mud, sand or salt flats; Intertidal marshes, includes salt marshes, salt meadows, saltings, raised salt marshes, includes tidal brackish and freshwater marshes; Intertidal forested wetlands, includes mangrove swamps, nipah swamps and tidal freshwater swamp forests; Coastal brackish/saline lagoons, brackish to saline lagoons with at least one relatively narrow connection to the sea; Coastal freshwater lagoons, includes freshwater delta lagoons; Karst and other subterranean hydrological systems, marine/coastal. **Inland Wetlands** – Permanent inland deltas; Permanent rivers/streams/creeks, includes waterfalls; Seasonal/intermittent/irregular rivers/streams/creeks; Permanent freshwater lakes (over eight ha), includes large oxbow lakes; Seasonal/intermittent freshwater lakes (over eight ha), includes floodplain lakes; Permanent saline/brackish/alkaline lakes; Seasonal/intermittent saline/brackish/alkaline lakes and flats; Permanent saline/brackish/alkaline marshes/pools; Seasonal/intermittent saline/brackish/alkaline marshes/pools; Permanent freshwater marshes/pools, ponds (below eight ha), marshes and swamps on inorganic soils, with emergent vegetation water-logged for at least most of the growing season; Seasonal/intermittent freshwater marshes/pools on inorganic soils, includes sloughs, potholes, seasonally flooded meadows, sedge marshes; Non-forested peatlands, includes shrub or open bogs, swamps, fens; Alpine wetlands, includes alpine meadows, temporary waters from snowmelt; Tundra wetlands, includes tundra pools, temporary waters from snowmelt; Shrub-dominated wetlands, shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils; Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils; Forested peatlands; peatswamp forests; Freshwater springs, oases; Geothermal wetlands; Karst and other subterranean hydrological systems, inland. **Human-made wetlands –** Aquaculture (e. g., fish/shrimp) ponds; Ponds; includes farm ponds, stock ponds, small tanks; (generally below eight ha); Irrigated land, includes irrigation channels and rice fields; Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture); Salt exploitation sites, salt pans, salines, etc.; Water storage areas, reservoirs/barrages/dams/impoundments (generally over eight ha); Excavations; gravel/brick/clay pits; borrow pits, mining pools; Wastewater treatment areas, sewage farms, settling ponds, oxidation basins, etc.; Canals and drainage channels, ditches; Karst and other subterranean hydrological systems, human-made.

The editors of the *Transylvanian Review of Systematical and Ecological Research* started and continue the annual sub-series (*Wetlands Diversity*) as an international scientific debate platform for the wetlands conservation, and not to take in the last moment, some last heavenly "images" of a perishing world …

This volume included variated original researches from diverse wetlands around the world.



The subject areas ( ) for the published studies in this volume.

No doubt that this new data will develop knowledge and understanding of the ecological status of the wetlands and will continue to evolve.

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The editors would like to express their sincere gratitude to the authors and the scientific reviewers whose work made the appearance of this volume possible.

The Editors

Editorial Office:

"Lucian Blaga" University of Sibiu, Faculty of Sciences, Applied Ecology Research Center, Dr. Ion Raţiu Street 5-7, Sibiu, Sibiu County, Romania, RO-550012, Angela Curtean-Bănăduc (ad.banaduc@yahoo.com, angela.banaduc@ulbsibiu.ro)

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BIOINDICATION OF WATER QUALITY OF THE XINLICHENG RESERVOIR BY ALGAL COMMUNITIES

*Sophia BARINOVA *, Na LIU **, Jiyang DING **,*
*Yonglei AN **, Xueming QIN *** and *Chenxin WU ***

* Institute of Evolution, University of Haifa, Mount Carmel, Abba Khoushi Avenue, 199, Haifa, Israel, IL-3498838, sophia@evo.haifa.ac.il
** Jilin University, Key Laboratory of Groundwater Resources and Environment, Changchun CN-130021, China, liuna@jlu.edu.cn, dingjiyang321@163.com, anyonglei85@jlu.edu.cn, 709455130@qq.com, 1172227543@qq.com

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KEYWORDS: phytoplankton, periphyton, water quality, self-purification, China.

ABSTRACT

The ecological analysis of 31 algae and cyanobacteria indicators assessed the water quality of the Changchun drinking water Xinlicheng Reservoir by using bio-indication methods. The water was fresh, low alkaline, low-saline, middle oxygenated, with reached nutrients and organic pollution and mesotrophic to eutrophic. Statistics reveal significant variables that impacted algal diversity were nutrients, water quality was low to the middle polluted Class II-III. The indices of saprobity and WESI show the high self-purification capacity and low-toxicity impact. We revealed potential threatening species of cyanobacteria. The improving water quality from 2007 up to now has been revealed.

ZUSAMMENFASSUNG: Bioindikation der Wasserqualitat des Xinlicheng-Reservoirs durch Algengemeinschaften.

Mit Hilfe einer ökologischen Analyse von 31 Algen- und Cyanobakterienindikatoren wurde die Wasserqualität des Changchun-Trinkwasser-Xinlicheng-Reservoirs unter Anwendung von Bioindikationsmethoden bewertet. Dabei ging es um Süßwasser, das niedrig alkalisch, salzarm, und mittel sauerstoffhaltig war, angerreichert an Nährstoffen sowie organischer Verschmutzung und meso- bis eutroph. Statistiken zeigen, dass signifikante Variablen, die Algenvielfalt beeinflussten, Nährstoffe waren und die Wasserqualität bis zur mittleren verschmutzten Klasse II-III niedrig war. Die Indizes für Saprobität und WESI zeigen die hohe Selbstreinigungskapazität und die geringe Toxizität an. Es wurden potenziell bedrohliche Arten von Cyanobakterien entdeckt. Von 2007 bis heute wurde eine Verbesserung der Wasserqualität festgestellt.

REZUMAT: Bioindicaţia calităţii apei a rezervorului Xinlicheng prin comunităţi algale.

Analiza ecologică a 31 de indicatori de alge și cianobacterii indicatoare a evaluat calitatea apei din rezervorul Xinlicheng a apei potabile Changchun utilizând metode de bio-indicație. Apa era dulce, slab alcalină, cu salinitate redusă, cu conținut mediu de oxigen, cu substanțe nutritive corespunzătoare, poluare organică și mezotrofă până la eutrofă. Statisticile relevă variabile semnificative care au influențat diversitatea algelor în nutrienți, calitatea apei a fost scăzută până la clasa II-III poluată mijlociu. Indicii de saprobitate și WESI arată capacitatea ridicată de auto-purificare și impactul toxic redus. Au fost identificate specii de cianobacterii potențial amenințătoare. S-a constatat îmbunătățirea calității apei din 2007 până în prezent.

INTRODUCTION

The maintenance of water quality at a high level is of considerable importance. For the most part, the water comes from natural sources, including rivers, lakes, and reservoirs. The quality of their water should be not only assessed but also predicted. Under natural conditions, water quality depends on the river watershed and the ecosystem of the water body. Considering that water quality assessment is rather expensive, elaboration of express-methods of its assessment is an urgent problem. Special attention is given to the water quality of natural water bodies used as drinking water sources. Because these types of body of water are an open natural system, many influences can affect its water quality. Usually, reservoirs are protected when it is possible, but in some circumstances, pollutants can inflow into its water.

Pollution in freshwater is represented as a complicated system of problems. Therefore, the methods for diminishing the impact of pollution requires more understanding of the ecosystem structure as well as in assessing the relevancy of methods for its state assessment. The methods and indices that can be used to evaluate the pollution impact on natural water bodies are based on the ecological point of view to the water and biota relationships. Protein production is provided by primary producers at the first level of the trophic pyramid; therefore, it can be assumed that algae can be used as bioindicators of the impact of pollution. Our Data Base of species-specific ecological preferences (Barinova et al., 2006, 2009) includes the freshwater algae grouping concerning the significant variables: pH, salinity, temperature, streaming and oxygenation, saprobity, nutrition type, and trophic level. This helps us to assess the water quality and ecosystem state with a systemic approach.

One of the parts of the aquatic ecosystem that is most suitable for the ecological evaluation of water quality is freshwater algae (Bellinger and Sigee, 2010). Therefore, many algal species are used as environmental indicators for the assessment of water quality. A bioindication approach has been implemented previously for the assessment of the water quality in the upper reaches of the Songhua River (Barinova et al., 2016) in China. This method yields productive results in the ecological assessment of water quality of other bodies of water close to this region like in India (Barinova et al., 2012) and the Russian Far East (Barinova et al., 2008, 2015).

Water supply and sanitation in China is undergoing a massive transition while facing numerous challenges such as rapid urbanization and a widening economic gap between urban and rural areas (BBC News, 2007).

The quality of groundwater or surface water is a significant problem in China because of man-made water pollution (Sun, 2011) or natural contamination (Browder et al., 2007; Ma, 2007). For this purpose, we implemented a new bio-indication methods for China (Barinova et al., 2016) for the water quality assessment that is important for large rivers, lakes, and reservoirs (Zalewski, 2000) like the Xinlicheng Reservoir (Berdnikov et al., 2006; Sun, 2011; Barinova et al., 2015) placed in the upper reaches of the Songhua River watershed. This reservoir takes our attention because a few years ago, there was an ecological incident that influenced the water quality (Sun, 2011). Some researchers have assessed water quality by chemical methods and by phytoplankton production, but bioindicational assessment of the reservoir was done for the first time on the frame of Sino-Israeli International Scientific Expedition in July 2015.

The aim of the present study is to assess the Xinlicheng Reservoir water quality by using bio-indication methods based on ecological preferences of phytoplankton and periphytonic algae statistical approach.

MATERIAL AND METHODS

Study area and its major problems

The Xinlicheng Reservoir is located southeast of Changchun City (Fig. 1), the capital of the Jilin province of northeastern China in GIS coordinates 43°37'37''N and 125°21'38''E. Water from the reservoir is used as the drinking source for Changchun.

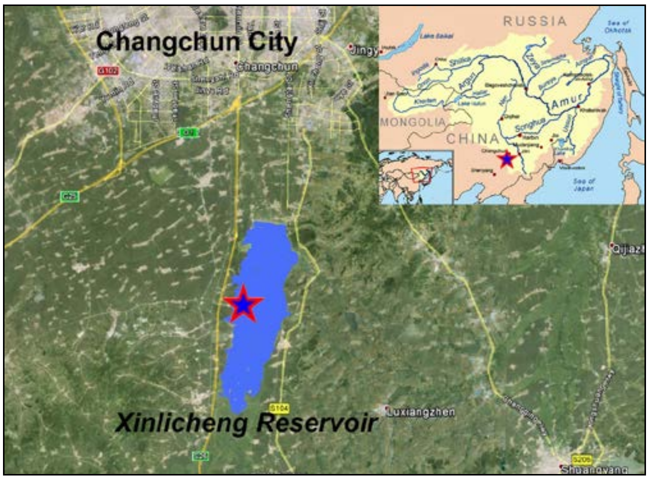

Figure 1: Sampling site (★) in the Xinlicheng Reservoir in July 2015.

The reservoir is placed between the hills, filled by rainwater, and its water surface is about 70 km^2. Its function includes aquaculture, flood-control, and anti-drought (Kao et al., 2013). Its volume is about $5.92\ 10^9$ $m^{3,}$and carrying capacity is up to $2.529\ 10^9$ m^3 of water. In the hot climatic summer season of 2007, the cyanobacteria erupted, and algal bloom occurred in Xinlichen Reservoir. Although the Changchun administration has adopted some techniques to reduce bloom, this problem recurs from time to time in this important drinking resource in the province (Li and Han, 2007). In the following years, attempts were made to find tools for assessing water quality, managing and predicting bloom, and assessing the trophic status of the reservoir. However, only monitoring data were used for chemical indicators and, sometimes, the number of plankton algae or the amount of chlorophyll (Xian et al., 2014). As a result, not only blue-green algae, but also diatoms and green algae (Kao et al., 2013) were identified as common species. The trophic status of the reservoir was initially assessed as eutrophic, and then, by 2011, as weakly eutrophic. Moreover, it was found as a result of studying the seasonality of phytoplankton development that the water body is most susceptible to eutrophication during the rainy winter season, while in the dry summer period, its trophicity decreased (Xian et al., 2013) on the base of Chlorophyll-a analysis. Thus, the role of nutrients stimulating the development of algae was revealed, as well as the catchment area, pollution from which is introduced into the water of the reservoir during the rainy season. This was indicated even during the study of the first catastrophic bloom in 2007 when the reservoir was cut off from the water supply system, and 24,000 people were left without drinking water (BBC News, 2007). The ingress of nitrogen and phosphorus compounds into the reservoir were leaked from economic and industrial enterprises located near the coast of the reservoir. However, in subsequent years, studies did not address the relationship between pollution of the catchment area with water quality and cyanobacterial blooms. The Sino-Israeli International Expedition carried out research on the water quality in the reservoir using modern methods of bioindication and statistics.

Sampling and identification

Material for work comes from 10 phytoplankton and 10 periphyton samples collected in July 2015 from four sampling sites of the Xinlicheng Reservoir (Figs. 2 and 3) (Tab. 1). Phytoplankton was collected along the reservoir shore with the Apstein phytoplankton net, gas 20 mesh. Periphyton was scrape (epilithic) and squeezed (epiphytic), placed in 10-ml plastic tubes, and fixed with 3% neutral formaldehyde solution. Samples of phytoplankton were placed in sampling tubes of 50 ml, partly fixed in the 3% neutral formaldehyde solution, and partly left as living for the study in the laboratory. In parallel with the phytoplankton samples in each site were taken samples of water about one liter for total analysis and 0.5 l for the BOD analysis with fixation. All samples were transported to the laboratory in an icebox.

Figure 2: The reservoir shore in sampling site of the Xinlicheng Reservoir in July 2015.

Figure 3: Algal communities on the sampling sites in the Xinlicheng Reservoir in July 2015.

Temperature was measured in the site with a thermometer and water transparency by the white Secchi disk. Acidity (pH), conductivity (EC), and TDS were measured with HANNA HI 9813-0. Measurements were made by adding the probe into the water until the reading was stabilized. Chemical variables were analysed in the Key Laboratory of Groundwater Resources and Environment, Ministry of Education, Jilin University according to EPA standard methods. The concentrations of some parameters were detected with the Chinese National Standard, as follows: biochemical oxygen demand (BOD_5), GB/T11901-1989, chemical oxygen demand (COD_{Cr}), GB/T11914-1989, total nitrogen (TN), GB/T11894-1989, ammonia nitrogen, GB/T7479-1987, GB/T11893-1989. The concentrations of nitrite, nitrate, chloride, phosphate, and sulfate were measured by Ion chromatography (DIONEX ICS-2100).

Algae were studied in the live and fixed state using SWIFT-M4000-D and OLYMPUS BX-40 dissecting microscope under magnifications 740x-1850x from three repetitions of each sample and were photographed with a DC (OMAX A35100U). For the study of diatoms were made permanent slides (Swift, 1967) modified for glass slides (Barinova, 1997) and were fixed in Naphrax® resin from two repetitions of each sample. Identification of the algae species was made using the relevant handbooks (Krammer and Lange-Bertalot, 1986, 1988, 1991a, 1991b; John et al., 2011), and their current scientific names were updated according to algaebase.org (Guiry and Guiry, 2018).

The frequency of the species was evaluated according to the six-score scale (Barinova et al., 2006; Barinova, 2017a). Water Ecosystem State Index (WESI) of aquatic ecosystem sustainability was calculated according to Barinova et al. (2006, 2009; 2017b) as (1): WESI = Rank S/Rank N-NO^3 (1), where: Rank S – rank of water quality on the Sladeček's indices of saprobity; Rank N-NO_3 – rank of water quality on the nitric-nitrogen concentration (Tab. 1).

If WESI is equal to or larger than one, the photosynthetic level is positively correlated with the level of nitrate concentration, if is less than one, the photosynthesis is suppressed, presumably according to toxic disturbance (Barinova et al., 2006; Barinova, 2017b).

The autecological data of the species were taken from our database (Barinova et al., 2019) according to substrate preference, temperature, oxygenation, pH, salinity, organic enrichments, N-uptake metabolism, and trophic states. The ecological groups were separately assessed according to their significance for bio-indications. Species that respond predictably to environmental conditions were used as bio-indicators for particular variables of aquatic ecosystems, the dynamics of which are related to environmental changes. The statistical methods are those recommended by Heywood (2004) for the development of floristic and taxonomic studies in Eastern Asia. The JASP program (Love et al., 2019) was used in comparative data approaches for calculating the similarity of algal communities in the studied sites. CANOCO program was used for the calculation of biological and environmental variables relationships (Ter Braak and Šmilauer, 2002). The water quality class is defined according to the EU 5-Classes system based on the species indicators content (Barinova et al., 2006, 2019; Barinova, 2017b).

The list of the algae species was combined with an ecological database in Office Access (Microsoft). The BiodiversityPro program was used for the Shannon indices calculation. Statistica 12.0 program was used to construct the plots of the relationships between biological and environmental variables.

RESULTS AND DISCUSSION

Environmental variables

Environmental properties of water in the studied reservoir are given in table 1, where it can be seen that all variables values are varied in a narrow range because the sites are close to each other. All measurements were done on one date as screening. Nevertheless, water pH was circumneutral; transparency was low at about 0.3 m, and water conductivity and total dissolved solids (TDS), turbidity (TSS) fluctuate synchronously. Studied reservoir water was sufficiently oxygenated, and the value of COD, chlorides, and sulfates was low and typical for freshwater lakes and reservoirs (Barinova 2017b). On the contrary, BOD, the forms of nitrogen and phosphorus, which normally should be in the same range, were in the middle range, which showed some periodic excessive enrichment of water with nutrients, which indicated their allochthonous, but not the autochthonous origin, as it was concluded for the Xinlicheng Reservoir earlier (Xian, 2013).

Table 1: Major averaged chemical and biological variables in the Xinlicheng Reservoir, July 2015.

Variable	min	max	STDEV
Secchi visible depth, cm	25	30	3.536
pH	8.7	8.9	0.141
DO, mg L^{-1}	8.85	8.95	0.071
T, ˚C	29.0	29.1	0.071
Conductivity, mSm cm^{-1}	0.33	0.33	0.0
TDS, mg L^{-1}	240	243	2.121
TSS, mg L^{-1}	13	14	0.707
COD, mg L^{-1}	28	30	1.414
BOD, mg L^{-1}	5.75	5.81	0.042
TN, mg L^{-1}	6.20	6.31	0.078
$N\text{-}NH_4^+$, mg L^{-1}	0.08	0.1	0.014
$N\text{-}NO_2^-$, mg L^{-1}	1.20	1.47	0.191
$N\text{-}NO_3^-$, mg L^{-1}	1.12	1.20	0.057
$P\text{-}PO_4^{3-}$, mg L^{-1}	3.45	3.54	0.064
Cl^-, mg L^{-1}	24.55	24.61	0.042
SO_4^{2-}, mg L^{-1}	40.1	40.42	0.226
Cl^-, mg L^{-1}	24.55	24.61	0.042
SO_4^{2-}, mg L^{-1}	40.1	40.42	0.226
Species in Division			
Cyanobacteria	6	7	0.707
Bacillariophyta	6	6	0.000
Chlorophyta	12	14	1.414
Charophyta	2	2	0.0
Total Species number	26	31	2.121
Species in Division			
Cyanobacteria	23	25	1.414
Bacillariophyta	9	9	0.000
Chlorophyta	31	40	1.414
Charophyta	3	3	0.000
Total frequency scores	66	77	2.828
Index Saprobity S	1.85	1.97	0.085
Index WESI	0.8	0.8	0.0
Shannon Index	3.259	3.312	0.037

Algal diversity and abundance

A total of 31 species of algae and cyanobacteria has been identified from 20 algal samples collected from four sites the richest but also abundant in the summer communities of the Xinlicheng Reservoir. We revealed differences in the distribution of species richness and abundance (as frequency scores) in four taxonomic Divisions (Fig. 4). Whereas species richness increased in line Charophyta – Cyanobacteria – Bacillariophyta – Chlorophyta, the cells abundance in Division have another order: Charophyta – Bacillariophyta – Cyanobacteria – Chlorophyta. This difference can reflect the species preferences in the biomass production for Chlorophyta and Cyanobacteria in contrary to diatom and charophyte algae. It is remarkable that the same distribution has been found in the summer communities of the

Songhua River in the catchment basin of which the studied reservoir is located (Barinova et al., 2016). Therefore, we can define that prevalence of green algae with followed cyanobacteria can be the face profile of aquatic communities of this region.

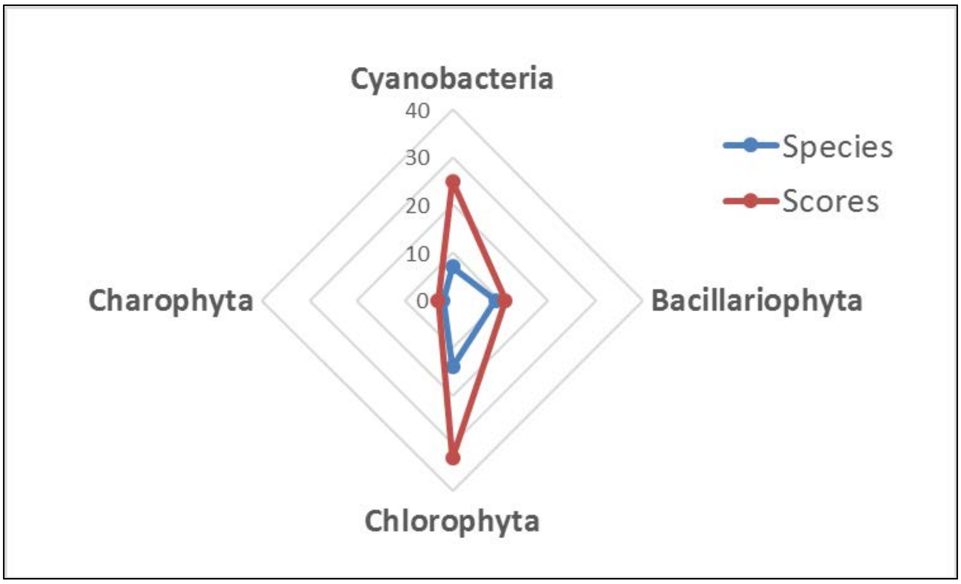

Figure 4: Distribution of species number and frequency scores in taxonomic Division in the Xinlicheng Reservoir, July 2015.

Bio-indication properties

Bioindication properties of all revealed species can be seen in table 2. We summarized revealed indicators over groups of indicated variables (Fig. 5). Moreover, in order to identify the most favorable indicator groups in the communities of the Xinlicheng Reservoir, we compared the distributions of the number of indicator species with the sum of the scores of each group. Table 2 and figure 5 show that planktonic-benthic species prevail in number, but the true planktonic organisms were also abundant. In species number and abundance, the group of preferred middle oxygenated waters species prevail, but interestingly, there were also abundant species that preferred standing water and those that preferred the tide zone. It means that oxygenation indicator abundance can be a character of a large water reservoir in which the surf zone is essential for the formation of algal communities. Among indicators of salinity, species with freshwater ecology prevailed, both in number and in abundance. Indicators of the Water Quality Class 3 were sufficient prevail in species number and in abundance with followed Class 2 species. Distribution of the nitrogen-uptake metabolism indicators demonstrated the prevalence of autotrophic species number (ats) but at the same time dominance of facultatively heterotrophic species (hce) in total abundance. Here we can mention *Nitzschia acicularis* not only as an organism with heterotrophic possibilities, but also as an indicator of organic pollution with a species-specific index of Saprobity 2.7. Most important in bioindication of water quality is the assessment of the reservoir trophic state, especially if this water body is used as a drinking water resource. Figure 5 shows only three groups of trophic state indicators placed on the plot in respect of increasing the group trophicity. It can be seen that both species number and abundance of eutrophic species were dominant in Xinlicheng Reservoir. These species are organic pollution indicators *Nitzschia* *acicularis* from diatoms and mentioned earlier *Microcystis aeruginosa* as an active causative species of flowering in the period 2007-2011 (Sun, 2011; Kao et al., 2013). Thus, we can consider the summer season 2015 as very favorable for the reservoir, when bloom by *Microcystis aeruginosa* was not found, but its potential causative species is present in planktonic communities in noticeable quantities.

Table 2: Taxonomic list of algae and cyanobacteria in communities of the Xinlicheng Reservoir with codes, abundance scores and ecological preferences of revealed taxa, July 2015.

Code	Taxa	Score	Hab	Reo	pH	T	Sal	D	Sap	S	Aut-Het	Tro
Cyanobacteria												
ANACLA	*Anathece clathrata* (West W. and West G. S.) Komarek, Kastovsky and Jezberova	**5**	P	–	–	–	hl	–	b	1.8	–	me
APHNIZ	*Aphanizomenon flosaquae* Ralfs ex Bornet and Flahault	**6**	P	–	–	–	hl	–	b	2.1	–	–
CHROTU	*Chroococcus turgidus* (Kützing) Nägeli	3	P-B	aer	alf	–	hl	–	o	1.3	–	–
DOLISP	*Dolichospermum spiroides* (Klebhan) Wacklin, Hoffmann L. and Komárek	1	P	st-str	–	–	i	–	o-b	1.5	–	–
MERMIN	*Merismopedia minima* Beck G.	2	B, S	aer	–	–	–	–	–	–	–	o
MICAER	*Microcystis aeruginosa* (Kutzing) Kutzing	**4**	P	–	–	–	hl	–	o-a	2.1	–	e
MICPUL	*Microcystis pulverea* (Wood H. C.) Forti	**4**	P-B	–	–	–	i	–	o-b	1.5	–	–

Table 2 (continued): Taxonomic list of algae and cyanobacteria in communities of the Xinlicheng Reservoir with codes, abundance scores and ecological preferences of revealed taxa, July 2015.

Bacillariophyta												
DIAHYE	*Diatoma hyemalis* (Roth) Heiberg	1	P-B	st-str	ind	cool	hb	sx	b-o	1.7	ats	–
NAVEXI	*Navicula exigua* Gregory	1	B	str	alf	–	i	es	x-o	1.4	ats	e
NITACI	*Nitzschia acicularis* (Kützing) Smith W.	**4**	P-B	–	alf	temp	i	es	o-b	2.7	hce	e
NITFIL	*Nitzschia filiformis* (Smith W.) Hustedt	1	B	st-str	alf	–	hl	es	x	2.5	hne	e
SURPIE	*Surirella peisonis* Pantocsek	1	B	–	–	–	–	–	a	–	–	–
SURTEN	*Surirella tenera* Gregory W.	1	P-B	st	alf	–	i	es	o	1.0	–	e
Chlorophyta												
ACUACU	*Acutodesmus acuminatus* (Lagerheim) Tsarenko P. M.	**4**	P-B	st-str	ind	–	i	–	b	2.1	–	–
CARTER	*Carteria* sp.	1	–	–	–	–	–	–	–	2.3	–	–
CLAGLO	*Cladophora glomerata (Linnaeus) Kützing*	6	P-B	st-str	alf	–	i	–	b-o	1.9	–	–

Table 2 (continued): Taxonomic list of algae and cyanobacteria in communities of the Xinlicheng Reservoir with codes, abundance scores and ecological preferences of revealed taxa, July 2015.

DESBRA	*Desmodesmus brasiliensis* (Bohlin) E.Hegewald	1	P-B	st-str	–	–	–	–	b	2.0	–	–
EUDELE	*Eudorina elegans* Ehrenberg	3	P	st-str	–	–	i	–	b	2.3	–	–
KIROBE	*Kirchneriella obesa* (West) West and West G. S.	2	P-B	st-str	–	–	i	–	b	1.8	–	–
MUCPUL	*Mucidosphaerium pulchellum* (Wood H. C.) Bock C., Proschold and Krienitz	2	P-B	st-str	ind	–	i	–	b	2.3	–	–
OEDOG	*Oedogonium* sp.	3	B	–	–	–	–	–	–	–	–	–
OOCSUB	*Oocystis submarina* Lagerheim	3	P-B	st	–	–	i	–	–	–	–	–
PEDDUP	*Pediastrum duplex* Meyen	**4**	P	st-str	ind	–	i	–	o-a	2.1	–	–
PLASPH	*Planctococcus sphaerocystiformis* Korshikov	3	P	st	–	–	–	–	–	–	–	–
POLSPI	*Polyedriopsis spinulosa (Schmidle) Schmidle*	2	P	st	–	–	–	–	b	1.9	–	–

Table 2 (continued): Taxonomic list of algae and cyanobacteria in communities of the Xinlicheng Reservoir with codes, abundance scores and ecological preferences of revealed taxa, July 2015.

SCEARC	*Scenedesmus arcuatus* (Lemmermann) Lemmermann	1	P-B	st-str	–	–	i	–	o-a	1.9	–	–
SCEELL	*Scenedesmus ellipticus* Corda	3	P-B	st-str	–	–	–	–	o-b	–	–	–
SCEOBT	*Scenedesmus obtusus* Meyen	1	P-B	st-str	–	–	–	–	b	1.8	–	–
WILAPI	*Willea apiculata* (Lemmermann) John D. M., Wynne M. J. and Tsarenko P. M.	1	P	–	–	–	–	–	b	2.2	–	–
Charophyta												
CLOACI	*Closterium aciculare* West T.	1	P	st-str	alf	–	–	–	b-o	1.7	–	–
SPIROG	*Spirogyra* sp.	2	B	–	–	–	–	–	–	–	–	–

Note: Abbreviation for ecological groups: Habitat preferences (Hab): B, benthic; P-B, planktonic-benthic; P, planktonic. Streaming and Oxygenation (Reo): aer, aerophiles, str, streaming waters inhabitant; st-str, low streaming waters inhabitant; st, standing water inhabitant. Water pH (pH): ind, indifferent; alf, alkaliphil. Water temperature (T): cool, cool-loving species; temp, temperate temperature water inhabitants. Water salinity (Sal): hb, halophobe; i, oligohalobious-indifferent; hl, oligohalobious-halophilous. Organic pollution, Watanabe (D): es, eurysaprobes; sp, saprophiles. Organic pollution and self-purification zones by Sládeček (Sap): indicators of Class of Water Quality I: x-o – 0.4 – xeno-oligosaprobiont; Class of Water Quality II: o – 1.0 – oligosaprobiont; o-b – 1.4 – oligo-beta-mesosaprobiont; Class of Water Quality III: x-a – 1.55 – xeno-alpha-mesosaprobiont; b-o – 1.6 – beta-oligosaprobiont; o-a – 1.8 – oligo-alpha-mesosaprobiont; b – 2.0 – beta-mesosaprobiont. Index saprobity s (S): species-specific index saprobity according Sládeček. Nutrition type as Nitrogen uptake metabolism (Aut-Het): ats, nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen; hne, facultatively nitrogen-heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen; hce, nitrogen-heterotrophic taxa, needing elevated concentrations of organically bound nitrogen. Trophic state (Tro): o, oligotrafentic; me, meso-eutraphentic; e, eutraphentic. The most abundance scores 4 and above are bolded.

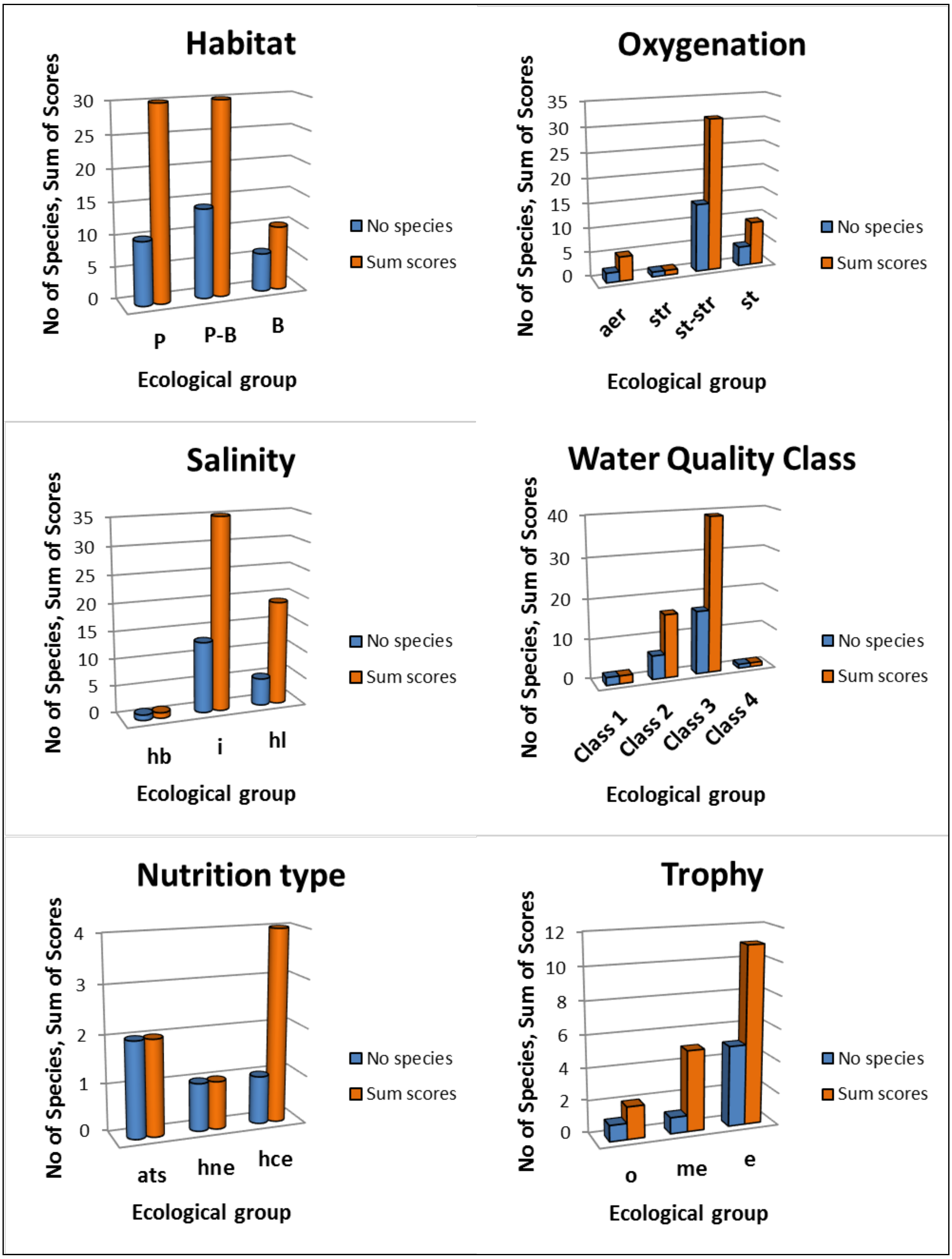

Figure 5: Distribution of algal species frequency scores and species number in Division in the Xinlicheng Reservoir, July 2015.
Ecological group abbreviation as in table 2.

Comparative statistics

A comparative approach provided for the grouping of algal communities with respect to their indicator value similarity. A similar plot of indicator compositions that was constructed for the Xinlicheng Reservoir communities showed two clusters at the similarity level of 50% (Fig. 6). Cluster 1 includes indicators of the most variables from which the closely related were groups of diatom indicators of organic pollution (D), indicators of nutrition type (Aut-Het), pH, and trophic state (Tro). The second cluster is negatively related to the first and unified abundance of species (Score) and its habitat preferences (Hab). Despite the fact that few data were collected for analysis, based on the correlation analysis of bioindicator groups, it can be said that the abundance of species and their association with the substrate is a common characteristic of the reservoir. In contrast, the most important groups for monitoring are indicators of trophicity and organic pollution.

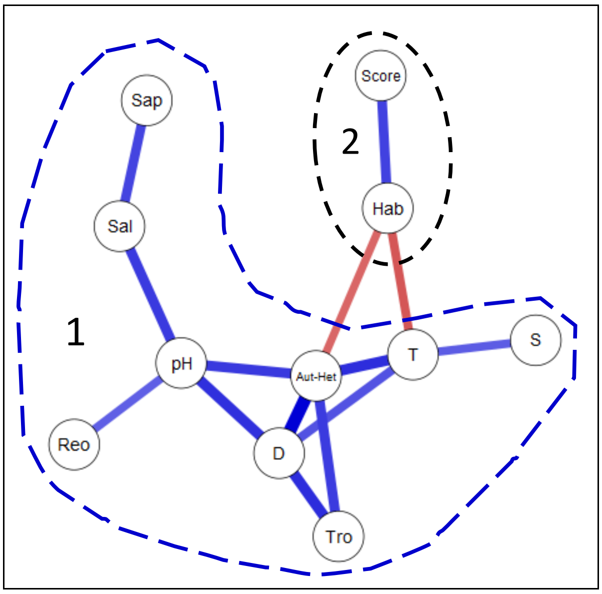

Figure 6: Indicator species correlation plot constructed in JASP of R-statistica program for the Xinlicheng Reservoir, July 2015. The indicated cariables placed in the net corners. The line thickness reflect of the correlation volume. The line color reflect positive (blue) or negative (red) correlations. The thickness of connected lines is corresponding to the percent of similarity that stay on the lines. Large circles marked by black or blue dushed lines are represent the indicator cores.

Canonical Correspondence Analysis

To continue the statistical analysis of species and environment relationships, we constructed Canonical Correspondence Analysis (CCA) plots based on environmental and biological variables of the studied reservoir water (Tabs. 1 and 2). A triplot of the most abundant species number in the communities of the Xinlicheng Reservoir and environmental variables demonstrated grouping of parameters in one arrow because the measurements were done on one date and studied sites are close positioning (Fig. 7a). Nevertheless, it can be seen in the dshed outline that *Diatoma hyemalis*, *Navicula exigua*, *Nitzschia filiformis*, and *Surirella peisonis* from diatoms and *Scenedesmus arcuatus* from green algae can be indicators, which positively related to revealed summer variables of the Xinlicheng Reservoir.

CCA of the most abundant species from table 2 with abundance scores four-six indicated that there were six species which included mostly cyanobacteria (*Anathece clathrata*, *Aphanizomenon flosaquae*, *Microcystis aeruginosa*, and *M. pulverea*), and only one species of diatoms and two of greens (*Nitzschia acicularis*, and *Pediastrum duplex*, *Acutodesmus acuminatus*, respectively) (Fig. 7b). All abundant species increase their numbers with an increase in the identified environmental variables, except for *Acutodesmus acuminatus*, which, on the contrary, developed more comfortably with lower values of variables.

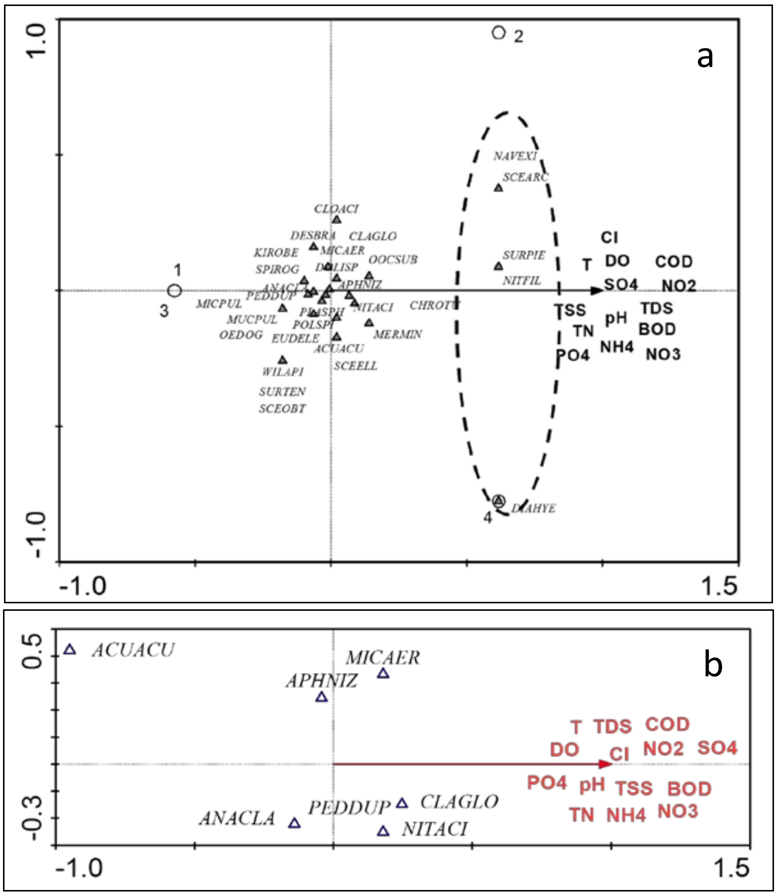

Figure 7a-b: CCA plots of algae and cyanobacteria species (a), and scores of abundant species (b), and environmental variables relationships in the Xinlicheng Reservoir, July 2015. Monte Carlo test result: significance of all canonical axes = 0.013, *P*-value = 0.0880.

Indices

We calculated Index saprobity S for assessing organic pollution value in the Xinlicheng Reservoir in summer of 2015. Table 1 shows that S value fluctuated in a small range between 1.85 and 1.97, which correspond to Class 3 of water quality, 3a self-purification zone and rank 4. Nitric nitrogen concentration (Tab. 1) can be corresponded to Class 3 of water quality, 3b self-purification zone and rank 5 (Barinova 2017b). Therefore, it can give us a base for calculation of the index of toxic impact to the algal community, the WESI, which was 4/5 = 0.8. As was mentioned in the Methods section, this value of index corresponds to low toxic influence to photosynthesis of inhabitant algae and cyanobacteria in the Xinlicheng Reservoir.

The Shannon index can be used for the water quality evaluation according to Wilhm and Dorris (1968) and Staub et al. (1970). This index values for algal communities in the Xinlicheng Basin varied from 3.259 to 3.312, corresponding to clean or slightly polluted water.

CONCLUSIONS

A total of 31 species of algae and cyanobacteria were identified in the 20 samples collected in July of 2015 in the Xinlicheng Reservoir in the frame of the Sino-Israeli International Scientific Expedition. Measured water properties confirm the fresh water with low to middle organic pollution by allochthonous nutrients. Bioindicator analysis was implemented for the first time for this important source of drinking water used by Changchun City. Because problems have arisen with the decreasing water quality that has been impacted a few times from 2007-2011 by an algal bloom, we revealed potential threatening cyanobacteria species. We assessed the significant variables, the increasing of which can provoke the bloom. Bioindication demonstrated that water was low saline, low alkaline, middle oxygenated fresh waters 3 Class of water quality with low dissolved ions. However, we found species indicators that have the heterotrophic properties with high frequency that reflect the toxic impact to photosynthesis of the primary producers in the reservoir. The calculated WESI index allows us to confirm the pollution impact on the ecosystem level due to the input of nutrients from the reservoir catchment area. As a whole, the water in the studied reservoir was assessed by bioindicators as eutrophic. This may be the highest trophic level during the year, because we took samples during the period of the most active functioning of the aquatic ecosystem. We cannot compare our list of species with previous studies in this reservoir because only two species were previously mentioned and that study was based on the chemistry and concentration of chlorophyll. In any case, we find improving water quality from 2007 up to 2015. The species list that could be a cause of the water bloom in the future was revealed with the help of statistics and represented variables, which can be recommended for monitoring.

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SENTINEL-2 FOR HIGH RESOLUTION MAPPING OF SLOPE-BASED VEGETATION INDICES USING MACHINE LEARNING BY SAGA GIS

Polina LEMENKOVA *

* Russian Academy of Sciences, Schmidt Institute of Physics of the Earth, Laboratory of Regional Geophysics and Natural Disasters, Bolshaya Gruzinskaya Street, 303, 10, 1, Moscow, Russian Federation, RU-123995, pauline.lemenkova@gmail.com

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KEYWORDS: Sentinel-2, SAGA GIS, Cameroon, remote sensing, vegetation.

ABSTRACT

Vegetation of Cameroon includes a variety of landscape types with high biodiversity. Ecological monitoring of Yaoundé requires visualization of vegetation types in context of climate change. Vegetation Indices (VIs) derived from Sentinel-2 multispectral satellite image were analyzed in SAGA GIS to separate wetland biomes, as well as savannah and tropical rainforests. The methodology includes computing 6 VIs: NDVI, DVI, SAVI, RVI, TTVI, CTVI. The VIs shown correlation of data with vegetation distribution rising from wetlands, grassland, savanna, and shrub land towards tropical rainforests, increasing values along with canopy greenness, while also being inversely proportional to soils, urban spaces and Sanaga River. The study contributed to the environmental studies of Cameroon and demonstration of the satellite image processing.

ZUSAMMENFASSUNG: Sentinel-2 zur Kartierung von Neigung bedingten Vegetationsindizes mithilfe von maschinellem Lernen von SAGA GIS.

Die Vegetation von Kameruns umfaßt eine Vielzahl verschiedener Landschaftstypen. Das Ökologische Monitoring von Yaoundé erfordert die Visualisierung der Vegetationstypen im Kontext des Klimawandels. In diesem Artikel wird die Erfahrung mit SAGA GIS vorgestellt, einem Hilfsmittel zur Satellitenbildverarbeitung. Die Arbeit analysiert die Vegetationsverteilung in Yaoundé anhand von sechs Vegetationsindizes (VIs) und einem hochauflösenden multispektralen Sentinel-2-Satellitenbild. Die Methodik umfasst eine Verarbeitung des Sentinel-2 zur Berechnung der VIs unter Verwendung verschiedener Algorithmen: NDVI, DVI, SAVI, RVI, TTVI, CTVI. Die grafische Darstellung der Häufigkeitsverteilung der Daten wird mittels eines Histogramms angezeigt. Die VIs zeigten eine Korrelation der Daten mit der Vegetationsverteilung, die von Feuchtgebieten, Grünland, Savanne und Gebüschen bis zu den tropischen Regenwäldern ansteigt und damit sich auch die grüne Saumdichte erhöht Der Anstieg ist umgekehrt proportional zu den Böden, städtischen Räumen und Sanaga Fluss. Die Satellitenbildverarbeitung in der Kartographie ist eine Frage von großer Aktualität und Bedeutung. Die Arbeit leistet einen Beitrag zu den Umweltstudien in Kamerun.

REZUMAT: Sentinel-2 pentru cartografierea indicilor de vegetație bazați pe înclinarea pantelor folosind învățarea automată de la SAGA GIS.

Vegetația din Camerun include o varietate de tipuri de peisaje cu biodiversitate ridicată. Monitorizarea ecologică a orașului Yaoundé necesită vizualizarea tipurilor de vegetație în contextul schimbărilor climatice. Indicii de vegetație (VI) derivați din imaginea de satelit multispectrală Sentinel-2 au fost analizați în SAGA GIS pentru a separa biomurile zonelor umede, savana și pădurile tropicale tropicale. Metodologia include calculul a 6 VI: NDVI, DVI, SAVI, RVI, TTVI, CTVI. VI au arătat corelația datelor cu distribuția vegetației care crește din zonele umede, pajiști, savane și arbuști spre pădurile tropicale, creșterea valorilor împreună cu verdele vegetaţiei şi invers proporţională cu solurile, spațiile urbane și râul Sanaga. Studiul a contribuit la studiile de mediu ale Camerunului.

INTRODUCTION

Wetlands are unique habitats that have become critically reduced in many areas, even becoming extinct in some places which raise the question of their protecting and conservation of their biodiversity (Brock and van Vierssen, 1992; Beatty et al., 2014; Schneider-Binder, 2020). This is caused by the perception that they have a lower value compared to the forests, and can be converted for more productive land use types (Bosma et al., 2017; Nawarathne et al., 2020). However, besides the environmental values, wetlands are highly important habitat for medical plants. For example, Fonkou et al. (2017) made a survey of wetland medicinal plants in the Western Highlands of Cameroon and documented that wetlands here are rich in medicinal macrophyte species, used as food and products for traditional health care. In total, 82 wetland macrophytes of medicinal importance, 64 genera and 40 families were documented to treat over 74 different ailments in Cameroon.

Nevertheless, wetland biodiversity recently became endangered in Cameroon (Wanzie, 2003). The destruction of the wetlands has resulted in a reduction in biodiversity and the endangerment of species that exists in wetland habitats (Price et al., 1992; Amenu and Mamo, 2018; Asomani-Boateng, 2019). Endangered wetlands can lead to social and economic drawbacks for local population who use medical plants growing in wetlands for their life maintenance. Deterioration of such precious landscapes would damage the tropical ecosystems of Cameroon. In view of this, the presented research demonstrated a technical approach of vegetation mapping using advanced cartographic methods of SAGA GIS. In response to the need of the environmental monitoring, this paper contributes to the methodological presentation of wetland conservation by introducing cartographic processing and visualization of the remote sensing data by SAGA GIS for environmental monitoring and detection of vegetation in Cameroon.

Satellite remote sensing applied in ecological studies enables to perform an advanced vegetation analysis, because high-resolution data is continuously provided by the space industry and placed in the open access data pool (e.g. GloVis), and can be used freely for thematic environmental mapping. The remote sensing data, such as Sentinel-2 or Landsat TM, creates advances in computational cartography allowing measuring VIs, capture land cover types variability, and map biodiversity patterns in various regions of the Earth. Among others, a progress in the machine-learning approaches in cartographic data visualization and interpretation includes new developed algorithms that measure VIs, as shown in this paper: NDVI, DVI, RVI, TTVI, CTVI, SAVI. Using publicly available large datasets from NOAA in combination with the GIS software, enables to model VIs of multiple species distributions at various scales (Gao, 1996; Jurgens, 1997; Xu, 2006; Lemenkova, 2014, 2015b).

Monitoring tropical wetlands is increasingly apparent in the face of climate and environmental change in Africa. Wetlands are distributed in various types of landscapes, such as coastal areas, mangroves, lakes, seasonally flooded meadows, sedge marshes, shrub or open bogs, swamps, fens, flood-plains, to mention a few. The costal lowlands of Cameroon are notable for a swampy environment of the humid tropical coasts. Extensive wetlands of Cameroon include mouths of coastal rivers along the humid tropical coastlines, costal lowlands from the Limbe area to the west, and the Douala area to the east; which today is characterized by a lagoon system (Asangwe, 2009). Simultaneously, the Cameroon recently is experiencing rapid urbanization which results in the extensive spatial expansion in the wetland areas.

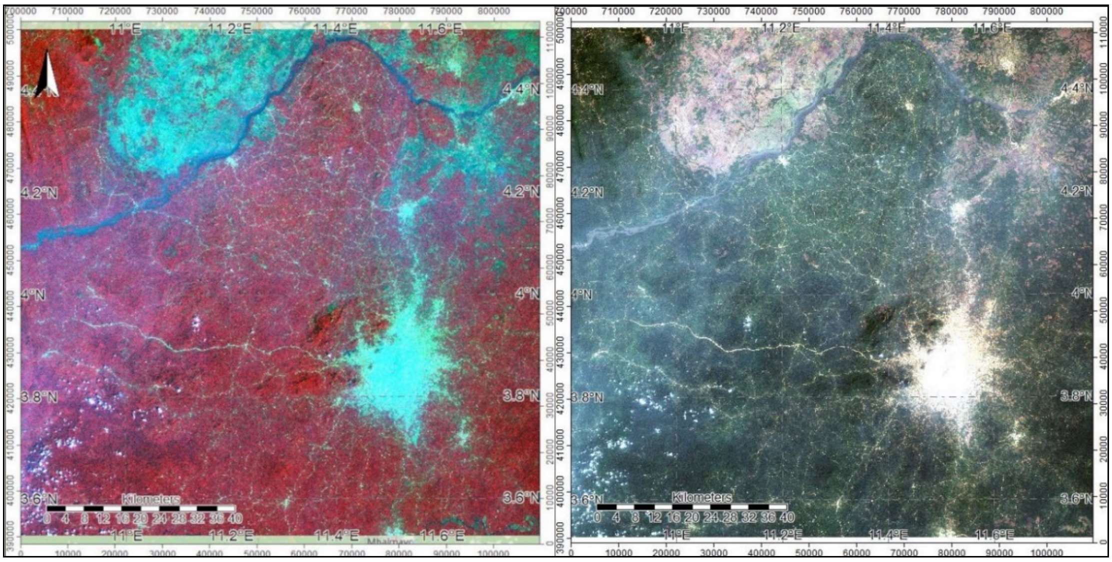

Figure 1: Sentinel-2 band composites: 8-4-2 (colour infrared, false colour composite), left, bands 4, 3, 2, natural colour composite, right; mapping: SAGA GIS.

As a consequence, wetlands areas diminished compared to the urban spaces which resulted in changes in vegetation distribution and land cover types (Asangwe, 2006). The territory of Cameroon is experiencing significant land use changes caused by the land re-structuring, intensification of agricultural activities and urbanization since 1990, varying in dynamics of the vegetation cover change and strength of anthropogenic activities in different regions of the country. For instance, a forest decline was detected in recent thirty years, the decrease of dense forest. Other types of landscapes experienced degradation by the anthropogenic impacts. For instance, these include the industrial emissions or increased domestic waste water discharge in the urban areas. The need for environmental mapping naturally evolved interest in GIS methods of spatial analysis of the vegetation distribution including wetland zones. In response to the need of the environmental monitoring of Cameroon, the research presents the functionality of SAGA GIS for remote sensing image processing which can be used to map various vegetation types including wetlands. The SAGA GIS enables accurate cartographic visualization of vegetation types by machine learning approach using high-resolution multispectral Sentinel-2 imagery (10 m) taken in 2020.

Land cover in Cameroon includes various types of vegetation and features of the land coverage, such as forest, equatorial ever green humid forests, savannas or grasslands, wetlands and bare lands. Due to the changed types of land use, the proportions of the natural vegetation and urban spaces are changing. The examples of the new land use types include development of the plantations (palm plantation), the forestry development, the harbour activities in the coastal areas of Cameroon and the effects of industrialization. After the land use changes, the biodiversity should be restored on land that has previously been heavily cultivated or abandoned, which takes time and additional processes on land re-cultivation, e.g. introducing restoration projects. The maintenance and monitoring of biodiversity within unchanged semi-natural landscapes contributes to the processes of the sustainable development of Cameroon. Vegetation Indices (VIs), as a combination of values in spectral bands of the satellite images can be used to highlight vegetation distribution in ecological studies. Specifically, the VIs are helpful in assessment of vegetation greenness and health, which is applicable in agricultural monitoring. VIs are a numerical computation of various bands with the most often used are red (R) and near infra-red (NIR) spectral bands, or a transformation of other VIs. The VIs are aimed to enhance the visibility of vegetation on a satellite image. The visualization of the VIs allows to perform spatial and temporal comparison of the photosynthetic properties of vegetation and canopy structure (Bannari et al., 1995). As a calculation of spectral bands, the VIs are calculated without any assumptions regarding land cover types, vegetation type, or climate settings using machine classification of the spectral reflectance. The VIs is useful in monitoring seasonal, quarterly, annual, or even long-term variations of canopy using a satellite scene. An analysis of the long-term variations is possible using the time-series analysis based on a set of several scenes.

The Vis are used for assessment of the environmental variables such as biophysical characteristics of plants, chlorophyll and pigment content, vegetation health or dry biomass, moisture content, phenological, biophysical characteristics of plants, structure of leaves, soil moisture, and plant temperature (Campbell, 2002). There is a number of VIs developed using various algorithms starting from a very simple Difference Vegetation Index (DVI) that only shows the difference between the R and NIR, to a very complex band combination, such as Thiam's Transformed Vegetation Index (Thiam, 1997) or Corrected Transformed Ratio Vegetation Index (Perry and Lautenschlager, 1984). Among all VIs, the most well-known is, by far, a Normalized Difference Vegetation Index (NDVI), which is also used in this study.

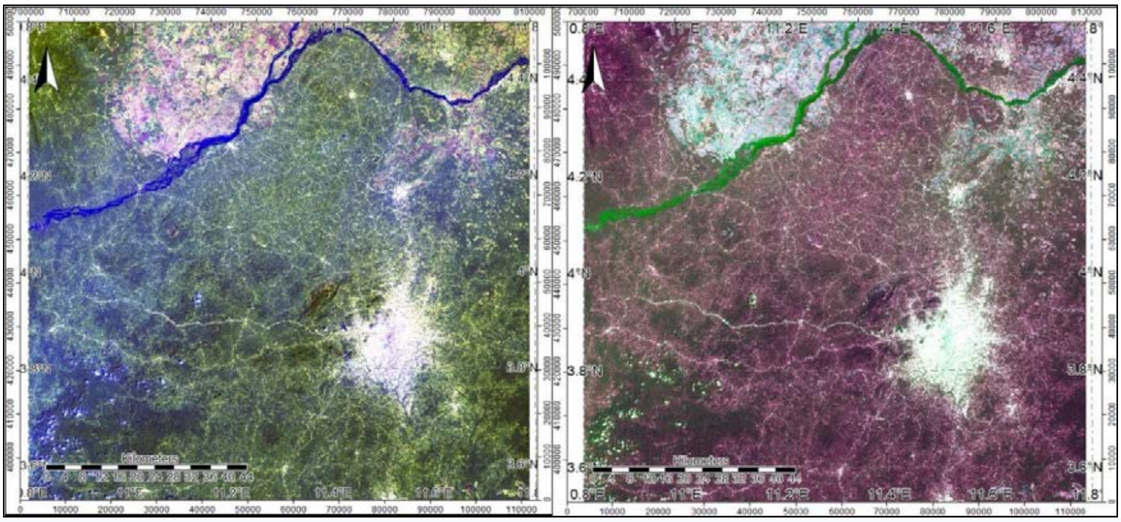

Figure 2: Sentinel-2 bands (B12-11-2), for geologic studies (left).
Sentinel-2 bands B11, B4, B12 for water detection (right).

With the increasing availability of remote sensing data at high temporal and spatial resolutions, such as Sentinel-2 with 10 m. (Fig. 1), there is a possibility of the effective processing of the imagery for the calculation of VIs. Alongside the increase in data variety (Landsat TM, Sentinel-2, MODIS), the resources to visualize images, compute, and plot VIs have boost. In response to such a need, the SAGA GIS (System for Automated Geoscientific Analyses), have proposed several VIs that can be applied for satellite data processing for vegetation mapping. SAGA GIS, an open source advanced GIS for raster analysis, has been developed by the Department of Physical Geography, University of Göttingen, Germany, and is a powerful tool for processing of the spatial data (Böhner et al., 2006).

The principle of the VIs calculation is based on the fact that vegetation is spectrally distinct from other land cover types, such as soils, urban areas, minerals and water (Lemenkova, 2011), due to its reflectance in individual wavelength regions (a.k.a. bands). The difference between near infra-red (NIR) reflectance and red (R) reflectance for soil is much less than that for the healthy green vegetation. This fact is widely used for the VIs calculations that enable it to detect regions with healthy green vegetation (forest, dense canopy trees, agricultural crop fields with green plants). Such areas can be clearly detected and distinct from other land cover types, especially urban city spaces, roads, water bodies, and so on. There are a variety of various VIs based on different approaches in mathematical algorithms. However, all of them are based on the fundamental accentuating the difference between R and NIR reflectance in image pixels with a focus on vegetation areas.

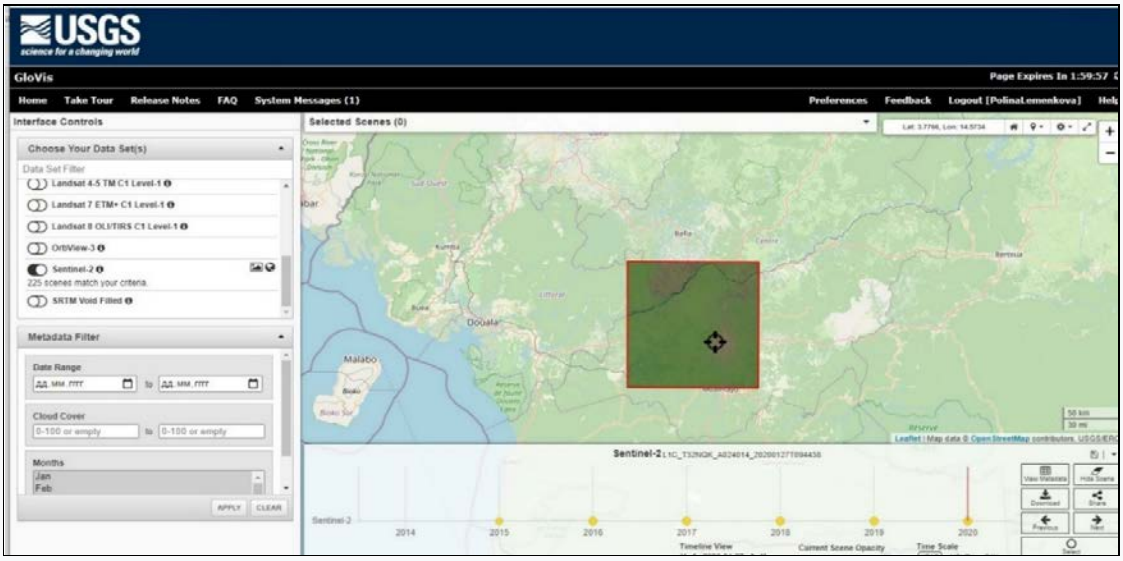

Figure 3: Data capture using the GloVis interface.

Six VIs were used with the following abbreviations: 1) NDVI – Normalized Difference Vegetation Index; 2) DVI – Difference Vegetation Index; 3) SAVI – Soil Adjusted Vegetation Index; 4) RVI – Ratio Vegetation Index; 5) TVI – Transformed Vegetation Index; 6) CTVI – Corrected Transformed Vegetation Index. Probably the most well-known is the NDVI NDVI = (NIR – R)/(NIR + R), while the simplest VI is the DVI (DVI = NIR – R). Various VIs have advantages and drawbacks, they are better suited to a variety of parameters (Crippen, 1990). For example, the DVI is more sensitive to the amount of vegetation and well distinguishes between soil and vegetation, however, it does not deal with the difference between reflectance and radiance caused by the atmosphere or shadows. We compared all the eight VIs applied for a Sentinel-2 image and to demonstrate the behaviour of the vegetation visualized on these VIs.

The study area includes the selected region of Yaoundé, Cameroon (Fig. 2), which includes various land cover types, such as wetlands, savannas, urban, rainforests, mixed forests, and agricultural regions. Some lands are affected by external factors such as climate change (Fokeng and Meli, 2015; Fokeng et al., 2020). This resulted in the development of biodiversity conservation program for the protected areas (Lambi et al., 2012). These include, for instance, Bafut-Ngemba Forest Reserve, according to the Convention on Biological

Diversity (Ministry of Environment and Forestry, 1994; Ministry of the Environment and Protection of Nature, 2009) and programs on forest management (Muam, 1999). Takem-Mbi (2013) showed an increase of deforestation along with farmland increased between 1978 and 2006 in Cameroon, supported by studies of Seiny-Boukar et al. (1992) on savannahs.

The climate impact factor can further be illustrated by deforestation, which has greatly increased in reserve areas of Cameroon due to the climate change and food crop plantations cultivated in villages. At the same time, ecological variables may reflect a complex impact from climate change. For instance, distribution of soil organic carbon is consistent with the agro-ecological and environmental patterns (Silatsa et al., 2020), or various land cover types along with the climate change reflecting soil quality in Cameroon (Ngo-Mbogba et al., 2015; Tsozue et al., 2015). These examples highly illustrate the actuality of the remote sensing data visualization using GIS for sustainable land management and analysis of climate change, improving the monitoring of vegetation health in Cameroon and ecological monitoring.

MATERIAL AND METHODS

The data include Sentinel-2 image covering the region of Cameroon, Yaoundé, and Central Africa. The metadata on the used image is presented in table 1. Data strip ID S2A_OPER_ MSI_L1C_DS_EPAE_20200127T104504_S20200127T094438_N02.08. The image is projected in UTM cartographic projection zone 32N, Datum WGS84, units in meters. Platform Sentinel-2A by ESA Agency. Acquisition: 2020-01-27T09:44:38.407Z and 2020-01-27T09:51:40.517Z. Entity ID is L1C_T32NQK_A024014_20200127T094438. Image resolution is 10, 20, 60 m, differing in various spectral bands. Tile number is T32NQK, archiving center: Environmental Protection Agency (EPA). The geodetic specifications include Sun Zenith Angle Mean (33.0302446510534°) and Sun Azimuth Angle Mean (133.8734719268990°). Data take type value: INS-NOBS (Nominal Observation). The product format is JPEG2000, zero cloudiness. The data were captured in GloVis repository (Fig. 3).

Table 1: Metadata specifications of the Sentinel-2 image.

EPSG Code	32632	Quantif.	10000	Center Latitude	4°01’26.45”N
Center lon dec	11.2953727	Vendor	EPAE	Center Longitude	11°17’43.34”E
Cloud Cover	0.00000	Vendor Tile ID	L1C_T32NQ_A024014_20200127T094438	NW Lat	4°31’18.05”N
Orbit Direction	Descending Orbit	Orbit Number	136	NW Long	10°48’08.16”E
Production Date	2020-01-27T10:45:04.000000Z	NE Corner Lat dec	4.5185436	NE Lat	4°31’06.76”N
Datatake Identifier	GS2A_20200127T093241_024014_N02.08	NW Long dec	10.8022674	NE Long	11°47’28.53”E
Data Type	UINT16			SE Lat	3°31’34.98”N
Product Type	S2MSI1C	NW Lat dec	4.5216809	SE Long	11°47’16.37”E
Processing Level	LEVEL-1C	SW Lat dec	3.5288293	SW Lat	3°31’43.78”N
NE Long dec	11.7912577	SE Lat dec	3.5263828	SW Long	10°48’00.31”E
SW Long dec	10.8000849	SE Long dec	11.7878806	Center Lat dec	4.0240124

Table 2: Algorithms of the calculation of VIs based on SAGA GIS; NIR = near infrared, R = red, S = soil adjustment factor.

1.	Difference Vegetation Index	DVI = NIR – R
2.	Normalized Difference Vegetation Index (Rouse et al. 1974)	NDVI = (NIR – R)/(NIR + R)
3.	Ratio Vegetation Index (Richardson and Wiegand, 1977)	RVI = R/NIR
4.	Transformed Vegetation Index (Deering et al., 1975)	TVI = [(NIR – R)/(NIR + R) + 0.5] ^ 0.5
5.	Corrected Transformed Ratio Vegetation Index (Perry and Lautenschlager, 1984)	CTVI = [(NDVI + 0.5)/abs(NDVI + 0.5)] * [abs (NDVI + 0.5)] ^ 0.5
7.	Thiam's Transformed Vegetation Index (Thiam, 1997)	RVI = [abs (NDVI) + 0.5] ^ 0.5
6.	Soil Adjusted Vegetation Index (Huete, 1988)	SAVI = [(NIR – R)/(NIR + R)]* (1 + S)

The reason for choosing Sentinel image consists in its following advantages. In contrast to other satellite data also used in agricultural monitoring, such as MODIS (Fritz et al., 2015; Testa et al., 2018) and Landsat-TM (Shang and Zhu, 2019), Sentinel has a higher spatial resolution: 10 to 20 m against 30 m by the Landsat TM (Claverie et al., 2018) and two satellites for synthetic aperture radar (SAR) in a Sentinel-1 and the optical sensor in a Sentinel-2. Besides, Sentinel-2 satellite has more spectral channels from the R bands compared to the Landsat-8. High-resolution Sentinel satellite images are a free and open source, which resulted from the Copernicus Program developing and being operated by European Space Agency (ESA) for an Earth observation technology.

The Sentinel-2 enables monitoring on vegetation ecosystem dynamics and functioning through the optical imagery at a fine spatial resolution (10-60 m) systematically acquired over terrestrial areas with a 290 km field of view (Nowakowski, 2015). The Sentinel-2 supports a broad range of cartographic applications such as vegetation mapping, land cover change detection, agricultural monitoring, raster data classification, and ecological mapping (Hagolle et al., 2018). The launch of the first satellite, Sentinel-2A, was in 2015. The Sentinel-2 is a multi-spectral data width 13 bands in the visible, near infrared, and short wave infrared part of the spectrum. In view of this, Sentinel-2 multi-spectral data are very promising materials for high-resolution mapping of vegetation (Bontemps et al., 2018; Lang et al., 2019). A series of the VI have been calculated by SAGA GIS. The methodology is based on the formulae embedded in the SAGA GIS summarized in table 2.

RESULTS AND DISCUSSION

With a VI-based analysis of Sentinel-2 satellite image, the vegetation coverage in Yaoundé, Cameroon, can be reliably assessed and continuously monitored. Validated by histograms, the data shown normal distribution. With the use of remote sensing and SAGA GIS technology, Sentinel-2 enables better visualization of the vegetation coverage. To better analyze the possibilities of Sentinel-2 bands, several colour composites have been visualized.

Figure 1 shows the false colour band combination including infrared, by bands 8-4-2 against the natural colour composite 4, 3, 2 (right). Since the natural combination is based on the visible bands, land cover types are resembling their appearance to the human vision: vegetation is dark green, and urban settlement areas of Yaoundé is bright yellow-white, roads can clearly be seen as white stripes agricultural fields have very light green hues, dry vegetation is brown, urban are steel grey. This band combination is mostly used for urban studies, and not applicable for agricultural studies, as sparsely vegetated areas are hard to distinguish. In contrast, false colour composite shows urban areas as bright cyan, while vegetation is bright red with various hues, which is useful for environmental monitoring.

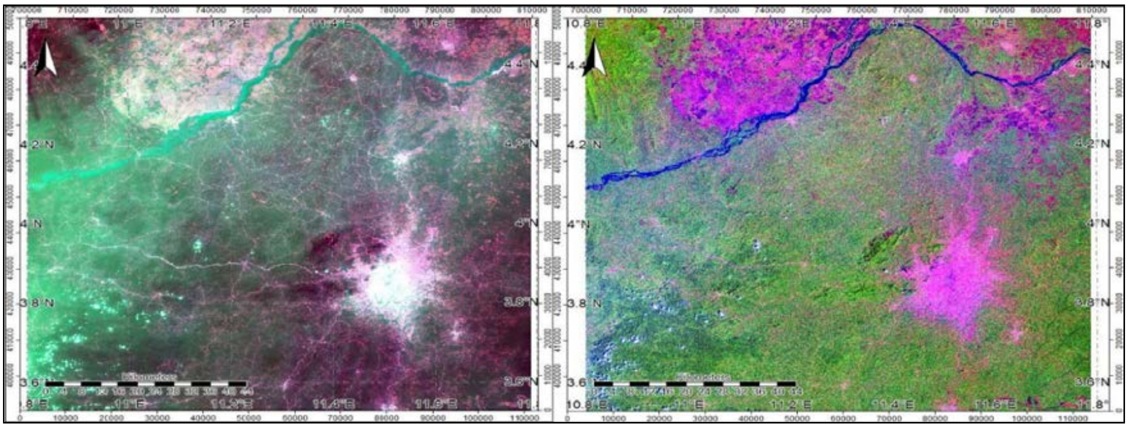

Figure 4: Sentinel-2 bands (B12-1-3) for wetland studies (left);
and Sentinel-2 bands (B11-8-2) for agriculture studies (right).

Comparison of Sentinel-2 bands shown in figure 2 presents band combination B12-11-2, useful for geologic studies due to the rock distinction (Fig. 2, left) against bands B11, B4, B12 which can be used for water detection (Fig. 2, right). The Sentinel-2 bands (B12-11-2), for geologic studies (left). Sentinel-2 bands 11, 4, 12 for water detection (right). Here, water areas are shown in bright green hues and can be separated from the land cove types, while vegetation is shown by burgundy color hues. Wetland and agricultural areas are better visualized with more contrasting colors in figure 4 showing combination of bands 12-1-3 highlighting wetland areas in bright green (left), and bands 11-8-2 for agriculture (right) where urban areas are colored magenta and can be separated from the vegetation areas and forests.

The Sentinel bands can also be visualized as single bands using either monochrome of discrete RGB colour palette. A comparative visualization of a single band 12 in monochrome shaded colours against the discrete 11 colours is shown in figure 5. The water area in monochrome shaded visualization is clearly visible as white colours, urban areas are black spots. However, the “raw” monochrome cannot be used for image classification due to the lack of information. A comparison of the pixel’s frequency distribution by values is presented in figure 6 where the monochrome colour visualization shows the classic bell-shaped histogram with adjusted distribution of grey values over the scaled value range, while the discrete approach of visualization groups pixels into clusters according to their values.

This, however, only concerns the visualization and does not change the values of the raster which varies from 88 to 1490.22 in both cases (X axis in figure 6). Visualized bands of Sentinel-2 B2 and B4 in discrete 11 colours are presented in figure 7 (left and right, respectively). The difference in colour representation illustrates technical characteristics of spectral bands 2 (blue) and 4 (red). As can be seen, the corresponding histogram in band 2 presents finer distribution of pixels with equalized histogram of an image with various levels of pixel values uniformly distributed, while pixels of band 4 are grouped in a coarser approach as colour bar (Fig. 8).

The NDVI is a good proxy vegetation index showing live healthy green vegetation (Fig. 9, left). The values for the Sentinel-2 image were selected as band 4 for red and band 8 for infra-red. The NDVI shows values in a range 0.2 to 0.67 where the lowest values of pixels close to zero (0.2) correspond to water areas (Sanaga River) followed by the group of low values (0.3-0.4) showing barren areas of rock, as well as sand. As can be noted, there are no negative values of NDVI for this particular scene of Cameron, since the area is located in tropical region with no snow or glacial areas on the image. Low positive values represent shrub and grassland (about 0.4), while high values indicate temperate and tropical rainforests (values approaching 0.4 to 0.67) with the bright green areas exactly corresponding to the vegetation. The DVI is derived from the simple subtraction of NIR – R, that is, band 8 – band 4, and is now well equalized in term of values (data range from 447,86 to 2010, 36) and data distribution, which can be seen in the histogram comparing to the NDVI (Fig. 10, left and right, respectively). The green areas of vegetation are visually represented by green colours in both cases and separated from "non-vegetation" areas which are coloured by brown hues.

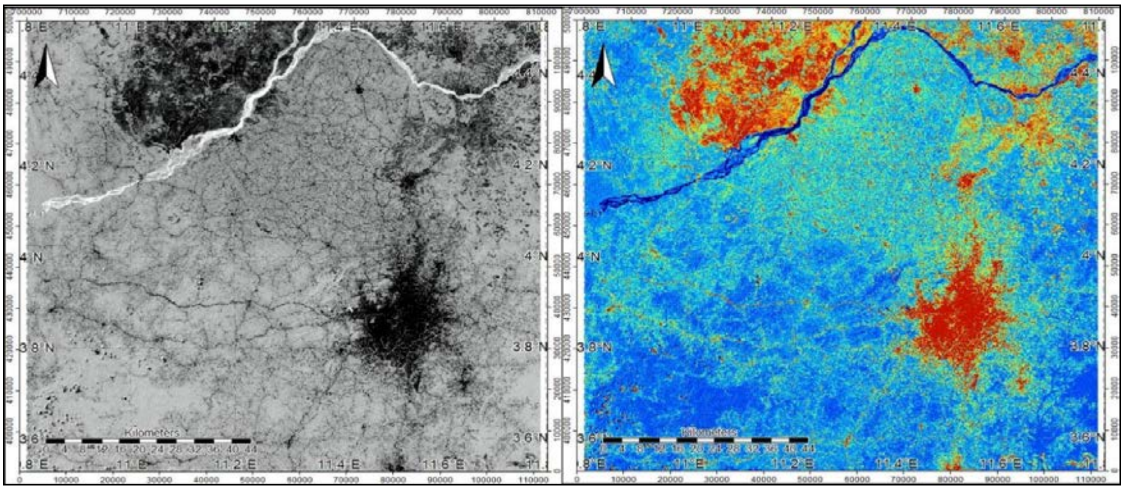

Figure 5: Sentinel Band 12 in monochrome shaded colours (left);
Sentinel-2 single band (B12) in discrete 11 colours (right).

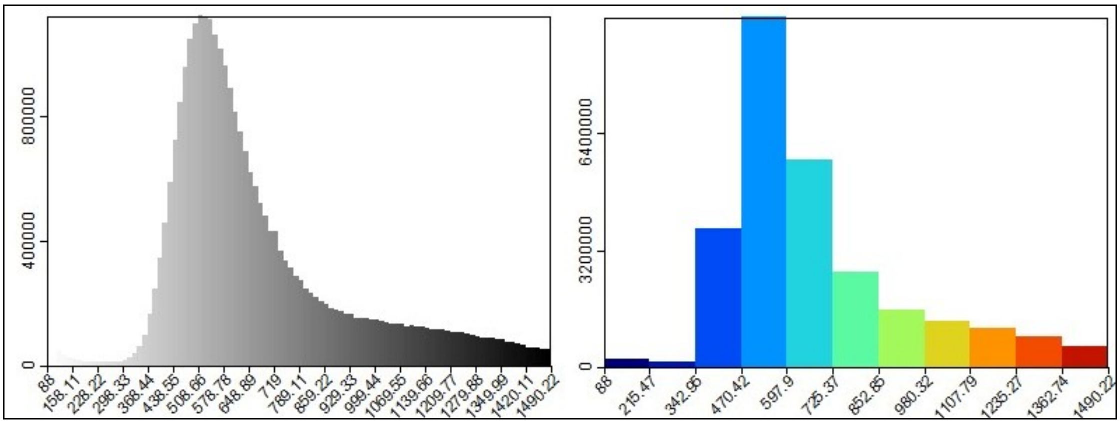

Figure 6: Histograms for the Sentinel Band 12 in monochrome shaded colours (left);
Sentinel-2 single band (B12) in discrete 11 colours (right).

The CTVI (Fig. 11, left) and RVI (Fig. 11, right) indices are also used in remote sensing to measure biomass or vegetative health, and to obtain data on land cover characteristics from multispectral bands of the Sentinel-2. Similar to the NDVI, the RVI is derived by processing two bands of the Sentinel-2: R/NIR, that is, band 4 divided by band 8 for Sentinel-2.

The CTVI has more complex formula according to the equation CTVI = [(NDVI + 0.5)/abs(NDVI + 0.5)] * [abs (NDVI + 0.5)] ^ 0.5, which results in the difference of the visualized images. The results of the CTVI calculations (Fig. 11, left) show the dataset range between the 0.83 for the lowest values to 1.09 for the green healthy vegetation. Adding a constant of 0.5 to the initial NDVI values enable to transform low values NDVI into the CTVI. The results of the RVI visualization (Fig. 11, right) show values from 1.4 to 3.9.

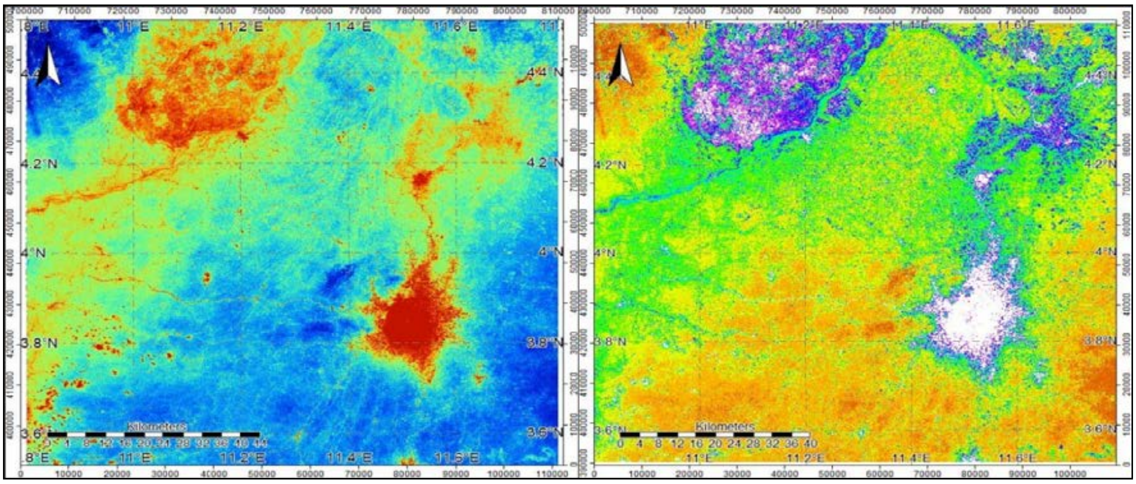

Figure 7: Sentinel-2 B2 in discrete 11 colors (left);
Sentinel-2 B4 in discrete 11 colors (right).

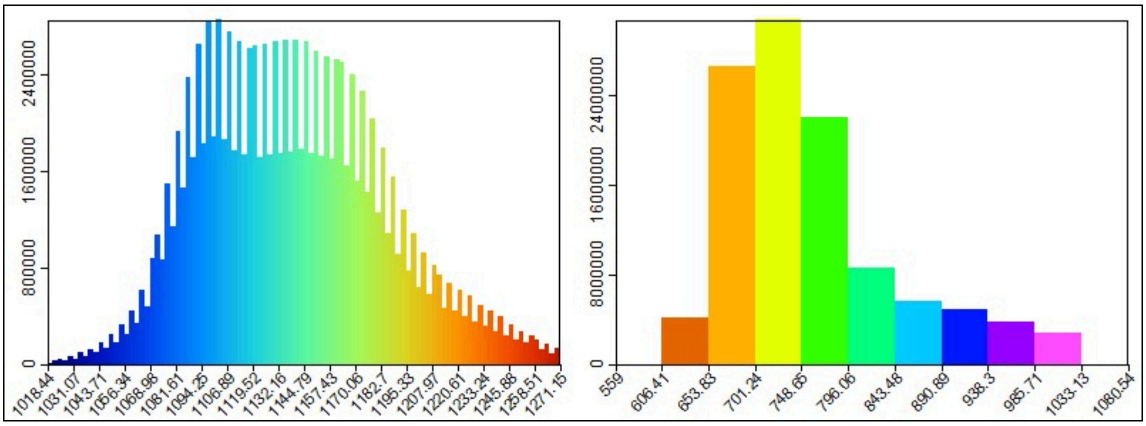

Figure 8: Histograms of pixel distribution of Sentinel-2 band 2 in discrete 11 colours (left);
Sentinel-2 band 4 in discrete 11 colours (right).

As can be seen in a histogram in figure 12, the values of CTVI range from 0.83 to 1.09, while the RVI differs in the range of 1.4 to 3.9, which is explained by the computational algorithm. Examining a colour image of the RVI for the study area of Cameroon, Yaoundé, enables the analyze of the distribution of vegetation, areas of sparse, moderate and dense vegetation coverage presented by green hues, while agricultural areas and urban spaces are shown in shades of brown and beige, and Sanaga River as dark brown. The plant fields have values of 0.87-0.96, areas with healthy vegetation are 0.98-1 (a modus of distribution) and the highest vegetation has a range of 1.0 to 1.05, while areas little vegetation have values of 0.98 to 0.99. The densest vegetation areas (dark green) with the highest values of index represent the strongest near-infrared reflectance, corresponding to the values in band 8 of Sentinel-2.

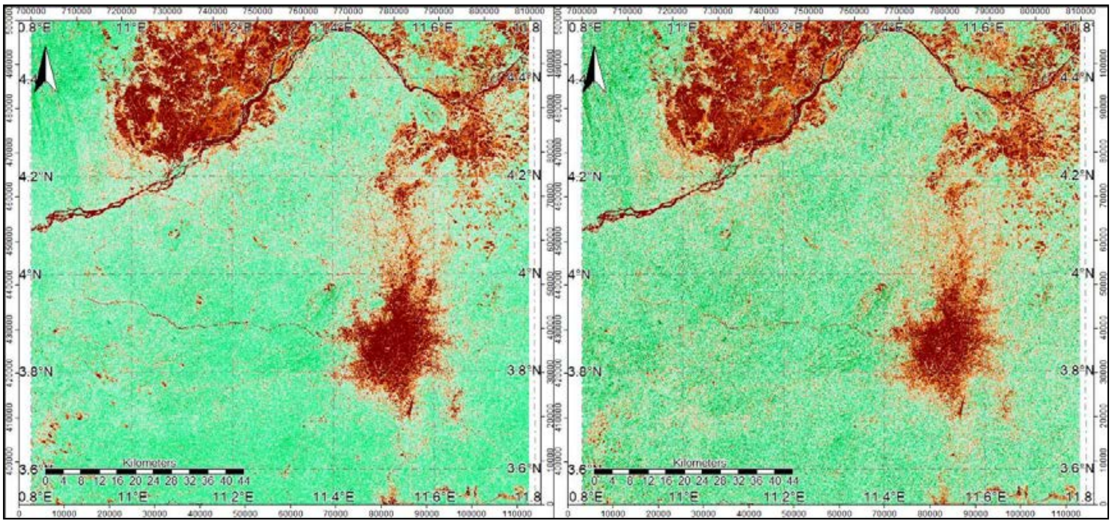

Figure 9: NDVI (left) and DVI (right)
based on Sentinel-2 B8 and B4 bands computation.

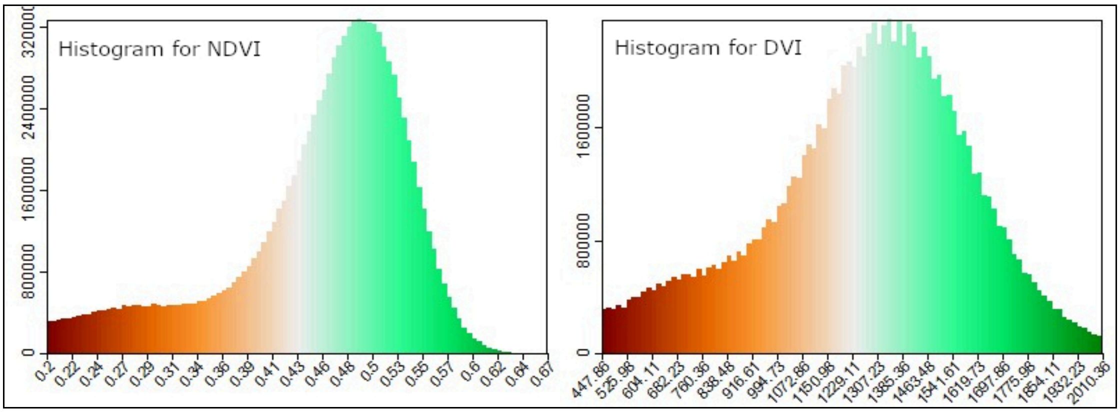

Figure 10: Histograms of pixel distribution
of NDVI (left) and DVI (right).

The bright green colors which represent vegetated areas in figure 13 computed by SAVI and TTVI represent the high values of pixels in the NIR where they have a stronger reflectance. This means a higher biomass, which is reflected in values of SAVI and TTVI ranging between 0.3 and one for SAVI and 0.83 to 1.09 for TTVI, respectively. This represents regions of dense forests plants in the tropical moist forest with good health, high leaf biomass, dense canopy, and high chlorophyll content in leaves. Conversely, lower SAVI and TTVI values indicate dark beige and brown colors in the urban areas and bare soils. This is as a result of the spectral reflectance, which is higher in the visible band than in the NIR, correlating with regions of water (here: the middle part of the Sanaga River area), mineral rocks, soil, and urban spaces.

The two histograms in figure 14 demonstrate the data distribution for the values of SAVI (left) and TTVI (right) ranging from 0.30 to 0.97 for SAVI and from 0.83 to 1.09 for TTVI, respectively. This represents regions of dense forests plants in the tropical moist forest with good health, high leaf biomass, dense canopy, and high chlorophyll content in leaves. Conversely, lower SAVI and TTVI values indicate a dark beige and brown colours in the urban areas and bare soils. This is as a result of the spectral reflectance, which is higher in the visible band than in the NIR, correlating with regions of water (here: the middle part of the Sanaga River area), mineral rocks, soil, and urban spaces.

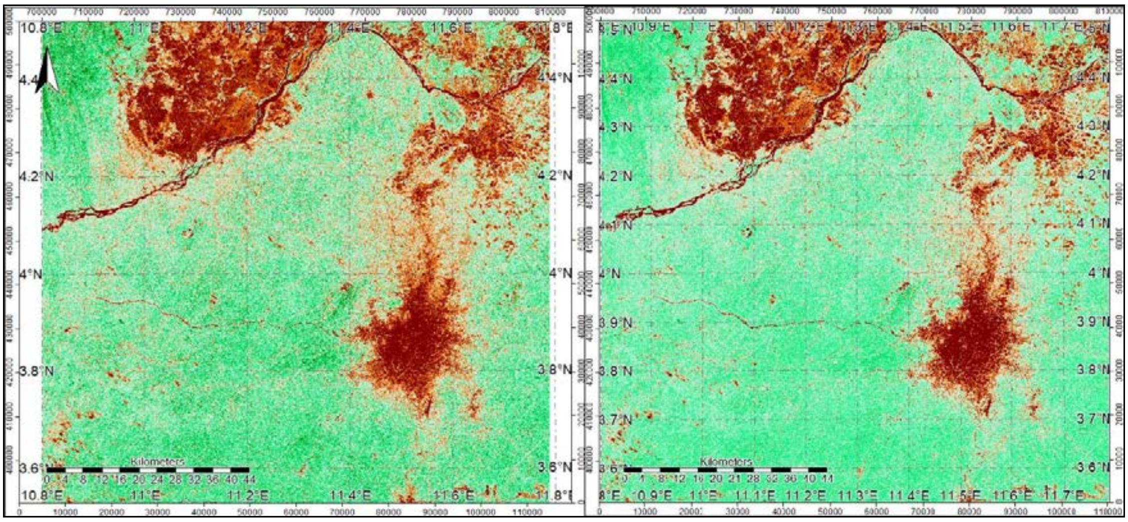

Figure 11: CTVI (left) and RVI (right)
based on Sentinel-2 B8 and B4 bands computation.

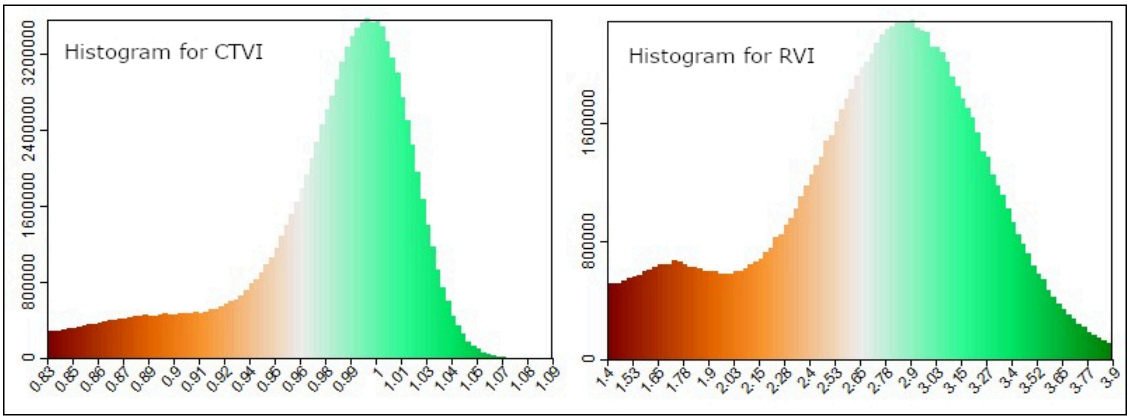

Figure 12: Histograms of pixel distribution
of CTVI (left) and RVI (right).

The agricultural activities can be mapped using the VIs maps for contouring the subsistence farming plantations and separating them from the natural landscapes. The communities of plants in Cameroon include several types of biomes, two types of savanna (moist and dry), and two types of tropical rain forests (evergreen and semi-deciduous). The biodiversity of Cameroon reflects a vast variety of landscapes and geomorphological types: coastlines, mountains, semi-deciduous forests, mixed vegetation, grassland/woody savanna forest deserts, and tropical rainforests to mention a few (Banoho, 2020).

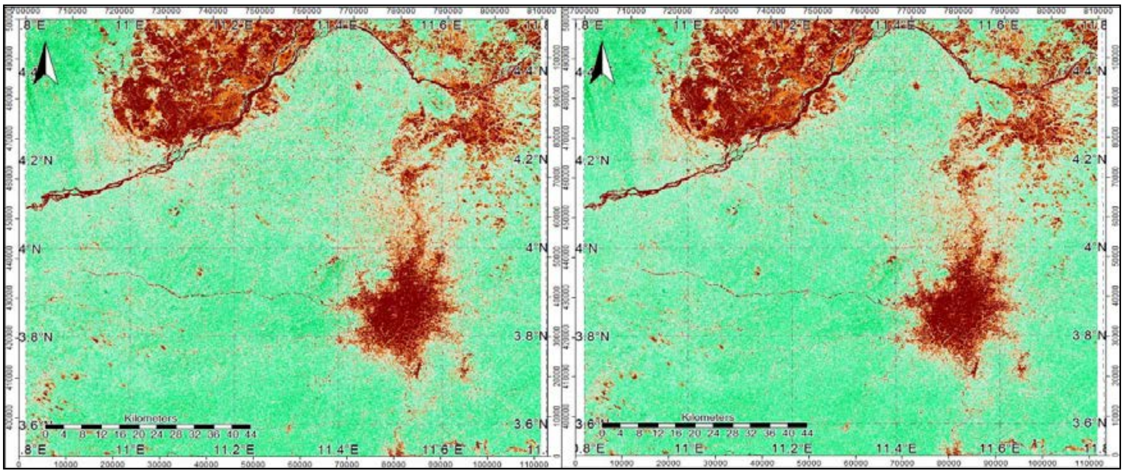

Figure 13: SAVI (left) and TTVI (right)
based on Sentinel-2 B8 and B4 bands computation.

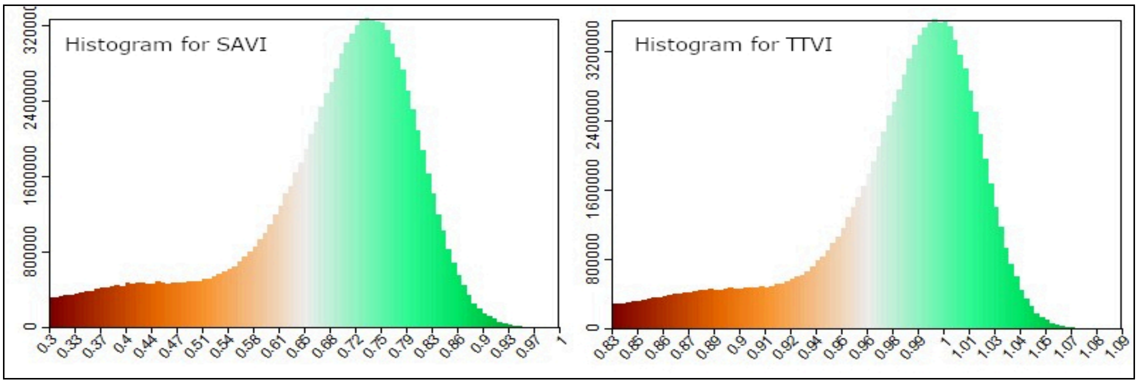

Figure 14: Histograms of pixel distribution
of SAVI (left) and TTVI (right).

Vegetation inventory and environmental mapping using remote sensing data and GIS tools are both key approaches in monitoring the vegetation structure, composition, biodiversity, biomass, as well as health, canopy and leaf closure. Rich biodiversity of Cameroon can be illustrated by the following facts: 9,000 plant species, 1,800 genera, and 230 families of vascular plants (Onana, 2011, 2015) including the endangered and endemic species (Sainge, 2016). Besides, tropical forests of Cameroon are precious extents of the Congo Basin and Lower Guinean forest ecosystem which provide a habitat for rare species. In view of this, environmental monitoring of rare ecosystems of Cameroon by GIS algorithms using high-resolution remote sensing data is an actual task that may contribute towards the global environmental monitoring.

CONCLUSIONS

Addressing the issue of advanced digital mapping for environmental monitoring is implemented not simply by GIS approaches, but by understanding the reasons behind the ecological change and land planning using GIS tools as proposed by Klaučo et al. (2017), as GIS methods are expected to provide additional information on land monitoring. Satellite data provide global coverage that can be used for such cases of the environmental monitoring and mapping ecological variables at high spatial resolutions. Various sensors provide useful geospatial information, for example, the combination of the SRTM and GEBCO, ETOPO1 and ETOPO5 global DEMs is largely used in marine mapping (Lemenkova, 2020a, 2020b). Traganos et al. (2018) used a combination of the Google Earth Engine and Sentinel-2 for a fine-scales bathymetric mapping. Land cover change detection can be derived from well-known Landsat 30-m resolution satellite images (e.g. Lemenkova, 2015a, 2015c) and provide the basis for thematic environmental mapping at multiple spatial and temporal scales.

On the other hand, the application of the machine learning approaches in GIS provide better possibilities for ecological monitoring with the necessary algorithms of data analysis and need to carry various types of cartographic processes (calculation VIs, colour composites, mapping layouts). The advantages of the use of scripting approach in Earth science can improve the GIS procedures so as to increase the quality of the data analysis (McKinney, 2010; Lemenkova, 2019d). The rise of programming technologies applied in Earth sciences makes it possible to quantify data variations through processing techniques by Python and R (e.g., Clewley et al. 2014; Lawhead, 2019; Lemenkova, 2020c, 2019a, 2019b). Machine learning significantly facilitate mapping techniques, while increasing the speed of plotting, and the precision of the output maps and plots (Schenke and Lemenkova, 2008; Lemenkova, 2019c) over the traditionally GIS based maps, for instance plotted in ArcGIS (e.g. Lemenkova et al., 2012; Suetova et al., 2005a, 2005b) which can be used for machine.

Other approaches, such as statistical analysis in GIS and environmental studies can provide new information about the retrieved datasets on vegetation and ecological ranking through assessment of the landscape metrics, respectively (e.g., Palmer, 2004; Cushman et al. 2008; Klaučo et al. 2014, 2013a, 2013b). These advances are coupled with an application of GIS and methods of geostatistical analysis. As demonstrated in this paper, using SAGA GIS techniques, it is possible to calculate a VIs at 10 m resolution based on a Sentinel-2 at a regional extent, and to detect urban areas of the city spaces from vegetation.

A series of the slope-based calculated VIs with shown maps and histograms for vegetation of the selected Sentinel-2 satellite scene of Yaoundé surroundings, Cameroon, has been presented for performing SAGA GIS image analysis based on six VI algorithms: 1) NDVI; 2) DVI; 3) SAVI; 4) RVI; 5) TTVI; 6) CTVI. All of the VIs are acceptable for environmental monitoring through SAGA GIS, allowing effective image processing to be easily calculated and visualized in a SAGA GIS GUI menu and applied to Sentinel scenes. Through SAGA GIS, six colour composite bands have been visualized, to illustrate their applicability in various cases: monitoring wetlands and mangroves, agricultural and geologic mapping, and environmental management. Additionally, to illustrate the properties of the Sentinel image, single bands have been visualized using monochrome shaded colours or discrete single band with an enable of bands B2, B4, B12. The study contributed to the environmental studies of Cameroon and demonstration of the satellite image processing for monitoring wetlands and vegetation distribution which can be used for assessment of the ecological resilience to climate change and environmental impacts.

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POLLINATION ECOLOGY OF INDIAN TULIP TREE, *THESPESIA POPULNEA* (L.) SOL. EX CORREA (MALVACEAE), A VALUABLE EVERGREEN TREE SPECIES FOR COASTAL ECORESTORATION

*Jacob Solomon Raju ALURI *, Venkata Ramana KUNUKU **, Prasada Rao CHAPPIDI ***, Bhushanam Jeevan Prasad KAMMARCHEDU ****, Sravan Kumar SAMAREDDY *****, Suneetha Rani TRIPURANA ******, Santhi Kumari MANJETI ******** and *Divyasree MOCHARLA *********

*, ****, *****, ******, *******, ********, Andhra University, Department of Environmental Sciences, Visakhapatnam, India, IN-530003, solomonraju@gmail.com, kbjpamith@gmail.com, sravankumarsamareddy@gmail.com, sunita.gandham@gmail.com
, * Andhra University, Department of Botany, Visakhapatnam, India, IN-530003, ramanabtny@gmail.com, prasadachram@gmail.com

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KEYWORDS: Hermaphroditism, self-compatibility, melittophily, floral biology, pollinators, fruiting, seed dispersal.

ABSTRACT

Thespesia populnea is a coastal evergreen tree species which flowers seasonally. The flowers are hermaphroditic, self-compatible, self-pollinating, and principally melittophilous. The fruits are indehiscent, turban-shaped, capsules, which release seeds in tidal water upon the decay of their pericarp. Both fruits and seeds are buoyant and typically hydrochorous. This species is a source of wood, dye, food, traditional medicine, being also used as an ornamental and avenue tree. Therefore, it is important in coastal eco-restoration and carbon sequestration.

ZUSAMMENFASSUNG: Bestäubungsökologie des Indischen Tulpenbaums *Thespesia populnea* (L.) Sol. ex Correa (Malvaceae), eine wertvolle immergrüne Art für die ökologische Küstenrenaturierung.

Thespesia populnea ist eine immergrüne Baumart der Küstenzone, die Saison bedingt blüht. Die Blüten sind zwegeschlechtig, selbstverträglich, selbstbestäubend und hauptsächlich melittophil. Die Früchte sind nicht aufspringende, turbanförmige Kapseln, die beim Zerfall ihres Perikarps Samen ins Gezeitenwasser freisetzen. Sowohl die Früchte als auch die Samen sind schwimmfähig und typischerweise hydrochor. Diese Art stellt eine Quelle für Holz, Farbstoffe, Nahrung, und traditionelle Medizin dar. Sie wird auch als Zier- und Alleebnaum verwendet. Daher ist sie für die ökologische Renaturierung der Küste und Kohlenstoffspeicherung von Bedeutung.

REZUMAT: Ecologia polenizării la arborele indian de lalea *Thespesia populnea* (L.) Sol. ex Correa (Malvaceae), o valoroasă specie sempervirescentă pentru refacerea ecologică a zonelor costiere.

Thespesia populnea este o specie perenă de arbore, care înflorește sezonier. Florile sunt hermafrodite, auto-compatibile, auto-polenizante și preponderent melitofile. Fructele formează capsule indehiscente sub formă de turban, care eliberează semințele în apa mareelor în urma degradării pericarpului lor. Atât fructele, cât și semințele sunt flotante și de obicei hidrochore. Această specie constituie o sursă de lemn, vopsea, alimente, medicamente tradiționale având importanță și ca arbore ornamental folosit și de-a lungul bulevardelor. Datorită acestui fapt arborele indian de lalea este important în restaurarea ecologică a zonelor coastiere maritime și în sechestrarea carbonului.

INTRODUCTION

Trees are an important part of the terrestrial ecosystems. Leaves, flowers, and fruits are seasonally available. On the ground underneath the trees, there is shade, undergrowth, leaf litter, fallen branches and decaying wood that provide other habitats. The trees stabilize the soil, averts rapid run-off of rain water, while also helping prevent desertification, and has a role in climate control and helps toward the maintenance of biodiversity and the ecosystem's balance (Lowman, 2009). The riverine ligneous vegetation is important for aquatic ecosystems status (Curtean-Bănăduc et al., 2014). Evergreen species exhibit different ecological strategies to cope with different climates (van Ommen Kloeke et al., 2012). Long-lived leaves of evergreen species potentially allow for a longer photosynthetic season than the leaves of deciduous species (González-Zurdo et al., 2016). Therefore, trees in general, along with evergreen tree species in particular, that have long lives and are bearing leaves throughout the year, are important in maintaining the biological and ecological aspects of the concerned ecosystems where trees are the main constituents.

The genus *Thespesia* Sol. ex Correa belongs to Malvaceae family. It consists of 16 different species of trees and shrubs distributed in Southeast Asia-Oceania, Chandigarh in India and America (Troup, 1921). The name "thespesia" is derived from the Greek word "thespesios", which means divine or sacred (Friday and Okano, 2006). The members of genus *Thespesia* are valued for their multiple uses; such as medicine, food, dye, timber, fibre, and ornamental aspect (Friday and Okano, 2006). Among these species, *T. populnea* is the most well-known typical coastal tree species of the tropical coasts (Areces-Berazain and Ackerman, 2016). It has a very broad native range and is widely distributed throughout the tropics, it's presence being most common in the coastal areas of Central America, northern South America, the Caribbean, Africa, Asia, northern Australia, and on Indian and Pacific Ocean islands (Little and Skolmen, 1989; Oudhia, 2007; USDA-ARS, 2015). It is cultivated occasionally in Central and South America (Francis, 2004). In India, it is a common species in the coastal tracts of the Indian Peninsula and in mangrove swamps. It is often developed as an avenue tree in cities and towns near sea coast (Troup, 1921). It is an important tree in the culture and religious practises of many countries of the Indo-Pacific region. In ancient times, the species of this genus were planted around the places of worship in Tahiti of French Polynesia (Fosberg and Sachet, 1972; Friday and Okano, 2006). Further, this tree species is used as an important source of wood for making boats and furniture because of its durability when continually exposed to water or ground, as well as termite-resistance (Little and Skolmen, 1989; Oudhia, 2007). Its flowers and young leaves are edible and are included in the list of species used as famine food. It's fibrous bark is used for curing leather while the fruit extract is used as a natural dye. Apart from these values, all plant parts are used in traditional medicine (Oudhia, 2007).

Despite the wide distribution and multiple uses of *T. populnea*, limited data is available on its pollination ecology, which is essential for its cultivation and use. Gandhi (2000) reported that this species is pollinated by sunbirds in India while Oudhia (2007) said that is likely to be pollinated by birds in Africa. Woodell (1979) noted that *T. populnea* is visited by the carpenter bee, *Xylocopa calens* Lepeletier 1841 on Aldabra Islands in the Indian Ocean. Singh and Kar (2011) based on melissopalynological study reported that the honey bees affect pollination in the Sunderbans of Bangladesh and Little Andamans of India. Shanmugapriya and Vanitharani (2015) noted that this species is pollinated by 14 species of lepidopterans in the Mandapam islands of India. These reports indicate that there is a lacuna of data on the pollination ecology of *T. populnea*. This study provides the details of floral biology, pollinators, fruiting and seed dispersal aspects of this species (Fig. 1a), to help understand it's sexual reproduction and regeneration for use in coastal eco-restoration.

MATERIAL AND METHODS

Thespesia populnea trees growing along the 135 km long coastline in Visakhapatnam city (17°42'N Latitude and 82°18'E Longitude), Andhra Pradesh, India, were used for this study during January 2018 – November 2019. Regular visits to the location of the trees were made to make field observations on flowering, floral biology, pollinators, fruiting, and seed dispersal. Fifteen mature buds about to anthesis on five plants spatially separated were tagged and followed to note anthesis and anther dehiscence schedules. The timing of anther dehiscence was confirmed by observing the anthers under a 10x hand lens. Fifteen fresh flowers from the same trees were collected and observed to record the flower type, sex, shape, colour, calyx, corolla, stamens, ovary, style and stigma. The floral morphology, nectar and pollen rewards presentation were observed in relation to the probing and forage collection activities of insects. Twenty mature buds comprising two buds each from ten plants were bagged and then tagged to measure nectar volume and sugar concentration. The nectar volume was collected by inserting a micropipette into the corolla base. The average nectar of ten flowers from five trees was taken as the total volume of nectar/flower and expressed in µL. Hand Sugar Refractometer (Erma, Japan) was used for recording nectar sugar concentration. The stigma receptivity was observed visually. Insects visiting the flowers for forage collection were observed all day-long on four different days using binoculars for their mode of approach, landing, probing behaviour and contact with the floral sexual organs; they were identified by tallying them with the specimens already identified by the Zoological Society of India, Calcutta, India and available in the Department of Andhra University, Visakhapatnam. The foraging visits made by each insect species were recorded for ten minutes every hour from 06:00 to 18:00 h. The data was used to record the foraging activity schedule in relation to the availability of flowers and to examine the pattern of foraging activity with the passage of time from morning to evening. The fruit maturation period, fruit and seed characteristics, fruit and seed dispersal aspects were observed by making field visits at four-day intervals during March-May for fruit development and maturation.

RESULTS

Floral Biology

Flowering occurs during November-March but shows sporadic flowering outside this period. Flowers are solitary with four-five cm long pedicel and borne in leaf axils mostly of terminal branches. They are bright yellow, bell-shaped, 5.8 ± 0.56 cm long with overlapping broad and rounded petals. The calyx is cupular with five minute teeth, green and accrescent. The corolla consists of five bright yellow glabrous broad 6.1 ± 0.23 cm long and 4.7 ± 0.7 cm wide petals and each petal has a maroon or purple coloured spot at its base representing nectar guide. The petals are shortly fused at base but twisted and free above. The androecium is composed of 2.5 ± 0.2 cm long staminal tube with numerous stamens (Fig. 1i); each stamens has 0.3 ± 0.01 cm long ascending filament and terminated with a reniform anther. The gynoecium has a five-carpelled syncarpous cup-shaped fleshy ovary and each carpel has two ovules arranged on an axile placentation (Fig. 1n). The ovary has a 3.3 ± 0.2 cm long slender tyle terminated with five broader elongated stigmas which are fused and longitudinally grooved; the ovary is green while the style and stigmas are yellow (Figs. 1i and lm).

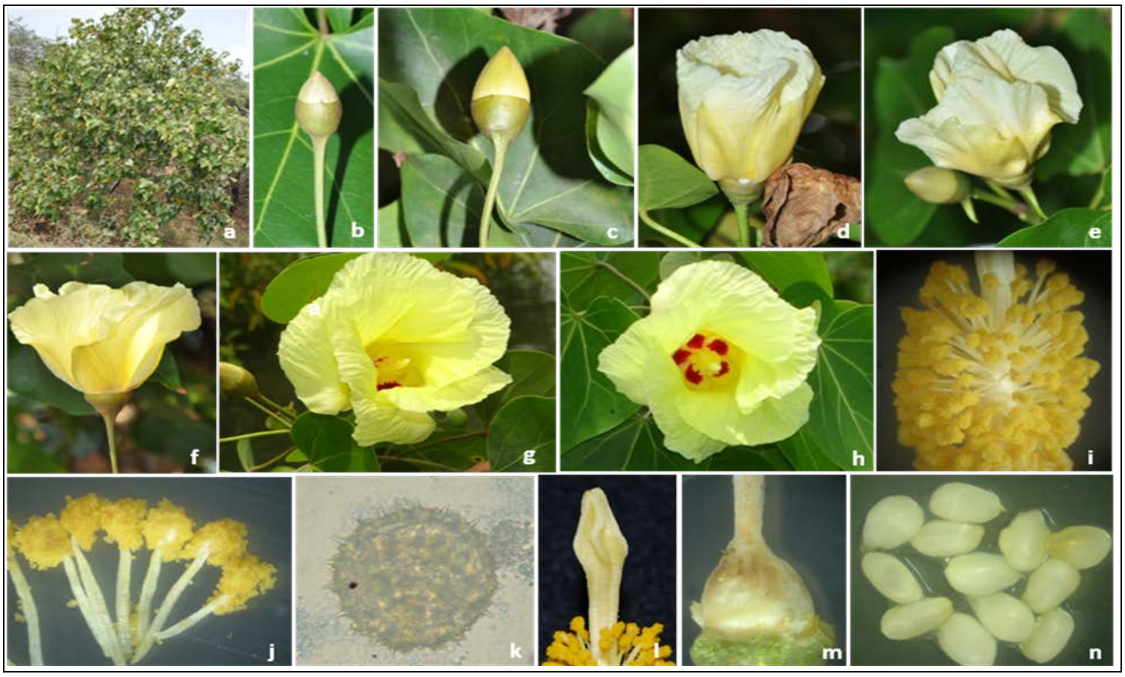

Figure 1: *Thespesia populnea* a. Habit, b-h. Bud to anthesis stages, i. Staminal column with style and stigma, j. Stamens with dehisced anthers, k. Pollen grain, l. Style and stigma, m. Ovary, n. Ovules.

Mature buds open early in the morning during 07:00-08:00 h. The process of anthesis takes 30-40 minutes to expose the sex organs (Figs. 1b-h). The flowers are protandrous with anther dehiscence occurring during mature bud stage (Fig. 1j). Individual flowers produce copious pollen. The pollen grains are yellow, sticky, spheroidal, pantoporate, and exine echinate (Fig. 1k). They are herkogamous with spatial separation of sex organs with anthers positioned well below the height of the stigmas. The stigma is wet and attains receptivity an hour after anthesis while it also ceases receptivity coinciding with the initiation of flower closure process. The nectar is secreted in minute volume which varies from 1.2 ± 0.7 µL per flower; its sugar concentration varies from 29 to 35%. The corolla colour which is yellow initially, turns light red between 11:00-12:30 and purplish-pink by early evening (16:00-17:00 h); it closes back enclosing the entire sexual apparatus by late evening hours (17:30-18:30 h) (Figs. 3a-d) and fall off either on 2nd or 3rd day.

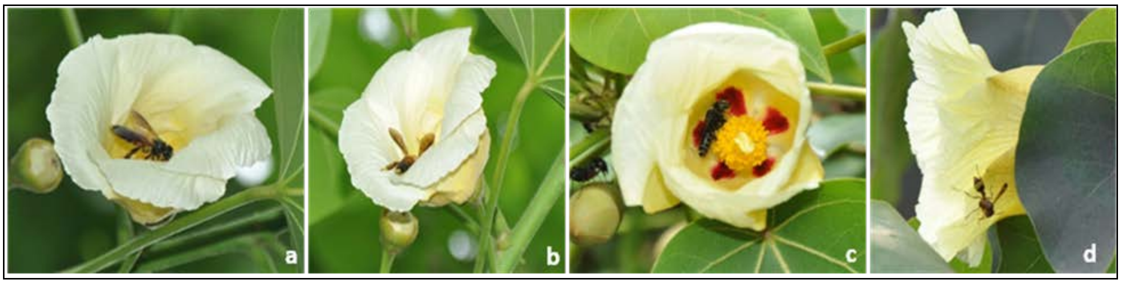

Figure 2: *Thespesia populnea*, a. and b. *Apis dorsata* collecting pollen, c. *Nomia* sp. collecting nectar, d. *Polistes* sp. leaving the flower after nectar collection.

Figure 3: *Thespesia populnea*, a-d. Gradual flower closure towards evening of the day of anthesis accompanied by corolla colour change from yellow to orange, e. Growing fruit, f. Maturing fruit, g. Mature dry fruit.

Pollinators

The fresh bright-yellow flowers in erect position or partially horizontal position are attractive to foraging insects. The flowers were visited by insect species only, they visited during daytime from 08:00 to 16:00 h. The insects included only four bee species, namely *Apis dorsata* Fabricius 1793 (Figs. 2a-b), *A. cerana* Fabricius 1793, *A. florea* Fabricius 1787 and *Nomia* sp. Latrielle 1804 (Fig. 2c) and one wasp species, *Polistes* sp. Latrielle 1802 (Fig. 2d). The bees foraged for both nectar and pollen, while the wasp foraged for nectar only. There was no competition among species for the floral rewards. Individual species foraging visits for the day were 118 for *A. dorsata*, 111 for *A. cerana*, 124 for *A. florea*, 100 for *Nomia* sp. and 97 for *Polistes* sp. The foraging activity of both bees and wasps was highest during 11:00-13:00 h. The bees approached the flowers in upright position, landed on the corolla and proceeded to collect either pollen or nectar, but not both in the same foraging visit. In case of nectar collection, after landing on the corolla, they directly proceeded to the corolla base for nectar collection by contacting or not contacting the sexual apparatus. After nectar collection, they departed from the flower by walking on the corolla with or without contacting the anthers. The nectar-collection visit was found to be enabling the bees to carry pollen on their ventral side with or without effecting pollination. In case of pollen collection, after landing on the corolla, bees proceeded towards the sexual apparatus, contacted the stigma first and then walked on the staminal column to collect pollen, enabling them to carry pollen on their ventral side. Occasionally, the bees directly landed on the stigmas effecting pollination (if they had pollen of previously visited flowers on their ventral side) and then walked on the staminal column to collect pollen. After pollen collection, they departed from the flower by walking on the corolla.

The pollen-collection visit was found to be effecting cross-pollination only. The wasp also approached the flowers in upright position, landed on the corolla and proceeded towards the corolla base with or without contacting the anthers to collect nectar. After nectar collection, it moved along the staminal column and the stigmas effecting pollination, and then left the flower. Occasionally, it directly landed on the stigmas and walked on the staminal column to reach the corolla base for nectar collection; in this case, if the wasp had pollen of the previously visited flowers on its ventral side, it would effect cross-pollination. After nectar collection, it moved to the corolla and left the flower. At about the time of initiation of flower closing process, the stigmas gradually reflex backwards and contact the upper level of anthers; the stigmatic movements was found to be a mechanism to facilitate autonomous autogamy in the event of the failure of vector-mediated pollination.

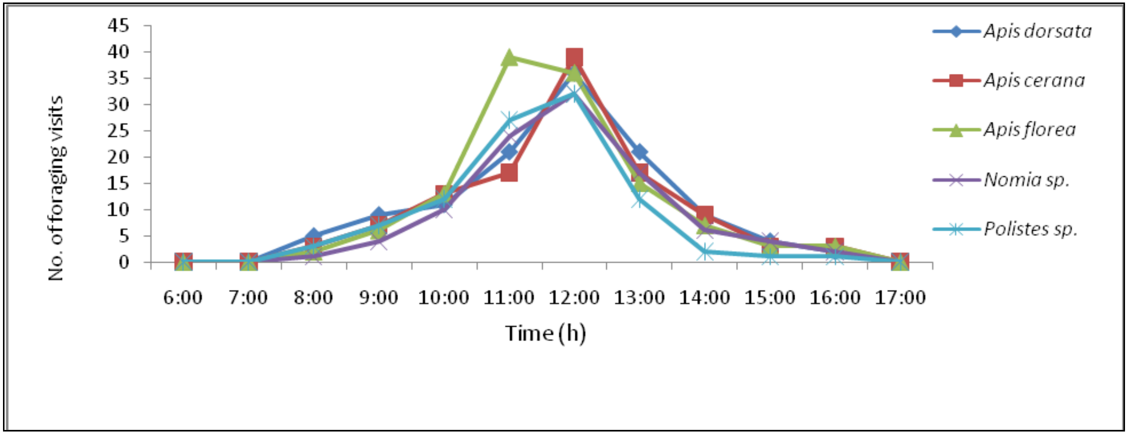

Figure 4: Hourly foraging activity of insects on *Thespesia populnea*.

Fruiting aspects

Fruits mature within four-five weeks. They are initially green and brown when mature and dry (Figs. 3e-g). They are five-celled globose, turban-shaped. Indehiscent, capsules, flattened, light weight and woody with disc-like persistent calyx at the base. Individual fruits produce four-10 triangular-ovoid, 10 ± 1.5 mm long, brown hairy, veined seeds. Each fruit with seeds inside detach when dry but the persistent calyx remained attached to the plant.

Dispersal aspects

Fruit is the primary organ of dispersal and it is not dispersed by wind and animals. Fruits and seeds are buoyant but seeds are released by the decay of the capsule in sea water.

DISCUSSION

Floral biology

The present study reports that in *T. populnea*, flowering and fruiting is seasonal, but sporadic flowering and fruiting occurs at other times of the year. This tree species is often confused with *Hibiscus tiliaceus* because both species have heart-shaped leaves and produce yellow bell-shaped flowers with dark maroon spots at the base of corolla. *T. populnea* can be easily distinguished by its large yellow bell-shaped flowers, yellow stigmas, rounded and flatten brown turban-shaped capsules. In *H. tiliaceus*, the flowers are large, yellow, bell- or cup-shaped with maroon coloured base inside the corolla, red stigmas, and ellipsoid loculicidal capsule (Little and Skolmen, 1989). The present study shows that *T. populnea* with bright yellow flowers against the background of green foliage are attractive even from a long distance. The flowers open early in the morning, produce minute volume of nectar and copious pollen, but they close back at the end of the day by which time their corolla colour turns from yellow to purplish-pink. This flower function indicates that the plant keeps its flowers for open-pollination for only one day to facilitate the occurrence of vector-mediated pollination. The stigmatic movements during the process of flower closure appear to be an evolved mechanism to facilitate the occurrence of autonomous autogamy to enable the plant to produce fruits. This mechanism also indicates that the plant is self-compatible and self-pollinating which is further substantiated by the exposure of sex organs by the plant to open-pollination for only one day.

Pollinators

The foragers of *T. populnea* include bees and wasps, the former collects both nectar and pollen while the latter only nectar. In case of bee foragers, they effect either self- or cross-pollination while collecting nectar but the occurrence of either of these pollination modes is related to the contact of the bee with the staminal column and stigmas indicating that each visit made by them for nectar collection does not effect pollination. The bees effect cross-pollination while collecting pollen. It is interesting to mention that bees do not collect both nectar and pollen in the same foraging visit to any given flower. The wasp is also important as pollinator because it is instrumental in effecting self- or cross-pollination while collecting nectar. Since nectar is produced in minute volume by individual flowers, this plant mainly serves as copious pollen source for bee foragers. The corolla colour change and retention of flowers for 2nd and 3rd day after their closure appear to be evolved traits to enhance attraction of flowers to insect foragers; these features might have evolved as a compensation for the production of a few flowers daily at plant level. Nevertheless, *T. populnea* is entomophilous in general and melittophilous in particular because bees are the principal pollinators.

Fruiting and seed dispersal

Kader and Chacko (2000) reported that *T. populnea* produces one-11 seeds per fruit while fertile seeds vary from three to five per fruit. In this study, it is found that *T. populnea* produces ten ovules per flower and individual fruits produce four-10 seeds. Tomlinson (1989) and Oudhia (2007) noted that *T. populnea* produces indehiscent fruits and disperse without shedding seeds which are leased only when fruit pericarp decays. The present study substantiates the report by Tomlinson (1989). Different authors mentioned that fruits and seeds of *T. populnea* float in tidal water and adapted for long distance dispersal by tides and ocean currents (Tomlinson, 1989; Kader and Chack, 2000; Friday and Okano, 2006). Further, Friday and Okano (2006) noted that *T. populnea* seeds remain viable for 24 months in tidal water while Oudhia (2007) mentioned that *T. populnea* seeds tolerate salt water and remain viable even after a year spent in water. Areces-Berazain and Ackerman (2016) noted that *T. populnea* is hydrochorous. The present study finds that in *T. populnea*, the fruits and seeds are buoyant because they are light in weight and also have air sacs. Further, saline tidal water has no effect on seed viability since they are viable even after spending more than a year as reported by Friday and Okano (2006) and Oudhia (2007). Therefore, *T. populnea* is hydrochorous.

The importance of *T. populnea* for various uses has been reported by different authors (Little and Skolmen, 1989; Friday and Okano, 2006; Oudhia, 2007). This study found that it can be used for coastal eco-restoration, cultivated as an ornamental tree species in urban ecosystems and gardens. Further, this tree species can also be raised as a plantation crop in ecologically degraded, damaged, and destroyed coastal areas for carbon sequestration and use its various parts for economic and medicinal purposes.

CONCLUSIONS

Thespesia populnea is an evergreen tree species which flourishes well in the coastal areas. It is a seasonal bloomer but blooms sporadically throughout the year. The flowers are hermaphroditic, nectariferous, self-compatible, self-pollinating and entomophilous but largely melittophilous. It is a prolific pollen producer and honey bees use this tree as a major pollen source during its blooming season. The flowers expose the sex organs for open-pollination for only one-day, change colour from yellow to light-red to purplish pink, close back after that, and remain in place for two more days to enhance attraction to the pollinator insects. The fruits are indehiscent capsules which release seeds upon decay of their pericarp in tidal water. Fruit and seed dispersal is hydrochorous.

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INVESTIGATION ON THE GLOBAL DISTRIBUTION OF INVASIVE FISH SPECIES, CONVICT CICHLID *AMATITLANIA NIGROFASCIATA* (PERCIFORMES, CICHLIDAE) OVER THE PAST YEARS WITH EMPHASIS ON IRANIAN INLAND WATERS

Ali Reza RADKHAH * and *Soheil EAGDERI* **

*, ** University of Tehran, Faculty of Natural Resources, Department of Fisheries, Karaj, Iran, alirezaradkhah@ut.ac.ir, soheil.eagderi@ut.ac.ir

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KEYWORDS: *Amatitlania nigrofasciata*, distribution, native species, Namak Lake.

ABSTRACT

The aim of this study was to investigate the global distribution of a non-indigenous and invasive fish species, the convict cichlid *Amatitlania nigrofasciata*, over time, with an emphasis on the inland waters of Iran. The results showed that the distribution range of the convict cichlid was initially based in Central America. Then, the distribution range of this species expanded to parts of North America. Finally, this fish species was introduced to other parts of the world such as Australia, Israel, Italy, Colombia, Germany, Peru, Slovakia, Japan, Indonesia, the Philippines, and Iran due to its extensive ability to spread. So far the presence of *A. nigrofasciata* has been reported in two domestic basins in Iran, namely Hormuz and Namak Lake. This study indicated that the distribution range of this species is not currently wide, but it is likely to expand towards the central plateau and southern parts of Iran.

RÉSUMÉ: Enquête sur la répartition mondiale des espèces de poissons envahissantes, condamner le cichlidé *Amatitlania nigrofasciata* (Perciformes, Cichlidae) au cours des dernières années en mettant l’accent sur les eaux intérieures iraniennes.

L’objectif de cette étude était d’étudier la répartition mondiale des espèces de poissons non indigènes et envahissantes, le cichlidé *Amatitlania nigrofasciata* au fil du temps en mettant l’accent sur les eaux intérieures de l’Iran. Les résultats ont montré que la répartition du cichlidé bagnard était initialement concentrée en Amérique Centrale. Ensuite, la répartition de cette espèce s’est étendue à certaines parties de l’Amérique du Nord. Enfin, cette espèce de poisson a été introduite dans d’autres parties du monde telles que l’Australie, Israël, l’Italie, la Colombie, l’Allemagne, le Pérou, la Slovaquie, le Japon, l’Indonésie, les Philippines et l’Iran en raison de sa grande capacité de propagation. Selon les résultats obtenus en Iran, la présence d’ *A. nigrofasciata* a été signalée jusqu’à présent dans deux bassins domestiques de ce pays, dont les lacs Ormuz et Namak.

REZUMAT: Investigarea distribuției globale a speciei de pești invazivi, ciclidul *Amatitlania nigrofasciata* (Perciformes, Cichlidae) în ultimii ani, cu accent pe apele interioare iraniene.

Scopul acestui studiu a fost de a investiga distribuția globală în timp a speciei de pește non-nativă și invazivă, ciclidul *Amatitlania nigrofasciata*, cu accent pe apele interioare ale Iranului. Rezultatele au arătat că arealul de distribuție a acestui ciclid a fost inițial concentrat în America Centrală. Apoi, arealul de distribuție a acestei specii s-a extins în diferite părți din America de Nord. În cele din urmă, această specie de pești a fost introdusă în alte părți ale lumii, cum ar fi Australia, Israel, Italia, Columbia, Germania, Peru, Slovacia, Japonia, Indonezia, Filipine și Iran, datorită capacității sale ridicate de răspândire. Potrivit constatărilor din Iran, până acum a fost raportată prezența speciei *A. nigrofasciata* în două bazine interioare din această țară, Hormuz și lacul Namak.

INTRODUCTION

Cichlids are a group of fish belonging to the family Cichlidae (Order Perciformes) (Coad, 2019). According to some recent reports, more than 1,600 species of cichlids have been described so far, many of which are popular aquarium fish (*, 2019).

Amatitlania (Schmitter-Soto, 2007) is a Neotropical genus belonging to the Cichlidae family that is distributed in Central America, from El Salvador and Guatemala to Panama (Froese and Pauly, 2019a). Researcher Juan Schmitter-Soto first described this genus in 2007 based on a study of the *Archocentrus* complex (Duffy et al., 2013). Schmitter-Soto (2007) stated that the genus *Amatitlania* is closely related to the genera *Archocentrus* (Gill, 1877) and *Cryptoheros* (Allgayer, 2001). According to Froese and Pauly (2019a), there are currently nine known species in the genus *Amatitlania*, including *A. coatepeque* (Schmitter-Soto, 2007), *A. nanolutea* (Allgayer, 1994), *A. siica* (Bussing, 1974), *A. siquia* (Schmitter-Soto, 2007), *A. altoflava* (Allgayer 2001), *A. septemfasciata* (Regan, 1908), *A. myrnae* (Loiselle, 1997), *A. kanna* (Schmitter-Soto, 2007), and *A. nigrofasciata* (Günther, 1867).

The convict cichlid (*Amatitlania nigrofasciata*) is one of the most important aquarium species in the ornamental fish industry. This species was first described in 1867 by Albert Günther as *Heros nigrofasciatus* (Radkhah and Eagderi, 2019). Subsequently, it was renamed *Cichlasoma nigrofasciatum* and *Archocentrus nigrofasciatus*, respectively (CABI, 2020). The type locality of this species was Amatitlán Lake in Guatemala (Radkhah and Eagderi, 2019). In 2007, according to some studies, the genus *Archocentrus* was moved to a new genus called *Amatitlania* (Schmitter-Soto, 2007; CABI, 2020). The convict cichlid has several synonyms, including *Heros nigrofasciatus*, *Archocentrus nigrofasciatus*, *Cryptoheros nigrofasciatus*, *Cichlasoma nigrofasciatum*, and *Astronotus nigrofasciatus* (NCBI 2019; Froese and Pauly, 2019b).

According to the information obtained, the broad environmental tolerance, the ability to occupy damaged habitats, opportunism, parental care, and rapid growth have all contributed to the offensive nature of the convict cichlid (*A. nigrofasciata*) (Radkhah and Eagderi, 2019; CABI, 2020). It should be noted that so far significant ecological effects of this species on native fish have been reported in different countries (CABI, 2020). For example, Tippie et al. (1991) stated that the presence of *A. nigrofasciata* reduced the populations of other fish species such as the White River springfish (*Crenichthys baileyi*). Contreras-MacBeath et al. (1998) also found that this fish species has negative effects on the population of Mexican fishery species, including *Amphiphilophus istlanus* and *Ictalurus balsanus*. Mendoza et al. (2015), confirmed the negative effects of the convict cichlid, stating that this species can compete with native fish due to its omnivorous diet and aggressive and territorial behaviours. These studies suggest that the introduction of the convict cichlid to new freshwater ecosystems may have significant negative ecological consequences.

Given the invasive nature of the convict cichlid (*A. nigrofasciata*) and its negative impact on freshwater ecosystems, this study aims to investigate the global distribution pattern of this fish species over the past years with emphasis on the Iranian inland waters.

The information presented in this study can be used by fishery managers to make management-conservation decisions and policies in the future.

MATERIAL AND METHODS

In the present study, the occurrence data on the convict cichlid (*A. nigrofasciata*) were collected from Global Biodiversity Information Facility (GBIF) available at www.gbif.org.

Initially, based on the obtained data, the distribution maps of the species were prepared with the GBIF website over different time periods. Then, shortcomings of the maps were examined by reviewing the references and literature in scientific journals and search engines (Yogurtcuoglu and Freyhof, 2020).

In this study, some field investigations and evaluations carried out in the Iranian drainage basins over the past years were used to investigate the distribution range of *A. nigrofasciata* in this country. As shown in figure 1, Iran has 19 main drainage basins, which include Urmia Lake, the Caspian Sea, Dasht-e Kavir, Dasht-e Lut, Bedjestan, Tedzhen, Namak Lake, the Tigris, Karun, Kor River, Maharlu Lake, Kerman, Esfahan, Sistan, Mashkid, Jaz Murian, Makran, Hormuz, and the Persian Gulf.

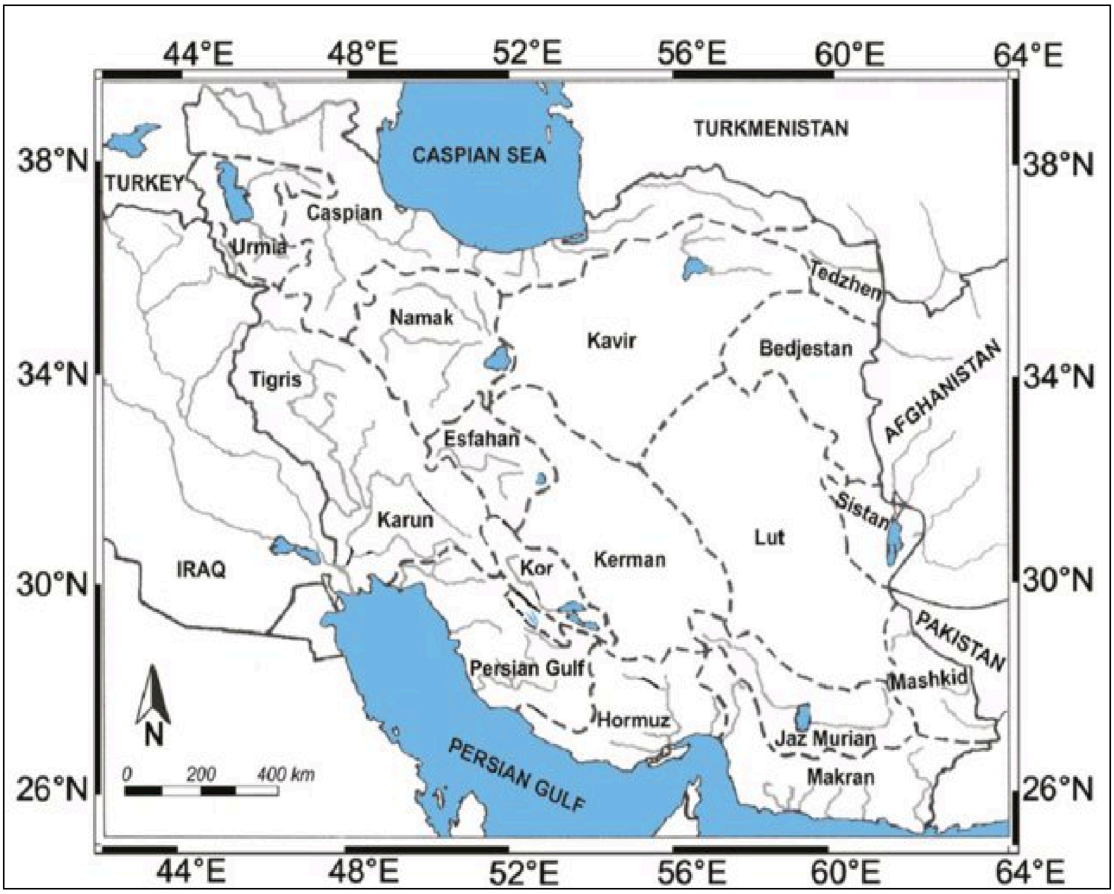


Figure 1: Map of study areas including the drainage basins of Iran (Extracted from Teimori et al., 2016).

RESULTS

Information on the presence of the convict cichlid in the years from 1900 to 2020 is shown in figure 2.

In addition, the global distribution maps of this fish species are presented in four time periods in figures 3-6.

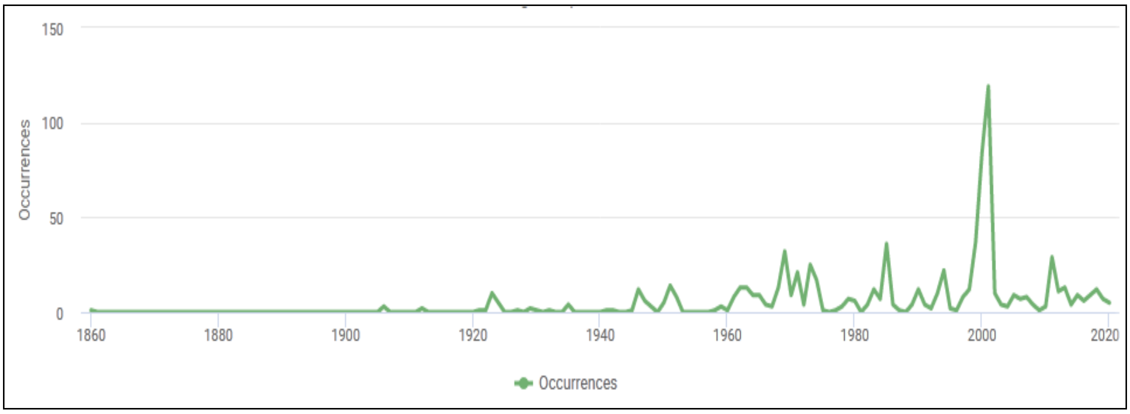


Figure 2: Information on the occurrence of *A. nigrofasciata* worldwide over time (GBIF).

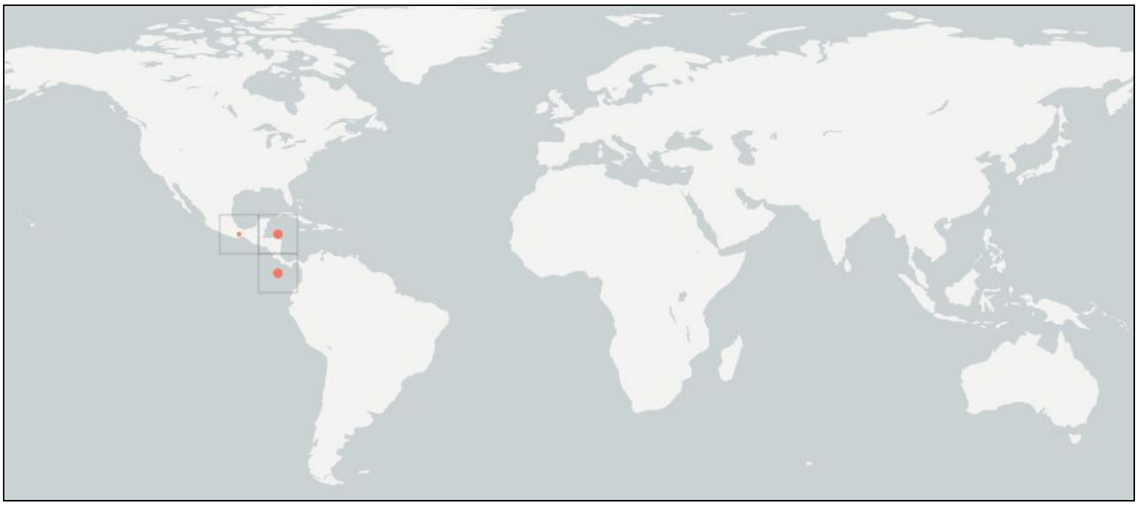


Figure 3: Global distribution of *A. nigrofasciata* in the years 1900-1950 (GBIF).

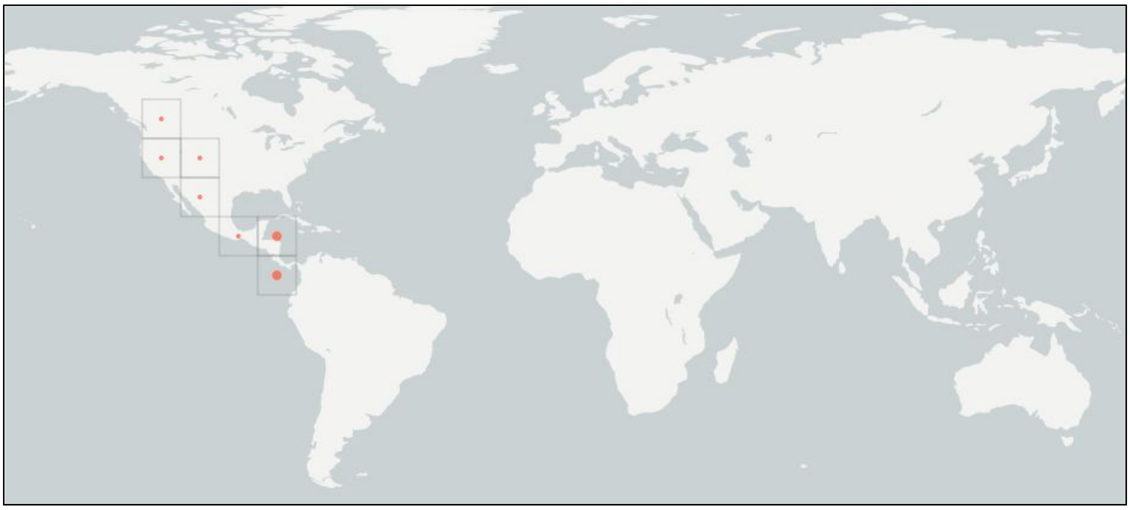


Figure 4: Global distribution map of *A. nigrofasciata* in the years 1950-1970 (GBIF).

Figure 5: Global distribution map of *A. nigrofasciata* in the years 1970-2000 (GBIF).

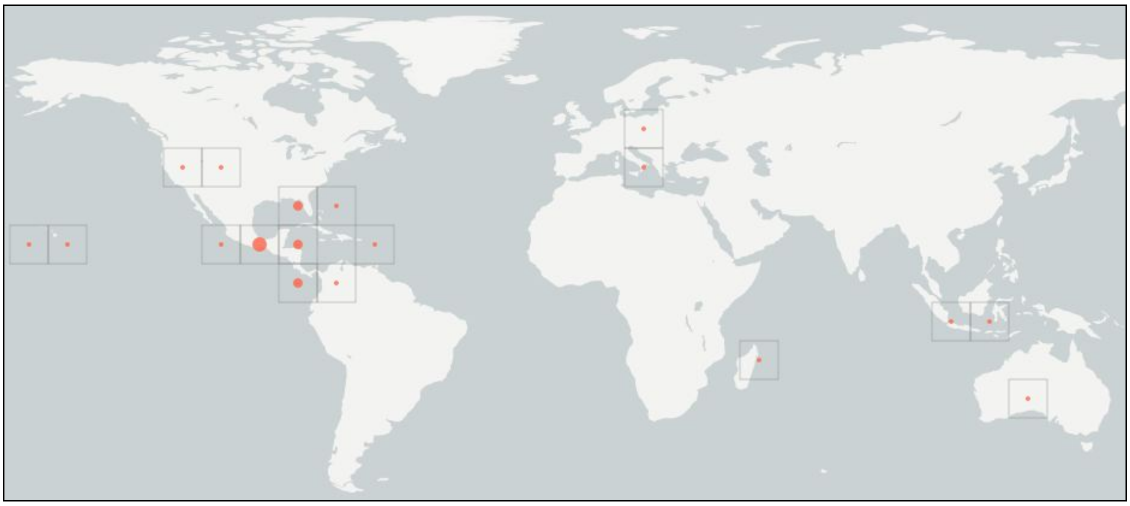
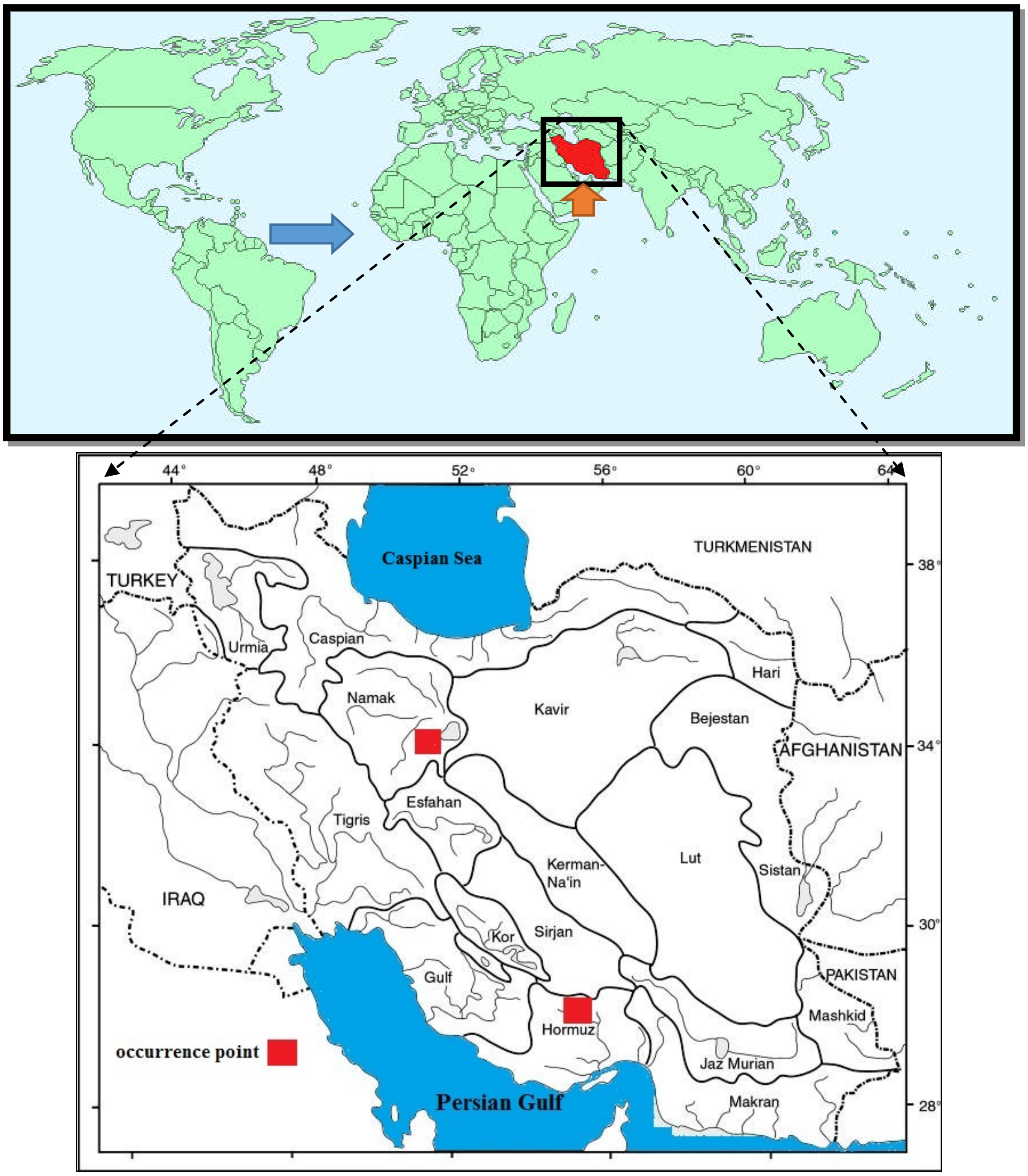


Figure 6: Global distribution map of *A. nigrofasciata* in the years 2000-2020 (GBIF).

Regarding the distribution of the convict cichlid (*A. nigrofasciata*) in Iran, a review of the scientific sources showed that two reports on the presence of this species have been prepared so far for the inland waters of Iran. The first report was presented by Esmaeili et al. (2013), the second by Mousavi-Sabet and Eagderi (2016) (Figs. 7-8).



Figures 7-8: Introduction of the convict cichlid from the Neotropical region (Central and South America) to other countries such as Iran;
The geographic distribution map of the convict cichlid in the Iranian inland basins (Map source: Coad, 2019).

The convict cichlid (*A. nigrofasciata*), as one of the popular aquarium species in the ornamental fish industry (Lukas et al., 2017), has been imported into Iran from the Neotropical region (Esmaeili et al., 2017). According to recent reports, the occurrence of this species has been recorded in two domestic basins of Iran. *A. nigrofasciata* was first reported by Esmaeili et al. (2013) from the Kol River, the Hormuz Basin (Fig. 9a). Subsequently, its occurrence in the Namak Lake basin (Sulaymaniyah Spring) was recorded by Mousavi-Sabet and Eagderi (2016) (Fig. 9b). Those researchers stated that the convict cichlid may have been introduced into the internal ecosystems of Iran by local people as an ornamental fish species. In explaining this, they acknowledge that since the Kashn City (located in Isfahan Province) is the largest centre of ornamental fish production in Iran, it is likely that this species has been transferred from ornamental fish breeding and rearing centres of Kashan to the Sulaymaniyah Spring. The examination of the distribution map of this species in the inland waters of Iran shows that, although the occurrence of this species has been recorded in only two localities in Iran so far, it can still spread widely if urgent management decisions are not taken

Figure 9: The convict cichlid habitats in Iran.
(A) Golabi spring (Hormuz Basin), (B) Sulaymaniyah Spring (Namak Lake basin).
(http://amernews.ir and https://www.nabro.ir).

The examination of the presence of the convict cichlid (*A. nigrofasciata*) over the past years showed that the highest number of reports on this species is observed in 2000 (Fig. 2). However, it should be noted that fewer reports in other years does not indicate a lower presence of the species.

The results of the distribution maps showed that from the 1900s to the 1950s, the distribution range of *A. nigrofasciata* was restricted to Central America. This result has been confirmed by Ishikawa and Tachihara (2010) and Zworykin (2011). They stated that the convict cichlid (*A. nigrofasciata*) is distributed in the rivers of Central America, from Guatemala to North Panama.

From the 1950s to the 1970s, the presence of *A. nigrofasciata* was recorded in significant parts of the Americas, such that USGS (2019) and CABI (2020) recently reported that this species has been recorded in a large number of United States of America states, including Florida, Texas, Arizona, Idaho, California, Alabama, Wyoming, Louisiana, Nevada, and Hawaii, as well as Puerto Rico.

The examination of the global distribution of the convict cichlid (*A. nigrofasciata*) from the 1970s to the 2020s showed that this species had a wide potential to be introduced to different parts of the world. Evidence of this potential spread is the introduction from Central America to all continents except Antarctica, during this period.

It should be noted that some of the information about the presence of *A. nigrofasciata* has not been registered on the GBIF website. Therefore, the shortcomings of this data were compensated by reviewing the previous sources. One of the available references that can be used to cover this shortage is CABI that has provided new reports on the distribution of the convict cichlid. CABI (2020) stated that in addition to the presence of the convict cichlid in the mentioned countries (Fig. 6), this species has been introduced to many other countries, such as Israel, Colombia, Germany, Peru, Slovakia, the Philippines, and Iran (Fig. 10).

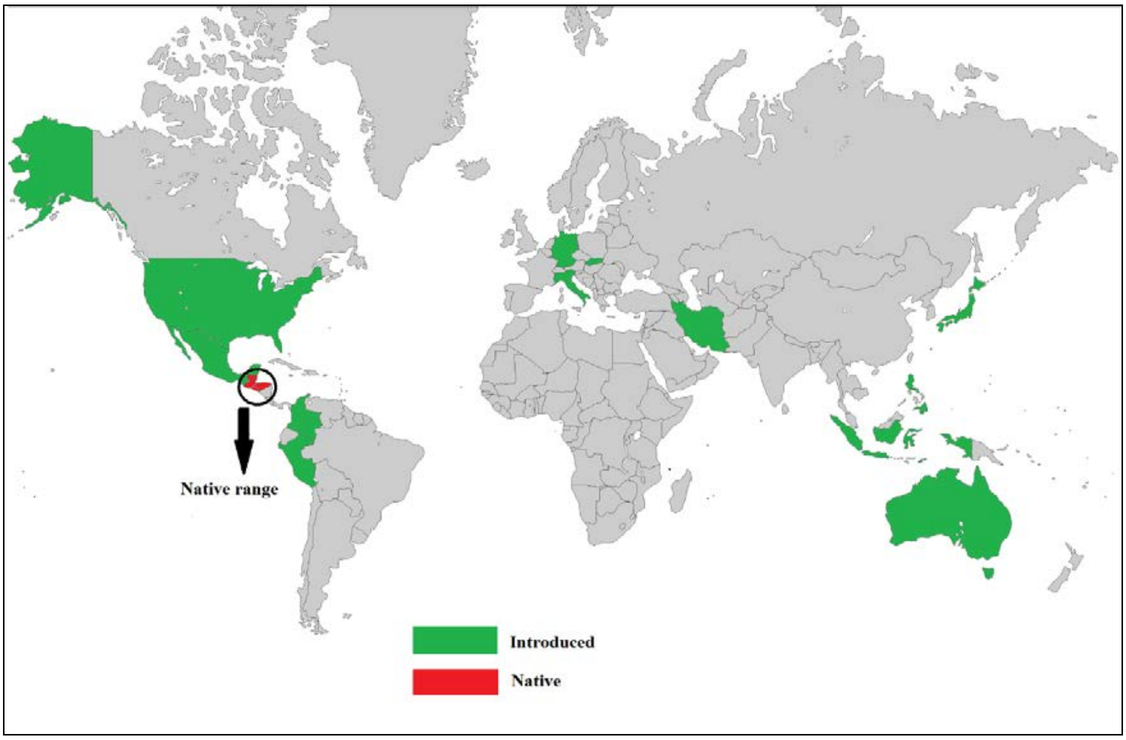


Figure 10: Global distribution map of the convict cichlid (*A. nigrofasciata*) based on CABI (2020).

Ecological impact

Examination of experiences and studies in different countries may be very helpful in better understanding the ecological threats posed by the convict cichlid in water bodies. In recent years, several studies in the United States of America have documented the ecological impact of this species on other fish populations. According to Deacon et al. (1964), the occurrence of the convict cichlid has reduced the population of the native *Rhinichthys osculus* in Lake Mead, Nevada. In addition, this species has been identified as a serious threat to populations of *Crenichthys baileyi* and other native fish in the White River in Nevada (USGS, 2019). According to other reports, this species has also reduced the growth of native fish in the Hiko springs of Nevada (USGS, 2019; Radkhah and Eagderi, 2019).

Possible ecological impact in the inland waters of Iran

In a study reporting the occurrence of the convict cichlid in the Sulaymaniyah Spring, Mousavi-Sabet and Eagderi (2016) stated that this species may have negative effects on native fish as *Capoeta aculeata* through competition, habitat changes and introduction of parasites and diseases. Esmaeili et al. (2013) also reported on the occurrence of other species from the Golabi Spring, including *Garra persica*, *Paraschistura sargadensis*, *Capoeta saadii*, *Carrasius auratus*, *Cyprinion microphthalmus*, *Gambusia holbrooki*, and *Carasobarbus luteus.* All of these species are native to the Golabi Spring except *G. holbrooki* and *C. auratus.* This result indicates that a significant number of species native to this spring may be affected by a non-native species such as the convict cichlid (Radkhah and Eagderi, 2019). Esmaeili et al. (2013) acknowledged that although the distribution of the convict cichlid is very limited in the Golabi Spring, it is still likely to succeed. In fact, this spring is distinct from the other water bodies and aquatic species such as the convict cichlid cannot be transferred to other parts without human intervention. Therefore, careful monitoring and control of these areas could prove useful in maintaining population structure and biodiversity in other different ecosystems.

Probability of expansion of distribution range in Iran

Temperature is one of the most important parameters in fish distribution. According to Froese and Pauly (2019b), *A. nigrofasciata* lives in the temperature range of 20°C – 36°C, which is related to the tropical zone. However, it is also likely for this fish to be distributed in the subtropical climate due to its high adaptability to new environmental conditions.

Given that Iran has different climates, it is possible that the distribution range of *A. nigrofasciata* extends into the Central Plateau and southern parts of this country (Fig. 11). Since the increase in air temperature affects the water temperature, this phenomenon can alter the habitat conditions for the successful presence of *A. nigrofasciata*. In fact, this condition can be very important for the adaptation of the species to the environmental conditions and its reproductive success in the future.

It should be noted that although the convict cichlid (*A. nigrofasciata*) is likely to be distributed in the Central Plateau and southern parts, the possibility of its presence in other parts of the country is not excluded. Studies have shown that this fish species has been recorded in many areas of the world that differ greatly in their environmental conditions (Radkhah et al., 2018, 2019a, b, 2020). The examination of some previous references indicates that many species of Neotropical origin have been introduced to other countries so far. According to the reports, certain species such as *Poecilia reticulata* and *P. latipinna* have been introduced from these areas into the Iranian inland waters (Radkhah et al., 2018, 2019a). The uncontrolled widespread dispersal of these fish over time has led to their recognition as dominant species in many freshwater systems (Radkhah and Eagderi, 2019b). Our studies show that, despite the widespread distribution of other invasive fish species in Iran, *A. nigrofasciata* has not yet been able to greatly expand its distribution range in the country. However, it is necessary to take some required measures to control and prevent the ecological threats posed by this fish species in Iran (Radkhah and Eagderi, 2019b).

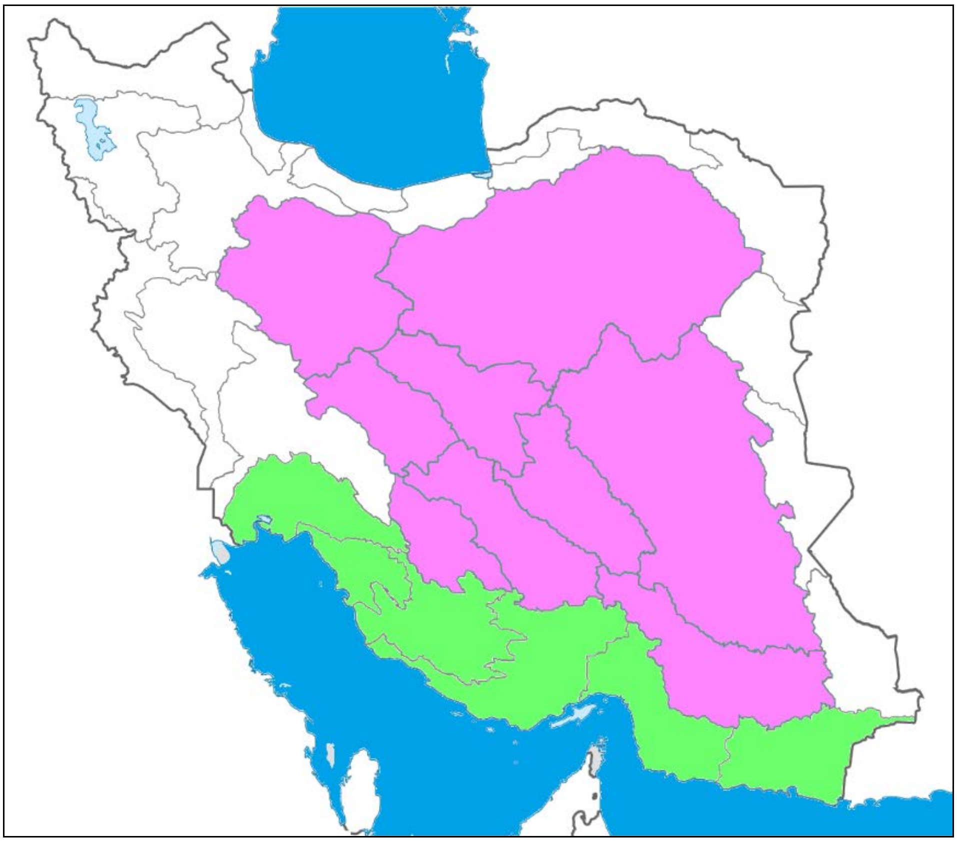


Figure 11: Expected areas for distribution of the convict cichlid (*A. nigrofasciata*) in fresh waters of Iran; pink and green colors show the Central Plateau and southern parts of Iran.

CONCLUSIONS AND FUTURE PERSPECTIVES

The present study indicated that the distribution area of the convict cichlid (*A. nigrofasciata*) was originally restricted to Central America. Subsequently, the area extended to North America and covered significant parts of the Americas. The widespread distribution of *A. nigrofasciata* continued until the presence of this species was recorded in various countries, including Australia, Israel, Italy, Colombia, Germany, Peru, Slovakia, Japan, Indonesia, the Philippines and Iran. The results of our study, which focused on the distribution of *A. nigrofasciata* in the Iranian inland waters, showed that this species has been reported in two domestic basins, including Hormuz and Namak Lake.

This study showed that the convict cichlid, due to its specific biological characteristics such as tolerance to a wide range of environmental conditions, opportunism, aggression, ability to capture disturbed habitats, and rapid growth, is capable of posing ecological threats to aquatic ecosystems. Ichthyologists have reported that the negative effects of non-indigenous species such as the convict cichlid are more likely to take a heavy toll on the native fish in the area. This species may have negative impact on the native fish populations of the country such as fish species belonging to the genus *Capoeta*. Hence, due to the negative impact of the introduced non-native and invasive species into native ecosystems, it is necessary to take appropriate control measures to prevent further spread. This study recommends that the national and international environmental and fishery organizations should engage broadly and sustainably to achieve this important goal.

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DIVERSITY AND STRUCTURE OF THE ICHTHYOLOGIC COMMUNITIES IN THE DIVING SITES IN HOLGUIN (CUBA)

Enrique REYNALDO DE LA CRUZ *, [c.a.],
María Eugenia VEGA CENDEJAS **, *Sheila RODRÍGUEZ MACHADO* ***,
Franklin GARCIA FERNÁNDEZ *** and *Antonio VEGA TORRES* *

* Centro de Investigaciones y Servicios Ambientales de Holguín, Street 18 s/n e/ 1st and Maceo, Delivery, El Llano, Holguín, Cuba, CU-80100, ereynaldodelacruz@gmail.com, vega@cisat.cu (c.a.)
** Centro de Investigación y de Estudios Avanzados del IPN, Unidad Mérida, km 6, antigua carretera a Progreso, Postal mail #73 Cordemex, Mérida, Yucatán, México, MX-97310, maruvega@cinvestav.mx
*** Instituto de Ciencias del Mar (ICIMAR), Avenue 1st #18406 e/ 184 y 186, Delivery, Flores, Playa, La Habana, Cuba, CU-11300, sheilaroma89@gmail.com, biolfranklin@gmail.com

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KEYWORDS: coral reef, marine fish, species richness, equity, replacement.

ABSTRACT

This study is aimed to determine the diversity and structure of the ichthyologic communities in the coral reefs of Holguín, Cuba. A total of 85 fish species were recorded, including in 32 families and 53 genera. Low species richness and equitability were estimated at different sampling sites throughout the reef system. Cadena de Vita and Canto Chiquito are the sites with the highest number of species 47 and 46 respectively. Cueva 1 and Punta Naranjo were the places with the highest equitability 0.76. Replacement of fish species among the reef sites studied is poor. Canto Azul with Canto Pionero and La Llanita, sharing 29 species. These results reflect a poor state of conservation of the marine fish communities in Holguín.

RESUMEN: Diversidad y estructura de las comunidades ictiológicas en los arrecifes de coral Holguín (Cuba).

Este estudio pretendió determinar la diversidad y estructura de las comunidades ictiológicas en el arrecife de coral de Holguín, Cuba. Un total de 85 especies fueron registradas, incluidas en 32 familias y 53 géneros. La baja riqueza y equitatividad de especies fueron estimada en los diferentes sitios de muestreo del sistema arrecifal. Cadena de Vita y Canto Chiquito son los sitios con el más alto número de especies 47 y 46 respectivamente. Cueva 1 y Punta Naranjo son los lugares con equitatividad mayor 0.76. El remplazamiento de las especies de peces entre los sitios estudiados del arrecife es pobre. Canto Azul con Canto Pionero y La Llanita, mostraron 29 especies. Este resultado refleja un pobre estado de conservación de las comunidades de peces marinos en Holguín.

REZUMAT: Diversitatea şi structura comunităţilor ihtiologice din recifii de corali Holguin (Cuba).

Acest studiu a avut ca scop determinarea diversităţii şi structurii comunităţilor ihtiologice din recifele de corali din Holguin, Cuba. Au fost înregistrate în total 85 de specii de peşti, incluşi în 32 de familii şi 53 de genuri. O bogăţie în specii şi o echitabilitate reduse au fost estimate în diferite situri de prelevare în sistemul recifal. Cadena de Vita şi Canto Chiquito sunt siturile cu cel mai mare număr de specii 47 şi respectiv 46. Cueva 1 şi Punta Naranjo au fost locurile cu cea mai mare echitabilitate 0.76. Înlocuirea speciilor de peşti printre recifele studiate este redusă. Canto Azul cu Canto Pionero şi La Llanita, împărţind 29 de specii. Aceste rezultate reflect o stare precară de conservare a comunităţilor de peşti marini din Holguín.

INTRODUCTION

If more and more world fish stocks were to become systematically overexploited and depleted, then the total marine catch would be expected to decline (Del Monte-Luna and Lluch-Belda, 2016), in this context extensive and intensive fish fauna assessments and monitoring is needed.

The Cuban marine platform is characterized by a wide diversity of marine organisms (Claro, 2006). Fish constitute a group of vital importance in said biota, and the relationship between these and other species of organisms keeps the structure of the different communities stable, which guarantees greater efficiency in the functioning and development of marine ecosystems (González-Sansón and Betancuor, 2003; Caballero et al., 2006). Particularly, in western Cuba, numerous investigations have been carried out related to the issues of structure, composition, and functioning of marine fish communities, as well as other aspects of the ecology of ichthyofauna (Claro and García-Arteaga, 1994; Claro and García-Arteaga, 2001; Chevalier and Cárdenas, 2006). However, in the North Eastern region of Cuba there is little information on the diversity and interaction between marine ichthyologic communities (Reynaldo et al., 2018).

Fish communities show specific organization patterns that can be detected despite the spatial-temporal variability that characterizes them (Ayala-Pérez et al., 2012). Among the emergent properties that characterize them, there are the taxonomic composition, the distribution of their abundances, their diversity (measured as heterogeneity), and equitability, among others (Begon et al., 2006). They also evolve over time and are characterized by their successional stages, within which they maintain structural and functional stability, given by the balance between their components and by environmental constancy (Aviles-Torres et al., 2001). This balance, however, can be affected by external factors, such as anthropic activities, natural environmental changes, or the introduction of species alien to its evolutionary history, known as invasive species (Campos, 2012).

In Cuba, the western portion of the tourist region of Holguín is the most developed area since the 1980s, featuring the highest levels of complexity in the territorial implementation of tourism (La et al., 2012). In this region, the coral reefs display a poor state of conservation, following the proposed methodology by Alcolado and Duran (2011). The investigations carried out by scientific entities in the region have been unpublished rapid inventories within the framework of technical projects, so there is a lack of information on the structure of marine fish communities (Vega et al., 2004). For this reason, it is necessary to determine the diversity and structure of the ichthyologic communities in the coral reefs for tourist use in Holguín, due to the human impact associated pressures, threats and risks.

MATERIAL AND METHODS

Study area and sampling method

From the 17th to the 30th of July, 2015, the coastal sector of Guardalavaca beach was sampled, in the northeastern platform of Cuba, northwest of the province of Holguín (Fig. 1). For this, 16 sampling sites (Figs. 1-4) were selected in the front area of the reef at an average depth of 12 m. Each site was georeferenced with a global positioning system, Garmin X12 GPS. Visual censuses were carried out at each site (Brock, 1954) in six linear transects of 50 m long by two m wide, occupying a total area of 600 m^2. The species of fish observed and the number of individuals belonging to each of them were recorded. Fish species were identified based on descriptions of Humann and Deloach (2002).

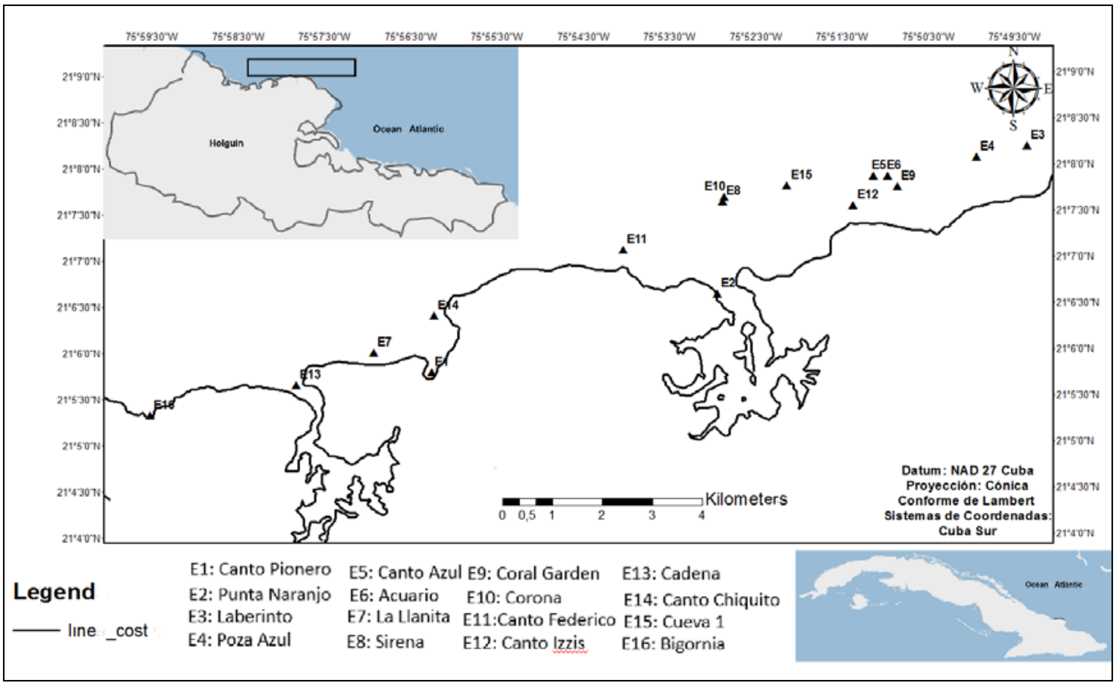

Figure 1: Location of sampling sites.

Figure 2: Sampling site.

Figure 3: Sampling site.

Figure 4: Sampling site.

Data analysis

The richness of ichthyologic species was estimated by the number of species recorded (S). The equity of Pielou (J) measures the proportion of the diversity observed in relation to the maximum diversity expected. The dominance of the species (D) was determined following Magurran (2004). Diversity was estimated from Fisher's alpha index, which is based on a logarithmic model of the distribution of the abundance of the species (Magurran, 1988). Beta diversity or diversity between habitats was estimated by the Whittaker index, which measures the degree of species replacement or biotic change through environmental gradients (Whittaker, 1972). Gamma diversity was obtained following the criteria (Landen, 1996), gamma diversity = average alpha + beta, from the richness of species:

Beta calculation based on species richness (Moreno, 2001):

$$Beta = \sum_j qj(ST - Sj) \quad (1)$$

where:

Beta = Beta diversity;

qj = Proportional weight of community *j*, based on its area or any other measure of relative importance;

ST = Total number of species registered in the set of communities;

Sj = Number of species registered in the community *j*.

For all diversity analyses, bootstrap processing was performed for an N = 10000 of the centered type for a 95% confidence interval. The statistical comparison of the ecological indices between sites was carried out using the diversity permutation test, for 9999 randomized matrices (Brower et al., 1997). The roughness of the seabed (cm) was determined following the AGRRA methodology (2000).

Clustering analysis was used to represent the present fish associations, using the Morisita (1959) index as modified by Horn (1966) as a measure of similarity. This specific analysis constitutes one of the most widely used models to quantify the similarity between communities from quantitative data. Of the quantitative models, it has been suggested that it is the most satisfactory (Magurran, 1988). To determine the statistical differences between the groups (70% similarity), an analysis of similarities (ANOSIM) was performed using 10000 permutations, and a SIMPER to establish the contribution of the abundance of the species, which most influenced the dissimilarity between the groups (Clarke, 1993). The statistical package used was Past. 4.0 (Hammer et al., 2001).

RESULTS

A total of 85 fish species were recorded, included in 32 families and 53 genera. The most representative species according to their abundances throughout the ecosystem are *Clepticus parrae* 5,273 individuals, *Chromis cyanea* 3,202 individuals and *Thalassoma bifasciatum* 1,014 individuals (Tabs. 2a and 2b).

The ichthyofauna of the Holguín coral reef area present a low species richness (Fig. 2) and equitability (Fig. 3) with an average of 37 species and 0.60 of equitability for 16 studied sites.

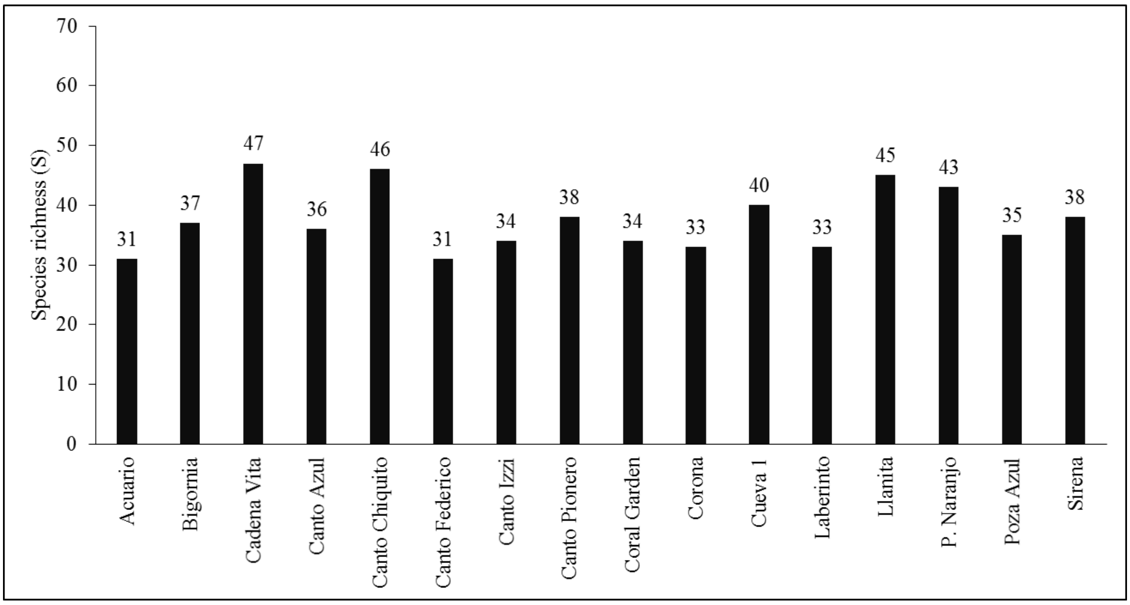

Figure 2: Species richness (S) by dive sites.

Table 1: Ecological indices at Holguín dive sites. The largest values are highlighted in bold. Richness of species Taxa (S), Equity (J), Dominance (D), and Fisher (A).

Index	Acuario	Bigornia	Cadena	Canto Azul	Canto Chiquito	Canto Federico	Canto Izzis	Canto Pionero	Cral Garden	Corona	Cueva 1	Laberinto	Llanita	Punta Naranjo	Poza Azul	Sirena
S	31	37	**47**	36	**46**	31	34	38	34	33	40	33	**45**	43	35	38
J	0.74	0.36	0.54	0.73	0.42	0.70	0.48	0.48	0.55	0.61	**0.76**	0.55	0.69	0.72	**0.76**	0.65
D	0.11	**0.48**	0.19	0.12	0.38	0.15	0.33	0.31	0.26	0.21	0.09	0.24	0.10	0.11	0.11	0.15
A	7.84	6.59	8.39	8.93	8.79	7.47	7.05	6.89	6.78	6.97	**10.9**	7.06	9.68	**11.5**	7.76	8.90

The sites with the highest species richness are shown in figure 2, where the following stand out: Cadena de Vita and Canto Chiquito with 47 and 46 species, respectively (Tab. 1). In relation to equity, the highest values were obtained in: Cueva 1 and Poza Azul (0.76), followed by Acuario (0.74), Canto Azul (0.73), and Punta Naranjo (0.72) (Tab. 1). The abundance of the species throughout the reef system is low, highlighting *C. cyanea* 571 ind./100 m^2 and *C. parrae* 1,219 ind./100 m^2, as the only species with high abundance, not observing the presence of large groupers or species of fish of bigger size (Tabs. 2a and 2b).

Table 2a: Abundance of the fish species for each sampling site in 100 m^2.

Species	Acuario	Bigornia	Cadena	Canto Azul	Canto Chiquit	Canto Federico	Canto Izzis	Canto Pionero
Abadeduf saxsatilis	0	0	0	0	16	0	0	16
Acanthostracion polygonia	1	0	0	0	0	0	0	0
Acanthostracion quadricornis	0	0	0	1	0	0	0	0
Acanthurus bahianus	23	21	18	5	5	10	9	0
Acanthurus chirurgus	0	0	0	0	0	0	0	0
Acanthurus coeruleus	19	9	9	15	12	9	13	30
Amblycirrhitus pinos	0	0	0	0	0	0	0	0
Anisotremus virginicus	0	1	0	5	2	1	0	4
Aulostomus macalatus	0	0	3	0	3	0	0	3
Bodianus rufus	0	3	3	1	1	0	1	1
Calamus calamus	0	0	0	0	0	0	0	0
Cantherhines macrocerus	1	0	0	0	0	0	0	0
Cantherhines pullus	0	1	0	0	0	0	0	0
Canthigaster rostrata	3	1	10	0	4	1	0	7
Caranx ruber	0	2	0	0	2	0	0	0
Cephalopholis cruentata	1	4	6	1	3	1	4	4
Cephalopholis fulva	10	8	1	1	4	8	5	4
Chaetodon capistratus	2	4	12	14	7	4	11	8
Chaetodon ocellatus	0	6	2	0	0	0	1	0
Chaetodon sedentarius	0	0	1	0	0	0	0	0
Chaetodon striatus	0	0	0	0	0	0	0	0
Chromis cyanea	96	269	571	148	350	24	467	487
Chromis insolata	0	0	0	1	0	0	0	0
Clepticus parrae	0	1219	701	14	947	104	0	813
Coryphopterus personatus	0	0	15	30	22	0	3	41
Epinephelus flavolimbatus	0	0	0	0	0	0	0	0
Epinephelus guttatus	0	0	0	0	0	0	3	0
Equetus punctatus	0	0	0	0	1	0	0	0
Gramma loreto	0	0	2	17	16	0	6	16
Gramma melacara	0	0	0	0	0	0	0	0
Haemulon aurolineatum	0	0	345	0	1	0	0	0
Haemulon bonariense	0	0	0	0	0	0	1	0
Haemulon carbonarium	0	0	0	0	0	0	0	0
Haemulon flavolineatum	4	31	187	13	10	17	5	28
Haemulon macrostomum	0	0	0	1	0	0	0	2
Haemulon plumieri	1	0	19	2	1	2	1	1
Haemulon sciurus	2	0	1	1	3	16	0	11
Halichoeres bivittatus	0	0	0	0	0	0	0	0
Halichoeres garnoti	10	9	4	2	7	10	13	2
Halichoeres maculipinna	0	0	0	0	0	0	0	0
Holacanthus ciliaris	0	0	0	0	1	0	0	0

Table 2a (continued): Abundance of the fish species for each sampling site in 100 m^2.

Holacanthus tricolor	2	5	12	3	1	1	4	1
Holocentrus adscensionis	0	1	2	0	0	1	0	0
Holocentrus rufus	2	0	21	5	5	3	3	22
Hypoplectrus gummigutta	0	0	1	0	1	1	0	0
Hypoplectrus guttavarium	0	0	1	1	1	0	0	1
Hypoplectrus indigo	0	0	2	0	0	0	1	1
Hypoplectrus nigricans	0	0	1	0	0	0	0	0
Hypoplectrus puella	0	4	8	1	8	1	7	4
Lactophrys triqueter	1	1	0	0	2	2	1	0
Lutjanus analis	0	0	0	0	0	3	0	0
Lutjanus apodus	4	2	2	8	0	0	1	1
Lutjanus griseus	0	0	0	0	0	0	0	0
Lutjanus jocu	0	0	0	0	1	0	0	0
Lutjanus mahogoni	0	0	3	11	1	0	0	32
Lutjanus synagris	0	0	0	0	0	0	0	0
Microspathodon chrysurus	2	0	0	2	0	0	0	2
Mulloidichthys martinicus	0	3	12	2	2	0	3	8
Mycteroperca bonaci	0	0	0	0	1	0	0	0
Myripristis jacobus	27	0	0	9	0	0	0	0
Neoniphon marianus	0	3	3	0	2	0	0	0
Ocyurus chrysurus	0	0	3	2	8	13	0	3
Pomacanthus arcuatus	0	1	3	0	0	0	0	0
Pomacanthus paru	0	0	0	0	0	0	0	0
Prognathodes aculeatus	0	1	1	1	0	3	1	0
Pseudopeneus maculatus	0	1	1	0	3	0	0	0
Pterois volitans	0	1	0	0	6	0	0	0
Sargocentron vexillarium	0	0	0	0	0	0	0	0
Scarus iserti	7	53	116	26	31	10	9	57
Scarus taeniopterus	75	43	74	41	68	27	71	5
Scarus vetula	2	0	1	1	1	0	0	0
Serranus tigrinus	0	3	0	0	0	5	1	0
Sparisoma atomarium	0	2	14	0	16	0	1	0
Sparisoma aurofrenatum	25	21	24	28	23	24	39	18
Sparisoma chrysopterum	0	0	0	0	0	0	0	0
Sparisoma rubripinne	1	0	0	0	0	0	0	0
Sparisoma viride	7	3	7	1	3	3	6	20
Stegastes adustus	1	0	0	0	0	0	0	0
Stegastes diencaeus	28	6	2	0	3	1	5	13
Stegastes leucostictus	1	0	0	0	0	0	0	2
Stegastes partitus	23	4	6	30	0	17	5	1
Stegastes planifrons	3	5	6	0	6	0	1	4
Stegastes variabilis	0	2	7	0	9	1	2	2
Synodus synodus	0	0	1	0	0	0	0	0
Thalassoma bifasciatum	17	37	17	49	13	143	161	20
Average abundance	4.71	21.05	26.6	5.8	19.21	5.48	10.17	19.94
Total species number	31	37	47	36	46	31	34	38

Table 2b: Abundance of the fish species for each sampling site in 100 m^2.

Species	Coral Garden	Crona	Cueva 1	Laberint o	Llanita	Punta Naranjo	Pza Azul	Sirena
Abadeduf saxsatilis	2	0	0	0	0	10	0	0
Acanthostracion polygonia	0	0	0	0	0	0	0	0
Acanthostracion quadricornis	0	0	0	0	0	0	0	0
Acanthurus bahianus	15	4	1	5	7	3	14	7
Acanthurus chirurgus	1	0	0	0	0	22	0	0
Acanthurus coeruleus	16	27	22	7	24	0	11	24
Amblycirrhitus pinos	0	0	0	0	0	0	0	1
Anisotremus virginicus	0	6	5	300	1	6	0	0
Aulostomus macalatus	0	0	1	0	0	0	1	0
Bodianus rufus	3	0	0	0	3	0	0	2
Calamus calamus	0	0	0	1	0	0	0	0
Cantherhines macrocerus	0	0	0	0	0	0	0	0
Cantherhines pullus	0	0	0	0	0	0	0	0
Canthigaster rostrata	3	0	1	0	2	0	0	0
Caranx ruber	0	2	0	1	1	2	2	1
Cephalopholis cruentata	2	1	2	1	7	1	1	0
Cephalopholis fulva	12	0	2	1	15	3	5	0
Chaetodon capistratus	3	11	1	5	8	5	8	13
Chaetodon ocellatus	0	0	0	0	0	2	1	3
Chaetodon sedentarius	0	0	0	0	0	0	0	0
Chaetodon striatus	0	3	0	0	0	0	0	0
Chromis cyanea	117	132	80	63	155	60	116	67
Chromis insolata	0	0	1	0	0	0	0	0
Clepticus parrae	470	317	20	33	119	133	183	200
Coryphopterus personatus	0	0	10	0	106	30	0	0
Epinephelus flavolimbatus	0	0	0	0	3	0	0	0
Epinephelus guttatus	0	0	0	0	0	0	0	0
Equetus punctatus	0	0	0	0	1	0	0	0
Gramma loreto	0	12	15	0	8	9	0	1
Gramma melacara	0	2	0	0	0	0	0	0
Haemulon aurolineatum	0	0	0	0	0	0	0	0
Haemulon bonariense	0	0	0	0	0	0	0	0
Haemulon carbonarium	0	0	0	201	0	0	4	0
Haemulon flavolineatum	2	6	40	0	13	2	13	4
Haemulon macrostomum	0	0	0	1	22	0	0	2
Haemulon plumieri	0	0	2	0	3	0	6	2
Haemulon sciurus	2	3	3	0	3	2	8	1
Halichoeres bivittatus	0	0	0	0	0	12	7	0
Halichoeres garnoti	14	4	10	7	3	5	14	1
Halichoeres maculipinna	1	0	0	0	0	0	0	0
Holacanthus ciliaris	0	0	1	0	0	0	0	1

Table 2b (continued): Abundance of the fish species for each sampling site in 100 m^2.

Holacanthus tricolor	3	2	2	4	3	2	6	2
Holocentrus adscensionis	1	0	1	2	1	0	9	1
Holocentrus rufus	0	3	9	0	5	2	16	3
Hypoplectrus gummigutta	2	0	0	0	0	0	0	0
Hypoplectrus guttavarium	0	0	0	0	0	1	0	0
Hypoplectrus indigo	1	2	1	0	0	1	0	1
Hypoplectrus nigricans	0	0	0	0	0	1	0	0
Hypoplectrus puella	0	3	3	1	7	3	1	1
Lactophrys triqueter	0	0	0	0	0	0	0	1
Lutjanus analis	0	0	0	0	0	0	0	0
Lutjanus apodus	0	6	6	2	4	2	18	2
Lutjanus griseus	0	0	0	0	1	0	0	0
Lutjanus jocu	0	0	0	0	0	0	0	1
Lutjanus mahogoni	0	1	2	0	2	1	6	0
Lutjanus synagris	0	0	0	2	0	0	0	0
Microspathodon chrysurus	3	0	0	0	1	0	0	2
Mulloidichthys martinicus	0	4	2	1	1	1	21	0
Mycteroperca bonaci	0	0	0	0	0	0	0	0
Myripristis jacobus	1	1	2	0	2	0	0	7
Neoniphon marianus	1	5	10	1	7	0	3	1
Ocyurus chrysurus	0	0	3	3	136	1	9	61
Pomacanthus arcuatus	0	1	2	0	1	1	0	0
Pomacanthus paru	0	0	2	0	0	0	0	0
Prognathodes aculeatus	0	1	0	1	2	0	0	0
Pseudopeneus maculatus	0	0	0	0	0	1	1	0
Pterois volitans	0	0	0	0	1	1	0	0
Sargocentron vexillarium	0	0	0	0	0	1	0	0
Scarus iserti	24	27	6	12	41	36	39	10
Scarus taeniopterus	56	47	72	40	82	22	54	83
Scarus vetula	9	1	5	3	2	0	4	8
Serranus tigrinus	4	0	0	0	0	0	0	0
Sparisoma atomarium	0	0	12	0	0	0	0	0
Sparisoma aurofrenatum	26	20	22	14	22	24	27	26
Sparisoma chrysopterum	0	0	1	0	0	0	0	0
Sparisoma rubripinne	0	0	0	0	0	1	0	2
Sparisoma viride	11	12	1	4	7	16	14	8
Stegastes adustus	0	0	0	0	0	0	0	0
Stegastes diencaeus	16	0	0	1	1	11	4	2
Stegastes leucostictus	1	0	0	1	0	2	0	0
Stegastes partitus	18	23	30	4	7	4	22	14
Stegastes planifrons	3	2	2	6	0	4	0	1
Stegastes variabilis	2	0	0	2	1	2	5	0
Synodus synodus	0	0	0	0	1	1	0	0
Thalassoma bifasciatum	166	92	0	16	157	24	42	60
Average abundance	11.89	9.21	4.85	8.77	11.75	5.56	8.17	7.37
Total species number	34	33	40	33	45	43	35	38

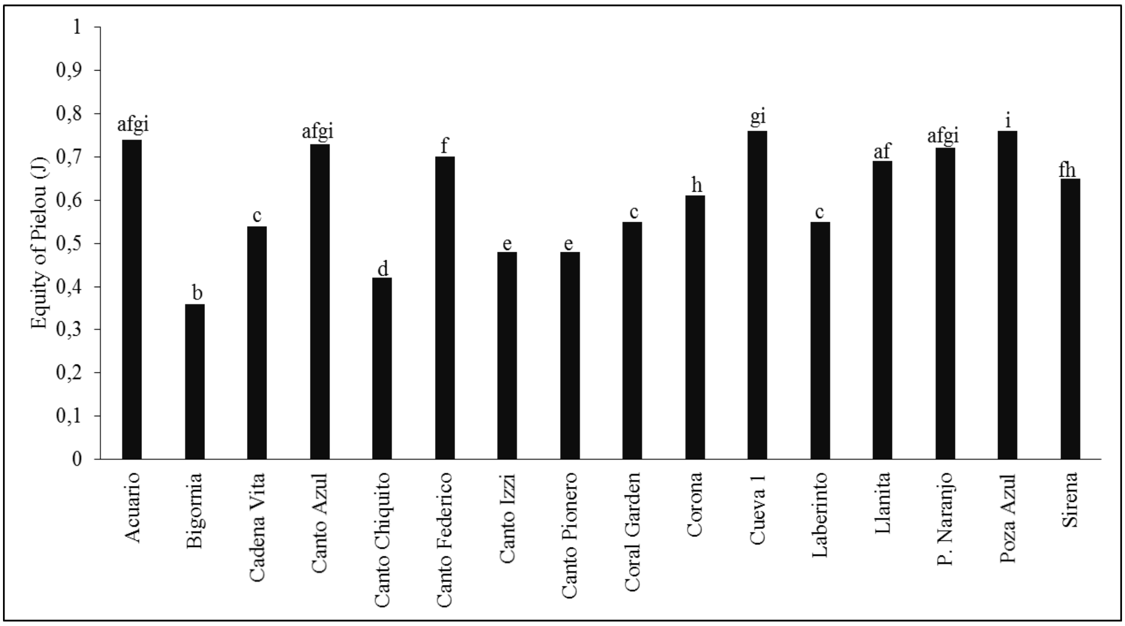

Figure 3: Statistical variability of the equitability of Pielou (J), between sites.
Equal letters represent that there are no statistical differences
and different letters that there are differences ($p \leq 0.0001$).

Dominance (Fig. 4). Bigornia and Canto Chiquito were the sites with the highest dominance and statistical variability ($p \leq 0.0001$) (Tab. 1). The species that most influenced in the dominance at these sites were *C. cyanea* and *C. parrae* respectively. These sites were characterized by a low species richness (40 and 47 species, respectively).

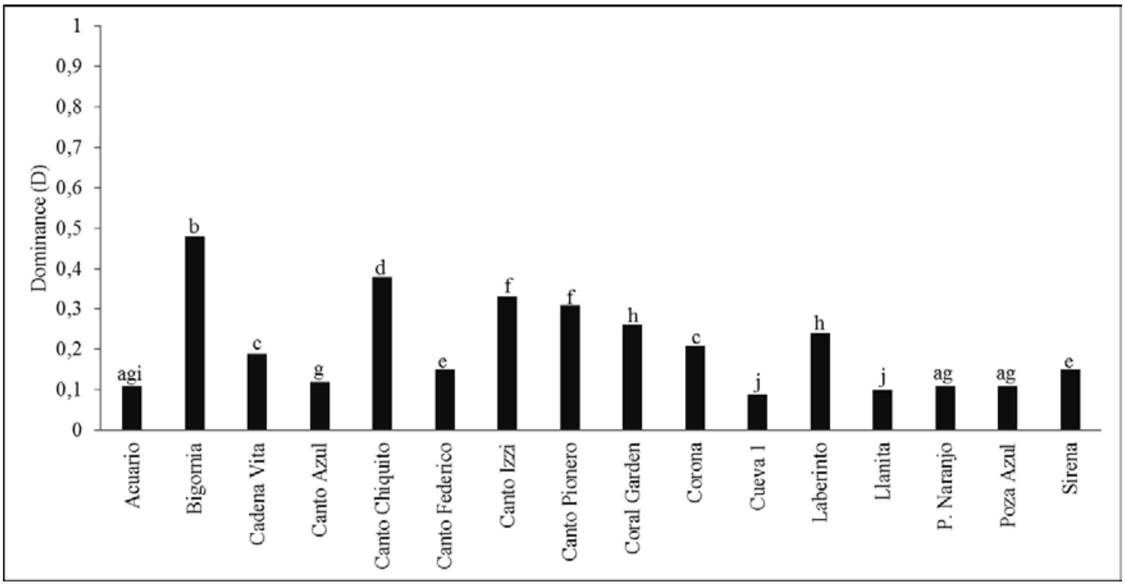

Figure 4: Statistical variability of Dominance (D), between sites. Equal letters represent that there are no statistical differences and different letters that there are differences ($p \leq 0.0001$).

Fisher's alpha diversity (Fig. 5). The highest values were recorded in Punta Naranjo (11.49) and Cueva 1 (10.94), which presented the highest number of species with the highest densities (Tabs. 1 and 2). The rest of the sites have few ichthyologic species with significant densities. The species with the highest densities in both sites were *C. parrae*, *C. cyanea*, *S. taeniopterus*, and *S. aurofrenatum* (Tab. 2). These sites did not show statistical differences between them, but with the other collection sites ($p \leq 0.0001$) (Fig. 5). The lowest diversities were recorded in Bigornia, Coral Garden, Canto Pionero, and Corona (Tab. 1) and in turn the sites with the highest statistical variability for this ecological index ($p \leq 0.0001$).

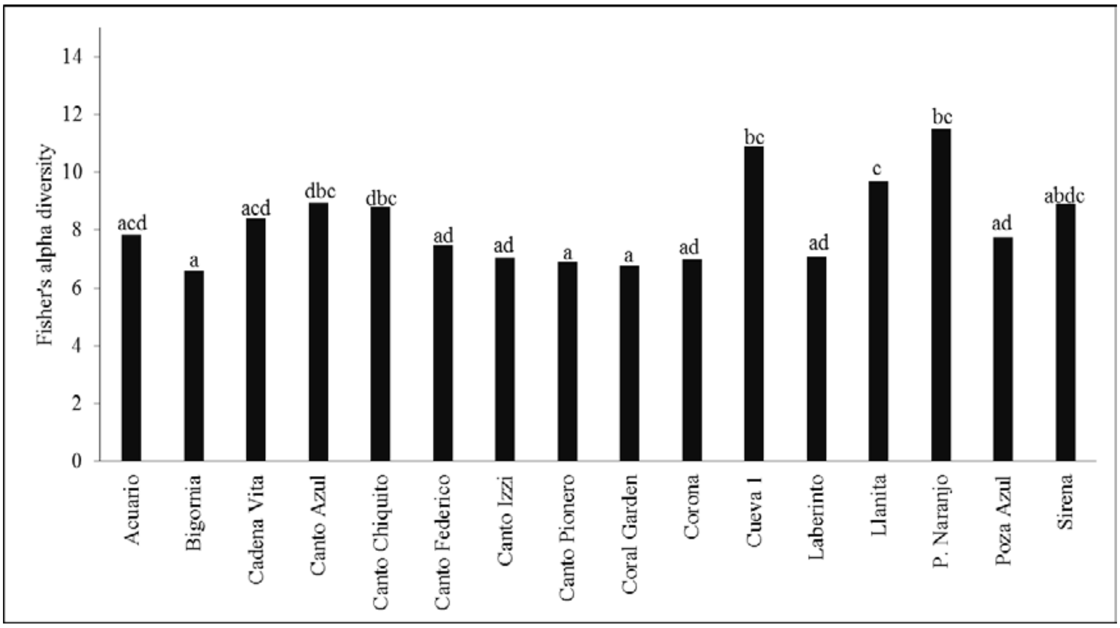

Figure 5: Statistical variability of Fisher alpha diversity, between sites. Equal letters represent that there are no statistical differences and different letters that there are differences ($p \leq 0.0001$).

Beta diversity. Wittaker's global Beta diversity index was (1.26). The sites with the least replacement of species were Acuario with Bigornia (0.41), Cadena de Vita (0.41), Canto Chiquito (0.42), Laberinto (0.40), and Punta Naranjo (0.43).

The species not shared between Acuario with the aforementioned sites were *Acanthostracion polygonia*, *Anisotremus virginicus*, *Cantherhines macrocerus*, *Caranx ruber*, *C. parrae*, *H. puella*, *Microspathodon chrysurus*, *Mulloidichthys martinicus*, *Myripristis jacobus*, *Sparisoma rubripinne*, *Stegastes adustus*, and *Stegastes variabilis*.

Other sites that shared fewer species were Canto Azul with Coral Garden 0.40 highlighting *Abudefduf saxatilis*, *A. quadricornis*, and *Acanthurus chirurgus*.

Table 3a: Beta diversity in the ichthyologic communities in the contemplative diving sites in Holguín, Cuba.

Sites	Acuario	Bigornia	Cadena	Canto Azul	Canto Chiquito	Canto Federico	Canto Izzis	Canto Pionero
Acuario	0	**0.41**	**0.41**	0.34	**0.42**	0.32	0.35	0.33
Bigornia	**0.41**	0	0.26	0.39	0.30	0.26	0.23	0.36
Cadena	**0.41**	0.26	0	0.27	0.20	0.30	0.25	0.22
Canto Azul	0.34	0.39	0.27	0	0.31	0.31	0.31	0.18
Canto Chiquito	**0.42**	0.30	0.20	0.31	0	0.32	0.35	0.23
Canto Federico	0.32	0.26	0.30	0.31	0.32	0	0.29	0.30
Canto Izzis	0.35	0.23	0.25	0.31	0.35	0.29	0	0.27
Canto Pionero	0.33	0.36	0.22	0.18	0.23	0.30	0.27	0
Coral Garden	0.29	0.32	0.33	**0.40**	0.37	0.29	0.38	0.30
Corona	0.37	0.31	0.30	0.24	0.36	0.37	0.34	0.32
Cueva 1	0.38	0.35	0.21	0.23	0.27	0.35	0.35	0.25
Laberinto	**0.40**	0.25	0.35	0.33	0.39	0.31	0.37	0.32
Llanita	0.36	0.26	0.21	0.18	0.25	0.28	0.34	0.22
Punta Naranjo	**0.43**	0.32	0.24	0.34	0.30	**0.40**	0.35	0.23
Pza Azul	0.36	0.27	0.21	0.29	0.28	0.27	0.33	0.28
Sirena	0.30	0.36	0.31	0.29	0.33	0.36	0.33	0.31

Table 3b: Beta diversity in the ichthyologic communities in the contemplative diving sites in Holguín, Cuba.

Sites	Coral Garden	Corona	Cueva 1	Laberinto	Llanita	Punta Naranjo	Pza Azul	Sirena
Acuario	0.29	0.37	0.38	**0.40**	0.36	**0.43**	0.36	0.30
Bigornia	0.32	0.31	0.35	0.25	0.26	0.32	0.27	0.36
Cadena	0.33	0.30	0.21	0.35	0.21	0.24	0.21	0.31
Canto Azul	0.40	0.24	0.23	0.33	0.18	0.34	0.29	0.29
Canto Chiquito	0.37	0.36	0.27	0.39	0.25	0.30	0.28	0.33
Canto Federico	0.29	0.37	0.35	0.31	0.28	0.40	0.27	0.36
Canto Izzis	0.38	0.34	0.35	0.37	0.34	0.35	0.33	0.33
Canto Pionero	0.30	0.32	0.25	0.32	0.22	0.23	0.28	0.31
Coral Garden	0	0.37	0.37	0.34	0.34	**0.40**	0.36	0.33
Corona	0.37	0	0.23	0.30	0.25	0.31	0.29	0.29
Cueva 1	0.37	0.23	0	0.36	0.24	0.34	0.28	0.30
Laberinto	0.34	0.30	0.36	0	0.28	0.36	0.23	0.35
Llanita	0.34	0.25	0.24	0.28	0	0.29	0.25	0.27
Punta Naranjo	**0.40**	0.31	0.34	0.36	0.29	0	0.28	0.38
Pza Azul	0.36	0.29	0.28	0.23	0.25	0.28	0	0.38
Sirena	0.33	0.29	0.30	0.35	0.27	0.38	0.28	0

Punta Naranjo was the other site that shared fewer species with Canto Federico and Coral Garden 0.40. The species with the lowest replacement were *A. coeruleus*, *C. rostrata*, *C. ruber*, *C. ocellatus*, *C. personatus*, *G. loreto*, *H. bivittatus*, *H. adscensionis*, *H. gummigutta*, *H. nigricans*, *L. apodus*, *L. mahogoni*, *M. martinicus*, *P. arcuatus*, and *P. maculatus*. The places that presented a higher degree of species replacement were Canto Azul, with Canto Pionero and La Llanita, sharing 29 species with abundance between one to 813 individuals 100 m^2 (Tabs. 2a and 2b).

Gamma diversity. A value of 87.93% was obtained in this research for the community complex.

Ichthyologic similarity (Fig. 8). The analysis of the similarity between the studied sites regarding the densities of the ichthyologic species allowed to establish four groups. The first made up of Laberinto and less similarity 18%. The second group with Canto Federico and La Llanita, with 74% similarity. The third structured with the highest number of sites and similarities above 80%. The fourth group constituted by Canto Azul and Canto Izzi 82%, Cueva 1 and Acuario with 84% (Fig. 6). The obtained cophenetic correlation was 92%.

The statistical comparison between the four groups established in this research analysis of similarity allowed obtaining a value of the level of significance p = 0.95, and a strength of the factors on the samples R = 0.02, with no statistical differences between the four groups. Similar results were obtained in independent analysis between each of the groups.

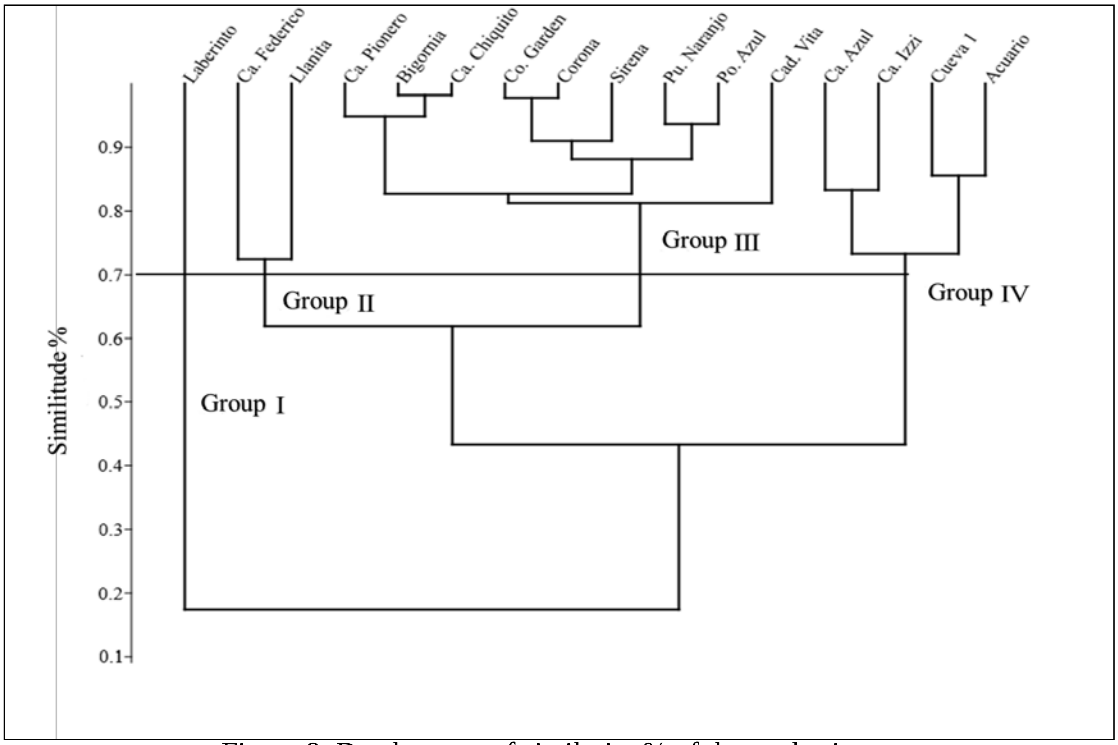

Figure 8: Dendrogram of similarity % of the study sites from the density of species for 100 m^2, Cophenetic correlation = 0.92.

The species that contributed the most to 80% dissimilarity were *C. parrae* 35.11%, *C. cyanea* 16.46%, *T. bifasciatum* 7.22%, *A. virginicus* 4.49%, *H. carbonarium* 2.90%, *S. taeniopterus* 2.87%, *O. chrysurus* 2.76%, *H. flavolineatum* 2.57%, *C. personatus* 2.53%, *H. aurolineatum* 2.50%. The roughness of the bottom averaged 21.9 cm, with the highest value in Canto Pionero (41.9 cm), and the lowest in Canto Federico (8.5 cm).

The Guardalavaca Holguín coral reef displays a richness of species with an average value of 37.56 species. The average abundances of herbivorous fish (parrots and barbers), and carnivores (snappers, groupers, and grunts) were extremely low (25 and seven individuals in 100 m^2, respectively (Tabs. 2a and 2b). The general equity in all the studied sites is poor with values between 0.36 and 0.76. Dominance presented values between 0.10 and 0.48. An average Fisher's alpha diversity of 8.24 was obtained. These results allow to infer a poor state of conservation of the fish communities that inhabit this coastal sector.

These environments are characterized by a higher habitat heterogeneity with the dominance of coral species *Agaricia agaricites* 38.7 ind./10 m^2, *Millepora alcicornis* 27.3 ind./10 m^2, *Siderastrea siderea* 25.8 ind./10 m^2, and *Stephanocoenia intercepta* 27.3 ind./10 m^2 (Busutil et al., 2015). The families Scaridae and Haemulidae were those that contributed in a greater number of species in both sampling sites, highlighting the *Scarus taeniopterus* species as the most abundant. Species richness is an ecological index that allows defining these sites with the best environmental conditions to support a greater number of taxa, among them greater availability of food and number of refuges stand out (Moreno, 2001).

Diversity is strongly linked to the concept of equity; more ecologically equitable fish communities are more diverse. Diversity has a minimum value when abundance is concentrated in a single species, while the others remain with a single individual, while also having a maximum value when all species are equally common (Moreno, 2001).

The Pielou equity index showed significant differences between the protected marine areas of Guanahacabibes and the Arrecifes Xcalak National Park ($F = 25.19$, $p < 0.001$). Presenting the marine area of Mexico higher values (0.75 ± 0.05) than the area of Cuba (0.62 ± 0.06) (Cobián-Rojas et al., 2018).

Results similar to those obtained in the Guanahacabibes area 0.62 were obtained in La Llanita and Canto Federico 0.69 respectively, Sirena 0.65 and Corona 0.61. Equity values close to those obtained in the Arrecifes Xcalak 0.75, National Park were determined in Cueva 1 and Poza Azul 0.76, Acuario 0.74, Canto Azul 0.73, and Punta Naranjo 0.73. The rest of the sites not mentioned presented lower values and statistical differences were obtained between the sites with the highest equity values and those with the lowest equity ($p = 0.0001$).

Ichthyologic similarity. The analysis of similarity between the different sampled sites in relation to the density of the fish, allowed to establish to Laberinto as the site with the least similarity. Bigornia, Canto Chiquito, Coral Garden and Corona as the sites with the greatest ichthyologic similarity. Sites that shared the highest species composition. No statistical differences were detected between the four groups established for 70% similarity. This result shows that the contribution of the densities between the sites was not significant. It obtained a value of 92% of the cophenetic correlation, allowing to establish a high correlation between the distances of the simulated matrix and the real one. This high correlation value allows us to infer a good representation of the individual distances between the sites located in the dendrogram of similarity (Gotelli and Ellison, 2004).

DISCUSSION

Species richness. The number of species is the most used measure-to-measure biodiversity in different ecosystems, since it reflects different aspects of ecology (Gaston, 1996; Moreno, 2000). The sites that presented the highest number of species were Cadena de Vita with 47 species distributed in 27 genera, 16 families and Canto Chiquito with 46 species distributed in 31 genera, 19 families. Species richness is an ecological index that allows for defining these sites with the best environmental conditions to support a greater number of taxa, among them greater availability of food and number of refuges stand out (Moreno, 2001).

Species richness is associated with local environmental factors and biotic interactions (Llorente and Morrone, 2001). Acuario, Corona and Coral Garden, were sites of less richness. In these latter sites, two commercial fishing bases (Guardalavaca and Puerto de Vita fishing base) carry out the fishing activity, both made up of approximately 60 vessels (Puga et al., 2018). Where different fishing gear is used, highlighting the nets of 100 m long and palanqrues of 100 hooks (Baisre, 2018). During the samplings, the occasional presence of people exercising the activity with pneumatic rifles in the work area was verified. This type of fishery is exerted selectively on the large predators and herbivores of the reef (Aguilar, 2005; Aguilar and González, 2007). Underwater fishermen report an average annual catch of approximately 995 kg in this coastal sector. Baisre (2018) found that 74% of the fishing sites in Cuba are overexploited and 5% have collapsed. The overfishing has been strongly correlated with ecological collapse in marine ecosystems, such as the absence of large predators, a characteristic present in the 16 monitored sites (Harborne et al., 2017).

Froese et al. (1998) suggested that the fishing exploitation of multispecies communities has an effect of change in the relative abundance in the different functional fish groups. He stated that the greatest expected effect is the succession of large groupers by small-sized and short-lived herbivorous species. In Cuba, there are more than 60 years of over-exploitation of fishing, establishing a significant decrease from the 90s in all fishing sites, with a reduction of 40% in 21 of the most commercially important species (Baisre, 2018). However, there are dissimilar factors that could be influencing the current condition of the sites with less richness, such as recruitment, climate change and the characteristics of the habitat, and food availability, among others (González and Aguilar, 2000). Another aspect that is considered is the selective fishing carried out in these sites on the ichthyologic communities.

Blaber (1985) found a relationship between the increase in fish richness and the variety of the habitat and the latitudinal changes, in Southeast Africa. Greater species richness may be associated with the high complexity of the relief, which provides abundant refuges and food for fish in Cuba (Cobián et al., 2018), as it has been confirmed by other authors in other regions (Núñez-Lara et al., 2005). Although, in this study the roughness of the bottom of the highest value was obtained in Canto Pionero site with 41.9 cm and a richness of 41 species, followed by Punta Naranjo 33 cm and a richness of 50 species and Acuario with 31 cm and 35 species. Indicating that greater roughness does not necessarily imply favourable ecological conditions in a coral reef. If it is considered that dead corals also increase the relief of the bottom (McField and Richards, 2007). A marked deterioration in the health status of Caribbean coral reefs has been observed, caused by anthropogenic stressors and climate change (Mumby et al., 2014; Graham et al., 2015)

The fish communities present in two marine protected areas, one in Guanahacabibes (Cuba) and the other in the Arrecifes Xcalak National Park (Mexico), these did not present statistical differences for the number of fish species. Presenting the Guanahacabibes area with a higher richness value (43 species) than the Arrecifes Xcalak National Park, (35 species) (Cobián-Rojas et al., 2018). Martínez-Iglesias and Serpa (1997), point out the significantly reduced abundance of fish present in Punta Francés, Isla de la Juventud, Cuba. The abundance of herbivorous fish in Cayo Levisa is also extremely low. These authors recorded 77 species of fish, the most abundant being *S. taeniopterus*, *C. cyanea*, *T. bifasciatum*, *S. partitus* and *G. loreto* (De la Guardia et al., 2005). Similar values obtained by Cobián-Rojas et al. (2018), were obtained in the different study stations of this work. Anthropogenic disturbance in the marine environment can influence the richness of ichthyologic species, being considered as the stress that excludes species at high trophic levels and does not prevent competitive exclusion by superior competitors (Paine, 1966; Huston, 1979; Connell, 1983).

Ichthyologic equity. Equity refers to the equitability in the abundances of the different species; and it is typically evaluated taking into account the number of dominant species in relation to the number of rare or not common species (Magurran, 2004; Moreno et al., 2011). The more species there are in a site, as well as the more homogeneous their distribution, the greater its diversity. The highest equitabilities were obtained in Cueva 1, Poza Azul, Acuario, Canto Azul and Punta Naranjo. Communities with greater equity indicate that they present are stable between the actions of the local biota and abiotic elements, competition, predation and immigration to other locations (Sonco, 2013). The species that most contributed to this ecological index in the aforementioned sites were: *A. bahianus*, *A. coeruleus*, *C. fulva*, *C. cyanea*, *H. garnoti*, *H. tricolor*, *S. taeniopterus*, *S. aurofrenatum*, and *S. partitus*. The abundances of these species were extremely low. This result may be indicating that there is a balanced pressure from legal and poaching at sites with close values of the equity index. This result is indicating that there is a balanced pressure of legal and poaching in sites with close values of the equity index (Cobián-Rojas et al., 2018).

Ichthyologic dominance. This index is inverse to the concept of community equity, since it takes into account the most important species without considering the rest of the species, being less sensitive to the richness of the species (Krebs, 1996; Magurran, 2004). Dominance is strongly influenced by the importance of the most dominant or common species (Magurran, 1988; Moreno, 2001), therefore they are more sensitive to changes in equitability (Feinsinger, 2003). The species that most influenced the sites of greatest dominance were *C. cyanea* and *C. parrae*. This last species was also the most abundant in the Guanahacabibes National Park (Cobián-Rojas et al., 2018). Bigornia and Canto Chiquito were the sites with the highest dominance, due to the fact that they are located on the reef slope (wall edge). This habitat favors a high dominance of a few species (*C. parrae, C. cyanea*, and *S. partitus*), which makes the equity lower and, therefore, the diversity index as well (Cobián-Rojas et al., 2018). The same behavior was observed in the reef slope of the Bahía de Cochinos (Cuba) (Chevalier and Cárdenas, 2006).

These two species present high densities in different dive sites in Cuba, such as in the coral reefs of María la Gorda, Guanahacabibes National Park (Cobián and Chevalier, 2009), registering densities for both species of 84.79 and 109.3 ind./100 m^2. Values lower than those obtained in this study for Bigornia, Cadena de Vita, Canto Chiquito, Canto Pionero, Coral Garden, Corona, Llanita, and Poza Azul (Tab. 2).

Fisher's alpha diversity. Punta Naranjo and Cueva 1 were the sites with the highest Fisher alpha diversity. They are the sites with the highest number of species and the highest densities. Presenting statistical differences with the places of less diversity. Highlighting the species *C. parrae*, *C. cyanea*, *S. taeniopterus*, and *S. aurofrenatum* with the highest abundances. Species diversity is an important indicator in the study of community ecology and conservation biology. A direct relationship has been established between alpha diversity and the functioning of ecosystems, such as productivity and stability (Maclaurin and Sterelny, 2008). Analysing this ecological index, Punta Naranjo and Cueva 1 constitute the most conserved sites in terms of ichthyologic communities. Bigornia, Coral Garden, Canto Pionero, and Corona places with less diversity. Indicating that the ichthyologic communities that inhabit these places have a poor state of conservation. The diversity is a characteristic that can be measured in marine ecosystems, such as productivity, density, and biomass (Alcolado, 1998). The diversity index reflects the complexity and structure of the system under study (Rodríguez-Zaragoza et al., 2011). The sites with low diversity are the product of fishing in this area, being more intense in the months of September to December, these sites are more accessible to fishermen (Baisre, 2018). Areas in Cuba exposed to intensive fishing and pollution, such as those along the Northwest coast, exhibit reduced coral density and ichthyology diversity (Duran et al., 2018).

Marine ecosystems with greater diversity will have better functioning and resilience (Hughes et al., 2003). The main causes of the loss of diversity are habitat destruction, overexploitation, pollution, climate change, and invasive species (Gutiérrez, 2006; Santos and Tellería, 2006; Capote et al., 2012). In the case of invasive species, the ichthyologic communities that inhabit these sites have been strongly affected by the presence of the lionfish (*Pterois volitans*), a generalist predator (Reynaldo et al., 2019). Other possible causes of the low fish diversity in the studied sites and the lower densities in the fish communities in the tourism sector of Holguín could be strongly influenced by the tourism and navigation activities themselves (Esslemont, 1999; Rouphael and Inglis, 2000; Zakai and Chadwick-Furman, 2002). As well as legal and illegal extractive and fishing activities (Padilla, 2000; Pikitch et al., 2004). These factors generate a pattern of chronic and constant stress that does not allow the recovery of fish communities (Buddemeier et al., 2004).

Close relationships have been determined between Fisher’s alpha diversity and latitude, climate, biological productivity, habitat heterogeneity, habitat complexity, disturbance, and geographic distances (Fischer, 1960, 1961; Pianka, 1966; Stehli et al., 1969; Brown and Gibson, 1983; Stevens, 1989; Ricklefs, 1990). The theory of environmental heterogeneity supports the idea that heterogeneous environments allow them to be colonized by a greater number of species, thereby increasing diversity (Badii and Landeros, 2007). The fishing constitutes the fundamental factor of the reduced ecological diversity of the ichthyological communities in the Guardalavaca reef, Holguín. Overfishing is one of the interventions of man that most alter the diversity of fish in Caribbean coral reefs, by removing herbivorous and carnivorous fish (Bellwood et al., 2004).

In Punta Frances marine park in Cuba, a reduction in the diversity in the ichthyologic communities was obtained as a result of illegal and commercial fishing. Reducing mainly the predatory families, Lutjanidae and Serranidae, as well as the species of the genus *Mycteroperca* (Angulo et al., 2007). Individuals of *S. coelestinus*, and *S. guacamaia*, important grazers of macroalgae, were present in Northwest Cuba up until the 1970 (Aguilar and Gonzalez-Sanson, 2007), species not recorded in this study. But they have been targeted by fishers in recent decades. Their current scarcity has put the region at risk of remaining in a coral-depleted alternative stable state (Steneck et al., 2014).

Abundant fishing areas in the Caribbean Sea are overexploited, including Cuba. These practices have changed the structure of fish communities of Caribbean coral reefs, reducing the abundance of predatory fishes (Valdivia et al., 2017). It is estimates that about 74% of Cuban fisheries are overexploited, 20% are fully exploited, and 5% have collapsed (Baisre, 2018). Groupers and snappers, which aggregate on a few, predictable spawning sites, are especially prone to uncontrolled fishing (Claro et al., 2009). Commercial catches of the Nassau grouper, *E. striatus*, have declined by 98% (Jones et al., 2004; Baisre, 2018).

Beta (β) diversity. Beta diversity is a measure of the change of species between different types of communities or habitats; as such, it corresponds to the spatial contiguity of different communities or habitats (Magurran, 2004). Halffter et al. (2005), defines Beta diversity as the degree of change or replacement in the composition of species between different communities of a landscape. In the present study, the communities that presented a greater replacement of species had a greater geographic distribution; Canto Azul is located from Canto Pionero at a distance of 16 km and from La Llanita at 18 km. This result allows inducing that despite being geographically, remote communities show high ecological similarities. Acuario was the site that had the least replacement of species with the Bigornia, Cadena de Vita, Canto Chiquito, Laberinto and Punta Naranjo sites. Like Canto Azul with Coral Garden. In addition to Punta Naranjo with Canto Federico and Coral Garden.

There are species that share the same natural resource between different sites and others that interact negatively with other species to obtain this limited resource. This resource can be food or shelter, modifying the structure, dynamics and productivity of the communities (Badii and Landeros, 2007). Fish communities that share a greater number of species are susceptible to interspecific competition. Competition between species is the driving force in the structure of communities, involving as a factor increasing levels of diversity in a given area (Badii and Landeros, 2007). The increase in temperature has an obvious direct effect on the displacement of the geographical limits of many ichthyological species (Southward and Boalch, 1994; Southward et al., 1995; Alcock, 2003). During this research sampling activities, elevated temperatures between 30 and 32°C were obtained. There is an increase in these temperatures in the last five years (INSMET, 2020). This is a possible cause of the replacement of the species between the different sites studied.

Gamma diversity. The gamma diversity is the number of species in the set of sites or communities that make up a landscape (Forman and Gordon, 1986). Whittaker (1972) defined it as the species richness of a set of communities that make up a landscape, resulting from both alpha and beta diversities. The result obtained in this research allows us to establish that alpha diversity comprises 42.71% and beta diversity 57.29% of the gamma diversity of the studied marine ichthyologic communities. All communities are structured mainly at the ecological level by the degree of differentiation between them or the degree of replacement of species through environmental gradients (Moreno, 2001). In this way, we can define that those communities with a greater replacement of species are the ones that should be more conserved, being Canto Azul, Canto Pionero, and La Llanita.

The fish species that most influenced the dissimilarity between Laberinto and the different sites were: *C. parrae*, *C. cyanea*, *T. bifasciatum*, *A. virginicus*, *H. carbonarium*, *S. taeniopterus*, *O. chrysurus*, *H. flavolineatum*, *C. personatus*, and *H. aurolineatum*. The species that contributed the most to group III similarity with the highest number of sites were: *A. bahianus, A. coeruleus, C. fulva, C. capistratus, C. cyanea, C. parrae, H. flavolineatum, H. garnoti, H. tricolor, S. iserti, S. taeniopterus, S. aurofrenatum, S. viride*, and *T. bifasciatum*. These species are specialized herbivores that constitute key elements in the structure and composition of fish communities in coral reefs; controllers of the overgrowth of algae on the coral reef (Williams and Polunin, 2001). The group IV made up of four sites had a greater contribution of the similarity of the species mentioned above in addition to *C. cruentata, H. plumieri, H. rufus, L. apodus,* and *S. partitus*.

Key fish in the control and growth of vegetation cover on the seabed (Williams and Polunin, 2001). The structure of ichthyologic communities includes ecological interactions that produce patterns (spatial, temporal, cyclical, and ordered) of distribution and abundance (Kikkawa, 1986). The number of interconnections in a community depends mainly on the interacting species. Among these interconnections, the interspecific competition, the trophic, and symbiotic interrelationship nested in trophic networks stand out. Increasing the complexity increases the stability of the community. The stability of fish communities depends on four principal components, which are the magnitude, frequency, elasticity (resilience), and the persistence of the species (Badii and Landeros, 2007).

In the dive sites of Holguín, Cuba, the greatest richness of ichthyologic species was obtained in Canto Izzi. The fish community with the highest equitableness and alpha Fisher diversity was recorded in Cueva 1, presenting a greater Bigornia ecological dominance. The sites with the highest species replacement were Canto Azul with Canto Pionero and La Llanita. The set of communities in these sites is structured mainly by the replacement of species. No statistical differences were found with respect to the density of the species between the different sampling stations.

CONCLUSIONS

In the Holguín reef, the ichthyologic communities have low species richness, equitableness and alpha Fisher diversity. We speculate that this difference could be related to commercial and illegal overexploitation of fishing in the coral reef, however, there is no direct, empirical evidence to support this assertion.

The greatest richness of ichthyologic species was obtained in Canto Izzi (47) area. The fish community with the highest equitableness and alpha Fisher diversity was recorded in Cueva 1 (11) area, presenting a greater Bigornia ecological dominance (0.48).

The results suggest the poor state of conservation of the fish communities present in the Guardalavaca reef, Holguín, Cuba.

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ON A RECENT PIONEERING TAXONOMIC STUDY OF THE FISHES FROM RIVERS DIYUNG, VOMVADUNG, KHUALZANGVADUNG, TUIKOI AND MAHUR IN DIMA HASAO DISTRICT OF ASSAM (INDIA)

Devashish KAR *, c.a and *Dimos KHYNRIAM* **

* Conservation Forum, Silchar, Assam, India, IN-788005; formerly Assam University, Department of Life Science, Silchar, Assam, India, IN-788011, devashishkar@yahoo.com, corresponding author
** Zoological Survey of India, North Eastern Regional Centre, Risa Colony, Fruit Garden, Shillong, India, IN-793003, dkhyn@rediffmail.com

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ABSTRACT

Ichthyofauna surveys in Diyung, Vomvadung, Khualzangvadung, Tuikoi, and Mahur rivers under Dima Hasao District of Assam resulted in the first report of 21 species of fish belonging to 19 genera, eight families, and four orders. These include Cypriniformes, Siluriformes, Synbranchiformes, and Perciformes. The species composition is highest in Vomvadung River with 11 species, followed by Diyung with eight species, Khualzangvadung with six species, Mohur with three species, and Tuikoi with two species. The conservation status of *Systomus clavatus*, *Tor tor*, *Neolissochilus hexagonolepis*, *Neolissochilus hexastichus* is near threatened, and *Pterocryptis barakensis* is endangered.

RÉSUMÉ: Sur une etude taxonomique récente des poissons des rivières Diyung, Vomvadung, Khualzangvadung, Tuikoi et Mahur dans le district de Dima Hasao à Assam (Inde).

L'étude de l'ichtyofaune dans les rivières Diyung, Vomvadung, Khualzangvadung, Tuikoi et Mahur sous le district de Dima Hasao de l'Assam a abouti au premier rapport de 21 espèces de poisons appartenant à 19 genres, huit familles et quatre ordres. Ceux-ci incluent les ypriniformes, les iluriformes, les Synbranchiformes et les Perciformes. La composition en espèces est la plus élevée dans la rivière Vomvadung avec 11 espèces suivies par la rivière Diyung avec huit espèces, Khualzangvadung avec six espèces, Mohur avec trois espèces et Tuikoi avec deux espèces. L'état de conservation de *Systomus clavatus, Tor tor, Neolissochilus hexagonolepis*, *Neolissochilus hexastichus* est presque menacé et *Pterocryptis barakensis* est en danger.

REZUMAT: Analiza unui studiu taxonomic recent inovator al peştilor din râurile Diyung, Vomvadung, Khualzangvadung, Tuikoi și Mahur din districtul Hasao, Assam (India).

Sondajul ihtiofaunei din râurile Diyung, Vomvadung, Khualzangvadung, Tuikoi și Mahur din districtul Hasao, provincia Assam a avut ca rezultat raportarea în premieră a 21 de specii de pești, încadrate în 19 genuri, opt familii și patru ordine. Acestea includ Cipriniforme, Siluriforme, Synbranchiforme și Perciforme. Cea mai bogată componență a speciilor se află pe râul Vomvadung, cu 11 specii, urmat de râul Diyung cu opt, Khualzangvadung cu şase, Mahur cu trei și Tuikoi cu două. Statutul de conservare al speciilor *Systomus clavatus*, *Tor tor*, *Neolissochilus hexagonolepis* și *Neolissochilus hexastichus* este aproape ameninţat, iar cel al lui *Pterocryptis barakensis* este ameninţat.

INTRODUCTION

The aquatic biodiversity is under pressure due to human-induced impacts, including effects on fish and their habitats (Adom, 2018; Shao et al., 2019; Kar, 2000; Bănăduc et al., 2020; Lacerda et al., 2020), studies regarding fish fauna are needed.

India is one of the mega biodiversity countries in the World (Jayaram, 2003, 2010). Out of 2,500 species of fishes in India, 930 are freshwater (FW) inhabitants, and 1,570 are marine (Kar, 2003, 2007, 2013; Jayaram, 2010). This bewildering ichthyodiversity of this region has been attracting many ichthyologists from different regions of the world.

Concomitantly, the North-Eastern (NE) region of India has been identified as a "Hotspot" for Biodiversity by the World Conservation Monitoring Centre (WCMC, 1998). The hills and the undulating valleys of this area give rise to numerous torrential hill streams, which lead to big rivers and finally become part of the Ganga-Brahmaputra-Barak-Chindwin-Kolodyne-Gomati-Meghna system (Kar, 2000, 2007, 2013).

The fish fauna of the North-East (NE) India mainly features elements of the Indo-Gangetic region; and partly of the Myanmarese and South-Chinese regions (Yadava and Chandra, 1994). There have been a significant number of works on the fish and fisheries. Ghosh and Lipton (1982) had reported 172 species. Sen (1985) reported 187 species from Assam and its environs. Sinha (1994) had compiled a list of 230 species of fishes from NE India. Nevertheless, Nath and Dey (1997) recorded 131 species of fishes from the drainages in Arunachal Pradesh alone. Sen (2000) comprehensively compiled a list of 267 species of fishes from NE India. Further, according to Sen (2000), of the 806 species of fishes inhabiting India's freshwaters (Talwar and Jhingran, 1991), the NE region of India is represented by 267 species belonging to 114 genera under 38 families and ten orders. It is 33.13% of the total Indian FW fishes. Further, of the 267 species, Cypriniformes dominates with 145 species, followed by Siluriformes (72), Perciformes (31), Clupeiformes (seven), Anguilliformes (three), Cyprinodontiformes (three), Osteoglossiformes (two), Synbranchiformes (two), Syngnathiformes (one) and Tetraodontiformes (one). Kar (2003) reported 133 species of fishes through a pilot survey conducted in 19 rivers spread in Barak drainage (Assam), Mizoram, and Tripura. Kar (2005) further reported the occurrence of 103 species of fishes through an extensive survey conducted in six principal rivers in Barak Valley (Assam), Mizoram, and Tripura. Kar (2007) and Sen (2007) have carried out a detailed study on fishes' biodiversity in North-East India with particular reference to Barak drainage, Mizoram, and Tripura.

The tropical Asian ichthyofauna constitutes a substantial part of the total lotic fish community. The Indian Peninsula supports 930 species of native FW fishes, which belong to 87 families (Kottelat, 1989; Kar and Sen, 2007; Jayaram, 2009). Several of tropical Asian FW fish share the African riverine ecosystems, both regarding the family and the generic level. Cyprinids, certain Siluriform catfishes, Channids, Mastacembelids, and Notopterids, are shared between the two regions. At the generic level, *Anabas, Clarias, Garra, Labeo*, and *Mastacembelus* occur in both African and Asian rivers. Tilapia, which have been introduced into India from Africa, have become widespread all over southern Asia. They have also replaced the native population in some places due to their dominance. There is a large-scale abundance of Cyprinids and Balitorids in Asia, in contrast to the predominance of Characids and Cichlids in Africa.

Incidentally, research on the ecology of the tropical fish communities is limited (Dudgeon, 1995). Further, there have been studies on fish diets and resource partitioning in specific Sri Lankan hill streams (Wikramanayake and Moyle, 1989). Niche' segregation is dependent on seasonality, diet, and habitat utilization, as was revealed from their studies. Also, there are morphological segregation and specialization in these fish communities.

MATERIAL AND METHODS

Fish samples were collected through experimental fishing using cast nets (diameter 3.7 m – 1.0 m), gill nets (vertical height 1.0 m – 1.5 m; length 100 m – 150 m), drag nets (vertical height 2.0 m), triangular scoop nets (vertical height 1.0 m) and a variety of traps. Camouflaging technique was also used to catch the fishes. Fishes have been preserved at first in concentrated formaldehyde in the field itself and then in 10% formalin. Fishes have been identified after standard literature (Day, 1873, 1885, 1878, 1889; Shaw and Shebbeare, 1937; Misra, 1959; Menon, 1974, 1999; Talwar and Jhingran, 1991; Jayaram, 1981, 1999, 2010) and fishbase.org (2019). The arrangement of classification, followed here, is that of Greenwood et a1. (1966) and Jayaram (1981, 1999, 2010).

RESULTS AND DISCUSSION

The ichthyological survey in rivers of Dima Hasao District resulted in a pioneering reports and the first record of eight fish species in river Diyung, 11 species in river Vomvadung, seven species in river Khualzangvadung, two species in river Tuikoi, and three species in river Mahur. These comprise the Cypriniformes – *Barilius bendelisis*, *Barilius barila*, *Devario aequipinnatus*, *Danio dangila*, *Pethia conchonius*, *Esomus danrica*, *Systomus clavatus*, *Tor tor*, *Neolissochilus hexagonolepis*, *Neolissochilus hexastichus*, *Garra lamta*, *Garra gotyla*, *Crossocheilus burmanicus*, *Psilorhynchus balitora*, and *Acanthocobitis botia*. Siluriformes – *Pterocryptis barakensis*, *Mystus bleekeri*, and *Olyra longicaudata*; Synbranchiformes – *Mastacembelus armatus*; and, Perciformes – *Badis badis* and *Channa gachua*.

Phylum: Chordata

Class: Actinopterygii
Order: Cypriniformes
Family: Cyprinidae

1. Genus *Barilius* Hamilton, 1822

Barilius Hamilton, 1822, Fish Ganges, 266, 384 (Type species: *Cyprinus barila* Hamilton).

Generic characters: Body moderately elongate and compressed. Abdomen rounded. Head sharply pointed; might have "peral organs" and tubercles. Mouth anterior or obliquely directed upwards. Eyes large and superior in the anterior half of the head, not visible from below the ventral surface. Upper jaw longer than lower. Characteristic muscular pads present in front of the bases of the pectoral fins. Dorsal fin inserted opposite the inter-space between pelvic and anal fins, nearer to caudal-fin base than to the tip of the snout. Caudal fin forked. Scales moderate. Lateral line concave. The body usually covered with vertical bands.

Material examined: two individuals, 05.11.2014, river Diyung, one individual, 31.01.2017, river Vomvadung, three individuals, 31.10.2014, river Khualzangvadung, two individuals, 14.11.2014, river Tuikoi and six individuals, 30.10.2014, River Mahur, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Anal fin short with seven-eight branched rays. Each scale usually has a black spot on it.

1.1. *Barilius bendelisis* (Hamilton, 1807)

Distribution: Throughout India, including Diyung, Vomvadung, Khualzangvadung, Tuikoi, and Mahur Rivers in Dima Hasao District, Assam (first report); Bangladesh, Bhutan, Myanmar, Nepal, Pakistan, Sri Lanka, and Thailand.

IUCN Status: Least Concern (LC).

Material examined: one individual, 14.11.2014, river Tuikoi, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Body with 14 or 15 short vertical bars extending from back to lateral line.

1.2. *Barilius barila* (Hamilton, 1822)

Distribution: Throughout North East India, river Tuikoi, Dima Hasao District, Assam (first report); Bihar, Delhi, Jammu and Kashmir, Madhya Pradesh, Mysore, Orrisa, Rajasthan, Uttar Pradesh, West Bengal. Bangladesh, Myanmar, and Nepal.

IUCN Status: Least Concern (LC).

2. Genus *Devario* Heckel, 1843

Devario Heckel, 1843, Ichthyologie (von Syrien) in von Russesa, Ereisen in Europa, Asia and Africa 1 (2): 1015 (Type species: *Cyprinus devario* Hamilton monotypy).

Generic characters: Mainly differentiated from *Danio* by a short and wide pre-maxillary ascending process, a short maxillary barbel, a “P stripe” extending to median caudal-fin rays. Infraorbital five or not or slightly reduced.

Material examined: one individual, 31.01.2017, river Vomvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: A lateral band along the sides of the body with thinner golden bands above and below it.

2.1. *Devario aequipinnatus* (McClelland, 1839)

Distribution: Throughout India, including river Vomvadung in Dima Hasao District in Assam (first report). Bangladesh, Myanmar, Tenasserim provinces, Nepal, Sri Lanka, and Thailand.

IUCN Status: Data Deficient (DD).

3. Genus *Danio* Hamilton, 1822

Danio Hamilton, 1822, Fishes of the Ganges, 321. 390 (Type species: *Cyprinus (Danio) dangila* Hamilton, by subsequent designation).

Generic characters: Body elongate, compressed, abdomen rounded, head moderate, blunt, snout obtuse, mouth anterior; cleft of mouth shallow and protractile, directed obliquely upwards. The end of the lower jaw in line with the dorsal profile and with a symphysial knob. Eyes large, centrally placed, not visible from below ventral surface. Lower jaw prominent with a knob at the symphysis. One or two pairs of barbels, rudimentary or none. Dorsal fin inserted opposite inter-space between anal and pelvic fins, nearer to caudal fin base than to tip of snout, with 10 or 19 rays. Anal fin with nine to 14 rays. Caudal fin emarginated, lunate, or forked. Scales moderate. Lateral line concave, complete with 32 to 42 scales. A stripe on the anal-fin rays. Two or more pigmented stripes on the caudal fin rays.

Material examined: one individual, 31.01.2017, River Vomvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Barbels very long. Anterior lateral bands break up into a network.

3.1. *Danio dangila* (Hamilton, 1822).

Distribution: Throughout Northeast India, including river Vomvadung in Dima Hasao District in Assam (first report); Bihar, West Bengal, Eastern Himalayas, Madhya Pradesh, Uttar Pradesh. Bangladesh, Bhutan, Nepal, and Myanmar.

IUCN Status: Least Concern (LC).

4. Genus *Esomus* Swainson, 1839

Esomus Swainson, 1839, Nat. Hist. Fishes, 2: 285 (Type-species, *Esomus vittatus* Swainson, by monotypy).

Generic characters: Body elongate and strongly compressed. Abdomen rounded. Head small, snout blunt. Mouth small, obliquely directed upwards without a symphysial knob. Two pairs of barbels; maxillary pair very long and extends up to anal fin. Dorsal fin inserted in the inter-space between pelvic and anal fins; nearer to the anal fin than to the pelvic fins, with six rays and no spine. Anal fin with five branched rays. Caudal fin forked. A lateral line may be absent or present with 27 to 34 scales.

Material examined: one individual, 31.01.2017, river Vomvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Body with a broad lateral band on sides, 27-30 scales in lateral series.

4.1. *Esomus danrica* (Hamilton, 1822)

Distribution: Throughout India, including river Vomvadung in Dima Hasao District in Assam (first report); Afghanistan, Bangladesh; Myanmar; Nepal; Pakistan, Sri Lanka, Thailand, and South Vietnam.

IUCN Status: Least Concern (LC).

5. Genus *Tor* Gray, 1834

Tor Gray, 1834, Illustrations of Indian Zoology, 2, Pl.96 (type-species, *Cyprinus tor* Hamilton, by monotypy).

Generic characters: Body elongate, moderately compressed. Abdomen rounded. Head small, broadly pointed. Snout angularly rounded, often with tubercles. Mouth inferior, usually arched. Eyes large; not visible from below ventral surface. Lips fleshy, continuous at angles of the mouth. Posterior lip with a median lobe and the post-labial groove continuous. Four barbels; one pair each of maxillary and rostral. Dorsal fin inserted above pelvic fins, with 12 to 13 rays and a strong, stout, smooth spine. Anal fin with seven or eight rays. The caudal fin deeply forked. Scales large. Lateral line complete with 22 to 37 scales.

Material examined: one individual, 05.11.2014, river Diyung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Head relatively smaller than body depth. Lateral line scales 22-27.

5.1. *Tor tor* (Hamilton, 1822)

Distribution: Throughout North east India including river Diyung in Dima Hasao District (first report); West Bengal, Bihar, Uttar Pradesh, Madhya Pradesh, Ganga, and Narmada river system, Eastern Himalayas. Bangladesh, Bhutan, China, Myanmar, Nepal, and Pakistan.

IUCN Status: Near Threatened (NT).

6. Genus *Neolissochilus* Rainboth, 1985

Neolissochilus Rainboth, 1985, Beaufortia 35 (3): 26 (Type species: *Barbus stracheyi* Day, 1871, by original designation).

Generic characters: Body deep anteriorly. Trunk and peduncle are smoothly tapering from anterior end to posterior end. Abdomen rounded. Head broad. Snout blunt. Mouth oblique,terminal to horizontal or inferior. Species with horizontal mouth often have the lobe of the snout overhanging the upper lip. Mouth smoothly rounded when the lower jaw is blunt. Eyes in the upper half of head; visible both from dorsal and ventral surfaces. Lips thick. Cheeks with many tubercles. Labial fold interrupted. Scales large and heavy.

Material examined: three individuals, 03.11.2014, 11 individuals, 05.11.2014, river Diyung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Mouth nearly truncate. Edge of lower jaw sharp.

6.1. *Neolissochilus hexagonolepis* (McClelland, 1839)

Distribution: Throughout North east India including river Diyung in Dima Hasao District in Assam (first report), Northern India, Darjeeling, and Eastern Himalaya. South and South-Eastern Asia.

IUCN Status: Near Threatened (NT).

Material examined: three individuals, 03.01.2014, river Diyung, one individual, 31.01.2017, river Vomvadung, one individual, 29.11.2014, river Mahur, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Mouth rounded smoothly, the edge of lower jaw blunt.

6.2. *Neolissochilus hexastichus* (McClelland, 1839)

Distribution: Arunachal Pradesh, Assam including rivers Vomvadung, Mahur, in Dima Hasao District in Assam (first report); Meghalaya, Mizoram, Nagaland, Rivers from Kashmir to Sikkim; Myanmar.

IUCN Status: Near Threatened (NT).

7. Genus *Pethia* Pethiyagoda, Meegaskumbura and Maduwage, 2012

Pethia, 2012, Pethiyagoda, Meegaskumbura and Maduwage: 80 (Type species: *Barbus nigrofasciatus* Gunther, 1868. Type by original designation).

Generic characters: Body short to moderately long, deep, and compressed. Abdomen rounded. Head short. Snout obtuse, conical, or pointed; sometimes, it may have tubercles. Mouth arched, anterior or inferior. The upper jaw may be protractile. Eyes moderate to large, dorsolateral; they are not visible from below the ventral surface. Lips thin, cover the jaws, without any horny covering. Jaws simple without any tubercle at the symphysis. Barbels four, two or may be absent. Dorsal fin short inserted nearly opposite to pelvic fins. Anal fin short. Caudal fin forked. Scales small, moderate, or large.

Material examined: two individuals, 31.01.2017, river Vomvadung, two individuals, 31.10.2014, river Khuolzangvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Barbel absent, lateral line incomplete, and caudal peduncle with a black blotch.

7.1. *Pethia conchonius* (Hamilton, 1822)

Distribution: Throughout North east India including river Vomvadung and river Khuolzangvadung in Dima Hasao District, Assam (first report); Bihar, Uttar Pradesh, Punjab, Maharashtra, Orissa, Eastern, and western Himalaya, Deccan, Afghanistan, Bangladesh, Myanmar, Nepal, Pakistan, and Sri Lanka.

IUCN Status: Least Concern (LC).

8. Genus *Systomus* McClelland, 1838

Systomus McClelland, 1838, 948 (Masc. *Systomus immaculatus* McClelland 1839. Type by subsequent designation).

Generic characters: Last simple dorsal-fin ray strongly serrated; soft dorsal fin rays usually eight. Presence of two pairs of well-developed barbels rostral and maxillary; some may have small maxillary barbels. Many of them have a longitudinal stripe extending the length of the body dorsal to the lateral line.

Material examined: one individual, 30.10.2014, river Mahur, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Presence of 40-42 lateral line scales and 14 pre-dorsal scales.

8.1. *Systomus clavatus* (McClelland, 1845)

Distribution: North east India including River Mahur, in Dima Hasao District in Assam (first report); Himalayan foothills. Bangladesh, Myanmar, Nepal.

IUCN Status: Near Threatened (NT).

9. Genus *Garra* Hamilton, 1822

Garra Hamilton, 1822, Fish Ganges: 343, 393 (Type species: *Cyprinus (Garra) lamta* by later designation).

Generic characters: Body short, sub-cylindrical. Ventral surface flat. Head little depressed anteriorly. Snout blunt; smooth or with pores; with or without a deep, transverse groove-like depression. Mouth inferior, transverse, semi-circular. Eyes small; in the posterior half of the head; lateral; not visible from below ventral surface. Lips thick and fleshy. Upper and lower lips are continuous without any lateral lobes. A proboscis may or may not be present. A suctorial disc of semi-cartilaginous pad present on the chin. Scales moderate.

Material examined: nine individuals, 03.11.2014, 13 individuals, 04.11.2014, river Diyung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species*:* A well-developed median proboscis and a transverse lobe at tip covered with spiny tubercles.

9.1. *Garra gotyla* (Gray, 1832)

Distribution: Throughout Northeast India, including River Diyung in Dima Hasao District, Assam (first report); The Himalayas, Chotanagpur plateau, and mountains of the Indian Peninsula area. Afghanistan, Bangladesh, Bhutan, Myanmar, Nepal, and Pakistan.

IUCN status*:* Least Concern (LC).

Material examined: 51 individuals, 03.11.2014, river Diyung, two individuals, 31.01.2017, river Vomvadung and two individuals, 31.10.2014, river Khualzangvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Snout rounded and smooth with a deep, transverse groove at the tip.

9.2. *Garra lamta* (Hamilton, 1822)

Distribution: Throughout North east India including rivers Diyung, Vomvadung, Khualzangvadung in Dima Hasao District, Assam (first report), Eastern Himalayas, and Western Ghats. Myanmar, and Nepal.

IUCN status: Least Concern (LC).

10. Genus *Crossocheilus* Kuhl and VanHasselt, 1823

Crossocheilus Kuhl van Hasselt, 1823, Algem-Konst. Letter-Bode, 2. P. 132 (Type species: *Crossocheilus oblongus* Kuhl and van Hasselt).

Generic characters: Body elongate with a comparatively smaller head. Mouth inferior, lower lip without a suctorial disc and margin of upper lip uniserial papillated. Barbels one or two pairs. Dorsal fin without spine branched dorsal-fin rays eight-nine. Paired fins are horizontally placed.

Material examined: one individual, 04.11.2014, river Diyung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Presence of a dorsal fin with nine branched rays. Absence of maxillary barbels.

10.1 *Crossocheilus burmanicus* Hora, 1936

Distribution: Arunachal Pradesh, Assam including river Diyung, in Dima Hasao District (first report); Manipur, Mizoram, Nagaland, Myanmar.

IUCN Status: Least Concern (LC).

Family: Psilorhynchidae

11. Genus *Psilorhynchus* McClelland, 1839

Psilorhynchus McClelland, 1839, Asiatic Researches, 19: 300, 428 (Type species: *Cyprinus sucatio* Hamilton, by subsequent designation).

Generic characters: Body spindle-shaped, arched dorsally and flattened ventrally; anteriorly depressed. Ventral surface markedly flattened. Snout flat obtusely pointed anteriorly. A shallow depression may be present on the cheek. Mouth small, inferior, transverse. Eyes large, dorsolateral in the posterior half of the head; not visible from below ventral surface. Lips entire, fleshy, continuous at the angle of mouth; reflected off from both the jaws; and, with glands and folds. Presence of a distinct lateral groove on either side passing along the sides of the snout. The upper jaw overhangs the mouth. Absence of barbels. Dorsal fins inserted ahead of pelvic fins with 10-12 rays. Pectoral fins simple with four-six rays. Anal fin short with seven rays. Caudal fin forked; upper lobe longer. Scales relatively large along the lateral line. Lateral line complete with 32-34 scales.

Material examined: one individual, 31.10.2014, river Khuolzangvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Pectoral fin with six-seven simple rays. Lateral line scales 30-34.

11.1. *Psilorhynchus balitora* (Hamilton, 1822)

Distribution: Throughout Northeast India, including: river Khuolzangvadung, Dima Hasao District, Assam (first report), North and West Bengal, Jamuna River; Bangladesh, Myanmar, and Nepal.

IUCN Status: Least Concern (LC).

Family: Nemacheilidae

12. Genus A*canthocobitis* Peters, 1861

Acanthocobitis Peters, 1861, 712 (Fem. *Acanthocobitis longipinnis* Peters 1861. Type by monotypy).

Generic characters: Body deeper than in most other nemacheilines, strongly compressed posteriorly. Head slightly compressed. Nostrils are placed close together. Snout blunt. Presence of a slight indication of an adipose keel. Upper lip covered by two or three rows of papillae. Lower lip broad on both the sides; interrupted in the middle and with numerous papillae. Dorsal fin with 10-18 branched rays. Edge of dorsal fin straight or slightly convex. Caudal fin slightly emarginated, linear or convex. Scales large all over the body. Lateral line complete; or, extend, at least up to under the dorsal fin. Presence of conspicuous black spot at the upper extremity of the caudal fin.

Material examined: one individual, 31.10.2014, river Khuolzangvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Dorsal fin with nine-11 branched rays. Lateral line complete.

12.1. *Acanthocobitis botia* (Hamilton, 1822)

Distribution: Throughout India except the Malabar coast and south of river Krishna. The first report in river Khuolzangvadung, Dima Hasao District, Assam. Bangladesh, Bhutan, China, Myanmar, Nepal, Pakistan, Sri Lanka, Thailand, and Yunan.

IUCN Status: Least Concern (LC)

13. Genus *Schistura* McClelland, 1839

Schistura McClelland, 1839, Asiat. Res., 19: 306, 439 (Type species: *Cobitis (Schistura) rupecula* McClelland by subsequent designation).

Generic characters: Body elongate of almost uniform depth; compressed posteriorly. Head either depressed or compressed. Snout usually blunt. The posterior nostril may be prolonged as a tube in some species. Lips with a few furrows; medially interrupted. Upper lip slightly furrowed; continuous or with a narrow median interruption. Lower lip interrupted in the middle; moderately furrowed. Processus dentiform of upper jaw present with a corresponding incision on the lower jaw in many species. Dorsal fin short; inserted ahead or opposite to pelvic fins; with seven-eight rays; rarely 10. An auxillary pelvic lobe may be present. Caudal fin slightly emarginated, forked, or truncate (never rounded); with a black bar. A general absence of adipose crest. If present, mostly in the posterior part of the body. Lateral line complete or incomplete. Presence of scales on the body generally. Usually, the presence of a characteristic color pattern.

Material examined: one individual, 31.10.2014, river Khuolzangvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Body with dark crossbars of varying forms, transverse bars at the caudal fin base.

13.1. *Schistura* sp.

Distribution: Throughout Asia, Europe, and some parts of Ethiopia. The first report in river Khuolzangvadung, Dima Hasao District, Assam.

Order: Siluriformes

Family: Bagridae

14. Genus *Mystus* Scopoli, 1777

Mystus Scopoli (ex Gronow), 1777, 451 (Masc. *Bagrus halepensis* Valenciennes 1840. Type by subsequent designation).

Generic characters: Body short or moderately elongated. Head short, flattened. Snout obtuse or rounded. Mouth sub-terminal, transverse. Eyes anteriorly situated, relatively large. Teeth are numerous. The upper surface of the head mostly smooth with one or two median longitudinal grooves of varying length. An occipital process long or short situated superficially and concealed under skin. Four pairs of barbels; one each of maxillary, nasal, and two of mandibular. Two dorsal fins; an anterior rayed dorsal with seven or eight rays and a spine; a posterior smooth low adipose fin of varying lengths. Pectoral fins with seven to 11 rays and a strong spine serrated along the inner edge. Pelvic fins with six rays. Anal fin with nine to 14 rays. Caudal fin forked, bilobed with unequal lobes; lobes may be rounded, pointed, or prolonged into filamentous extensions. Lateral line simple, complete.

Material examined: one example, 31.01.2017, river Vomvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Presence of three broad conspicuous dark bands separated by two pale lines on each side of the lateral line.

14.1. *Mystus bleekeri* (Day, 1877).

Distribution: North and North-East (NE) India including river Vomvadung in Dima Hasao District, Assam (first report), Mahanadi headwaters, Baroda, Godavari, Kerala, Maharashtra, Tamil Nadu. Bangladesh, Bhutan, Indonesia, Myanmar, Malaya, Nepal, Pakistan, Sumatra, and Thailand.

IUCN Status: Least Concern (LC).

15. Genus *Olyra* McClelland, 1842

Olyra McClelland, 1842, Calcutta J. nat. Hist. 2., p. 588 (Type species: *Olyra longicaudata* McClelland by subsequent designation).

Generic characters: Loach-like, elongate, small-sized fishes with body long, slender, flattened in front of pelvis and compressed behind. Nostrils widely separated; anterior tubular; nearer to snout than to eyes; posterior with nasal barbels. Mouth not wide, not fleshy. Labial groove widely interrupted. Barbels eight; generally well-developed. Gill openings very wide and extend as far as forward to the eyes. Gill membranes extensive and united with each other across the isthmus. Rayed dorsal fin short and without a spine. Adipose dorsal fin long, low, smooth; not confluent with either rayed dorsal or caudal. Paired fins inserted horizontally. Pectoral fins with a sharp serrated spine. Anal fin of moderate length; embedded in the skin; not confluent with caudal. Caudal fin long, lanceolate or forked; upper part better developed than lower. Lateral line present; may be indistinct.

Material examined: one individual, 31.01.2017, river Vomvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Presence of 18-23 anal fin rays. Upper lobe of caudal fin almost twice as long as lower.

15.1. *Olyra longicaudata* McClelland, 1842

Distribution: Arunachal Pradesh, Assam including river Vomvadung, Dima Hasao District, Assam (first report), Meghalaya, Mizoram, Nagaland, Tripura, and West Bengal. Myanmar.

IUCN Status: Least Concern (LC).

Family: Siluridae

16. Genus *Pterocryptis* Peters, 1861

Pterocryptis Peters, 1861, Monotst. Konig. Akad. Wissens. Berlin 7: 712 (Type species: *Pterocryptis gangelica*).

Generic characters: Body laterally compressed. Head broader than the body and somewhat flattened. Dorsal profile straight over the body, descending gently from dorsal fin to snout tip. Snout with rounded anterior profile and extends beyond gape. Anterior nostril is located anteromedial to maxillary barbel base, at the tip of the short wide tube, the posterior rim of which is higher than the anterior one. Posterior nostril located posteromedial to maxillary barbel base bordered by well-developed fleshy membranes. Eyes small. Gape of mouth horizontal, extending to or just beyond vertical to anterior margin of eyes. Two or three pairs of well-developed barbels, maxillary and mandibular; additional pairs of mandibular barbels may be present, when three pairs. Gill membranes free from each other and also from the isthmus. Rayed dorsal fin inserted just anterior to ventral at the level of pelvis, with four to five rays and no spine. Pectoral fins are extending to pelvic-fin base, spine serrated along the inner edge. Pelvic fins are reaching anal fin. Anal fin continuous with the caudal or separated by a narrow notch. Caudal fin emarginated, lobes may be unequal. Minute sensory pores may be present on the head.

Material examined: three individuals, 03.11.2014, river Diyung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Anal fin with 65-77 rays and confluent with caudal fin.

16.1 *Pterocryptus barakensis* Vishwanath and Sharma 2006

Distribution: Barak drainage, Assam including river Diyung in Dima Hasao District (first report), Manipur.

IUCN Status: Endangered (EN).

Order: Synbranchiformes

Family: Mastacembelidae

17. Genus *Mastacembelus* Scopoli, 1777

Mastocembelus Scopoli, 1777, Introd. Hist. Nat. 458 (Type species: *Ophidium mastacembelus* Banks and Solander, by subsequent monotypy).

Generic characters: Body eel-like elongated, compressed, long, pointed. Snout long, conical. Mouth inferior. Cleft narrow. Eyes small, superior; situated in the middle of the head; not visible from below the ventral surface. Rim of anterior nostrils with two finger-like fimbriae and two flaps. Pre-opercle generally spiny at its angle. A pre-orbital spine may be absent. Dorsal fin inserted above the middle of pectoral fins, with 32-40 detached, depressible spines and 67-90 rays. Anal fin with three spines and 46-90 rays. Caudal fin rounded. Dorsal and anal fins may or may not be confluent with the caudal. Presence of scales on the body.

Material examined: one individual, 31.10.2014, river Khuolzangvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Body with zig-zag lines and a row of spots along the soft dorsal fin base.

17.1. *Mastacembelus armatus* (Lacepede, 1800)

Distribution: Throughout India including river Khuolzangvadung, Dima Hasao District, Assam (first report). Bangladesh, Bhutan, Baluchistan, Cambodia, Indonesia, China, Hainan Island, Java, Malaysia, Myanmar, Nepal, Pakistan, Sri Lanka, Sumatra, Thailand, and Vietnam.

IUCN Status: Least Concern (LC).

Order: Perciformes

Family: Badidae

18. Genus *Badis* Bleeker, 1853

Badis Bleeker, 1853, Verh. Bat. Genootsch, 25: 106 (Type species, *Labrus buchanani* Bleeker = *Labrus badis* Hamilton-Buchanan, by autonomy).

Generic characters: Body moderately elongated, compressed. Abdomen rounded. Head usually large, compressed. Snout bluntly rounded. Mouth relatively small, slightly upturned, terminal, and slightly protractile; cleft does not extend to the eyes anterior margin. Eyes large; not visible from below ventral surface. Lips thin. Lower jaw longer. Opercle with one sharp spine. A single dorsal fin inserted above the base of pectoral fins; the spiny portion more extended than the soft portion; with 16-18 spines and seven-10 rays. Anal fin with three spines and six-eight rays. Caudal fin rounded. Scales ctenoid and are of moderate size. Lateral line interrupted or absent with 26-33 scales, when present. Some of the unique characters include black stripe along the middle of the dorsal fin; dark bars on the trunk; modified in adults, displayed as two narrow vertical lines; dark pigment on the caudal-fin base differentiated into three vertically-aligned blotches.

Material examined: one individual, 31.01.2017, river Vomvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Scales in lateral row 26-28. A row of dark spots along the base of the dorsal fin.

18.1. *Badis badis* (Hamilton, 1822).

Distribution: Throughout India, including river Vomvadung, Dima Hasao District, Assam, (first report). Bangladesh, Bhutan, Myanmar, Nepal, Pakistan, and Thailand.

IUCN Status: Least Concern (LC)

Family: Channidae

19. Genus *Channa* Scopoli, 1777

Channa Scopoli, 1777, Introd. Hist. Nat.: 459 (Type species, *Channa orientalis* Bloch and Schneider, by subsequent designation).

Generic characters: Body elongated, sub-cylindrical anteriorly. Abdomen rounded. Head large depressed with plate-like scales. Snout somewhat obtuse. Mouth reasonably large; opening moderate to wide; may extend to below orbit. Eyes lateral, moderate; in the anterior part of the head. The lower jaw protrudes beyond the upper. Gill openings wide. Membranes of two sides connected beneath the isthmus. Dorsal fin long; inserted almost above the pectoral fins with 29-55 rays and no spine. Anal fin long with 21 to 36 rays. Both dorsal and anal fins are free from caudal fin. Caudal fin rounded; scales small; cycloid or ctenoid; scales on the head are more extensive than those on the body. Lateral line abruptly curved or almost interrupted with 37 to 110 scales.

Material examined: two individuals, 31.01.2017, river Vomvadung, Dima Hasao District, Assam. Collectors: Kar and Party.

Key to species: Presence of 22 anal fin rays and 39-50 lateral line scales.

19.1 *Channa gachua* (Hamilton, 1822)

Distribution: Arunachal Pradesh, Assam including river Vomvadung, Dima Hasao District, Assam, (first report), Manipur, Nagaland, Maharashtra, and West Bengal. Afghanistan in the west to Indonesia through South and Central Asia.

IUCN Status: Least Concern (LC).

The river Diyung (25°27'36"N; 92°59'42"E; altitude 989 m a.s.l.), one of the most significant rivers in the region, originates from the Borail Hills in Dima Hasao District of Assam and after receiving several small streams, it joins the river Kopili of the Brahmaputra drainage. In river Diyung, eight species of fish were recorded, including the Cypriniformes – *Barilius bendelisis* (Hamilton, 1807), *Tor tor* (Hamilton, 1822), *Neolissochilus hexagonolepis* (McClelland, 1839), *Neolissochilus hexastichus* (McClelland, 1839), *Garra lamta* (Hamilton, 1822), *Garra gotyla* (Gray, 1832), *Crossocheilus burmanicus* Hora, 1936 and Siluriformes – *Pterocryptis barakensis* Vishwanath and Nabeshwar Sharma 2006. The river Vomvadung (25°34'72"N; 93°02'02") originates from the Diyungbra region in the hills of Dima Hasao District and ends in river Diyung. Eleven species of fish were recorded in river Vomvadung, which includes the Cypriniformes – *Neolissochilus hexastichus* (McClelland, 1839), *Devario aequipinnatus* (McClelland, 1839), *Danio dangila* (Hamilton, 1822), *Garra lamta* (Hamilton, 1822), *Pethia conchonius* (Hamilton, 1822), *Esomus danrica* (Hamilton, 1822), *Barilius bendelisis* (Hamilton, 1807), Siluriformes – *Mystus bleekeri* (Day, 1877), *Olyra longicaudata* (McClelland, 1842) and Perciformes – *Badis badis* (Hamilton, 1822) and *Channa gachua* (Hamilton, 1822). The river Khualzangvadung (25°34'64"N; 93°01'8"), ends in river Mahur after originating from the Nuomzang region in the hills of Dima Hasao District. In river Khualzangvadung, the six species recorded include the Cypriniformes – *Barilius bendelisis* (Hamilton, 1807), *Psilorhynchus balitora* (Hamilton, 1822), *Pethia conchonius* (Hamilton, 1822), *Acanthocobitis botia* (Hamilton, 1822), *Garra lamta* (Hamilton, 1822), *Schistura* sp. and the Synbranchiformes – *Mastacembelus armatus* (Lacepede, 1800). The River Tuikoi (25°34'07"; 93°01'08") originates from the Muollien region in the hills of Dima Hasao District and ends in river Jinam. Two species of Cypriniformes – *Barilius bendelisis* (Hamilton, 1807) and *Barilius barila* (Hamilton, 1822) were recorded from the Tuikoi River. The river Mahur (25°32'05"; 93°13'08") originates from the Pangmuol region in the hills of Dima Hasao District and ends in river Diyung. Three species of Cypriniformes – *Barilius bendelisis* (Hamilton, 1807), *Systomus clavatus* (McClelland, 1845), and *Neolissochilus hexastichus* (McClelland, 1839) were recorded from the river Mahur. The conservation status of *Systomus clavatus*, *Tor tor*, *Neolissochilus hexagonolepis*, *Neolissochilus hexastichus* are near threatened and *Pterocryptis barakensis* is endangered.

A glimpse into these studied rivers' habitat inventory parameters indicated that the rivers Diyung, Vomvadung, Khuolzangvadung, Tuikoi, and Mahur exhibited mostly "fall", "cascade" "riffle-pool" types of micro-habits in their upstream rheophilic stretches in the hills of Dima Hasao District of Assam. However, riffle-pools were also found in some of these rivers' mid-stream stretches at little lower altitudes. Accordingly, the substrata also did reveal variations according to the stretches of the rivers at different altitudes. The fall and cascade regions had portrayed mostly bedrock and boulders, while the riffle-pool regions mainly depicted cobbles and gravels. These micro-habitats and substrata are essential breeding grounds for these hill stream fishes. Unfortunately, their harvests by people for different purposes have been damaging the microhabitats causing irreparable losses to the fishes breeding grounds. The coveted fishes, not finding a substratum for anchorage (with suckers, etc.), are often lost to oblivion, being driven away by the hill stream' fast torrents, causing colossal loss to the biodiversity. Aquatic sanctuaries are to be declared in specific stretches of the rivers to protect the precious fishes.

The sampled fish have been taxonomically characterized based on their morphometric and meristic features (Tabs. 1a, 1b, 2a, 2b, 2c, 3a, 3b, 4 and 5).

Table 1a: Morphometrics and meristic counts of fishes from river Diyung.

Morphometrics	*Barilius bendelisis* (n = 2)	*Tor tor* (n = 1)	*Crossocheilus burmanicus* (n = 1)	*Neolissochilus hexastichus* (n = 3)
Weight (g)	11.42-20.57	19.01	26.14	9.19-31.43
Total Length (cm)	10.8-12.9	12.9	14.9	10.1-14.4
Standard Length (cm)	8.7-10.3	9.8	11.6	7.7-11.4
Head Length (cm)	2.2-2.6	3.2	2.5	2.2-3.2
Head Depth (cm)	1.6-1.8	1.9	1.7	1.7-2.6
Head Breadth (cm)	1.1-1.3	1.5	1.5	1.1-1.8
Pre-Orbital Length (cm)	0.7	1.2	1.2	0.7-1.0
Post-Orbital Length (cm)	1.2-1.3	2.0	1.8	1.2-1.7
Snout Length (cm)	0.7	1.2	1.2	0.7-1.0
Eye Diameter (cm)	0.5	0.7	0.6	0.5-0.7
Pre-Dorsal Length (cm)	4.9-5.9	5.6	5	4.0-5.8
Post-Dorsal Length (cm)	4.8-5.7	6.5	8.4	5.2-6.9
Length of Dorsal fin base (cm)	1.0-1.4	1.3	1.9	1.2-1.8
Height of Dorsal fin (cm)	1.5-2.2	2.3	2.9	1.9-2.6
Pre-Pectoral Length (cm)	2.2-2.8	2.9	2.3	2.0-3.0
Post-Pectoral Length (cm)	8.5-10.5	9.4	12	8.1-11.4
Length of Pectoral fin base (cm)	0.4-0.5	0.4	0.6	0.3-0.5
Height of Pectoral fin (cm)	1.7-2.2	2.1	2.2	1.7-2.3
Pre-Pelvic Length (cm)	4.3-5.2	5.4	5.5	4.0-5.8
Post-Pelvic Length (cm)	6.6-7.8	6.6	8.1	5.9-8.8
Length of Pelvic fin base (cm)	0.3-0.4	0.4	0.6	0.3-0.5
Height of Pelvic fin (cm)	1.2-1.7	1.7	2.1	1.5-2.2
Pre-Anal Length (cm)	6.4-7.5	7.7	8.9	5.8-8.2
Post- Anal Length (cm)	3.7-4.3	4.1	4.6	3.6-5.3
Length of Anal fin base (cm)	1.1-1.3	0.6	0.8	0.7-0.9
Height of Anal fin (cm)	1.3-1.6	1.6	2.0	1.5-2.3
Body Depth (cm)	2.1-2.6	2.7	2.0	2.0-3.5
Length of Caudal Peduncle (cm)	1.5-1.7	1.6	2	1.4-2.5
Height of Caudal Peduncle (cm)	0.8-1.0	1.1	1.3	0.9-1.4
No. of Pectoral Fin Rays	12	15	12	16
No. of Spines in Pectoral Fin Rays	0	0	0	0
No. of Pelvic Fin Rays	9	9	9	9
No. of Spines in Pelvic Fin Rays	0	0	0	0
No. of Anal Fin Rays	9	7	7	7
No. of Spines in Anal Fin Rays	0	0	0	0
No. of Dorsal Fin Rays	8-9	10	9	9
No. of Spines in Dorsal Fin Rays	0	1	0	1
No. of Caudal Fin Rays	19	20	19	19
Shape of Caudal fin	Forked	Forked	Forked	Forked
No. Lateral Line Scales	40-42	26	38	23-25
No. of Scales above Lateral Line	7.5	4.5	5.5	4.5
No. of Scales below Lateral Line	4.5-5.5	4.5	5.5	4.5
No. of Nasal Barbels	0	0	0	0
No. of Rostral Barbels	2	2	2	2
No. of Maxillary Barbels	2	2	0	2
No. of Mandibulary Barbels	0	0	0	0
Pre-Dorsal Scales	17-19	11	13	7-8

Table 1b: Morphometrics and meristic counts of fishes from river Diyung.

Morphmetrics	*Neolissochilus hexagonolepis* (n = 14)	*Garra gotyla* (n = 22)	*Garra lamta* (n = 51)	*Pterocryptis barakensis* (n = 3)
Weight (g)	8.26-143.03	11.79-46.3	3.83-15.36	42.03-47.36
Total Length (cm)	10.20-22.4	9.9-15.4	6.0-10.7	18.0-19.3
Standard Length (cm)	7.8-18.6	8.0-12.5	4.6-8.6	15.9-17.2
Head Length (cm)	2.3-4.9	1.9-2.9	1.2-2.0	2.7-2.9
Head Depth (cm)	1.4-4.9	1.4-2.2	0.8-1.5	1.8-2.5
Head Breadth (cm)	1.1-3.2	1.4-2.2	0.9-1.5	2.1-2.6
Pre-Orbital Length (cm)	0.6-1.7	0.9-1.6	0.6-1.1	0.9-1.2
Post-Orbital Length (cm)	1.2-2.5	1.4-2.1	0.8-1.5	1.2-1.6
Snout Length (cm)	0.6-1.7	0.9-1.6	06-1.1	0.9-1.2
Eye Diameter (cm)	0.5-0.8	0.4-0.6	0.3-0.4	0.3-0.4
Pre-Dorsal Length (cm)	4.0-9.1	3.4-5.7	2.2-3.7	4.0-4.3
Post-Dorsal Length (cm)	5.4-12.2	5.3-7.5	3.0-5.3	14.2-16.1
Length of Dorsal fin base (cm)	1.0-3.1	1.4-2.1	0.6-1.4	0.1-0.2
Height of Dorsal fin (cm)	1.7-4.1	1.7-3.0	1.0-1.9	0.4-0.5
Pre-Pectoral Length (cm)	1.9-4.4	1.7-2.6	1.0-2.0	2.7-2.8
Post-Pectoral Length (cm)	8.1-18.5	8.0-12.5	5.1-8.9	15-16.3
Length of Pectoral fin base (cm)	0.3-0.9	0.5-0.8	0.3-0.5	0.6-0.8
Height of Pectoral fin (cm)	1.6-4.0	1.4-2.3	1.1-1.6	1.5
Pre-Pelvic Length (cm)	4.0-9.2	3.8-6.5	2.4-4.1	5.1-5.2
Post-Pelvic Length (cm)	6.0-13.5	4.2-9.0	3.5-5.8	12.6-14.1
Length of Pelvic fin base (cm)	0.3-0.8	0.3-0.6	0.3-0.5	0.7
Height of Pelvic fin (cm)	1.6-3.1	1.4-2.4	0.9-1.5	1.0-1.1
Pre-Anal Length (cm)	6.0-13.4	5.9-9.7	3.7-6.5	5.9-6.3
Post- Anal Length (cm)	3.6-8.0	3.3-5.5	2.0-3.8	1.7-1.8
Length of Anal fin base (cm)	0.5-1.3	0.5-0.9	0.4-0.8	10.1-11.4
Height of Anal fin (cm)	1.3-3.2	1.0-2.5	0.9-1.6	0.4-1.1
Body Depth (cm)	1.9-4.6	1.5-3.0	0.9-1.9	2.8-3.1
Length of Caudal Peduncle (cm)	1.4-3.7	1.4-2.4	0.8-1.7	0.6
Height of Caudal Peduncle (cm)	0.8-2.1	0.9-1.6	0.6-1.2	1.2-1.3
No. of Pectoral Fin Rays	12-17	14-16	14	12-15
No. of Spines in Pectoral Fin Rays	0	1	0	1
No. of Pelvic Fin Rays	9	8-10	9	10
No. of Spines in Pelvic Fin Rays	0	0	0	0
No. of Anal Fin Rays	7	7	6	68-70
No. of Spines in Anal Fin Rays	0	0	0	0
No. of Dorsal Fin Rays	8-10	9-10	9	3-4
No. of Spines in Dorsal Fin Rays	1	0	0	0
No. of Caudal Fin Rays	17-20	19-20	18	17-18
Shape of Caudal fin	Forked	Forked	Forked	Round
No. Lateral Line Scales	26-30	30-35	31-34	0
No. of Scales above Lateral Line	3.5-4.5	4.5	3.5-4.5	0
No. of Scales below Lateral Line	3.5-4.5	4.5-5.5	5.5-6.5	0
No. of Nasal Barbels	0	0	0	0
No. of Rostral Barbels	2	2	2	0
No. of Maxillary Barbels	2	2	2	2
No. of Mandibulary Barbels	0	0	0	2
Pre-Dorsal Scales	9-12	8-13	9-12	0

Table 2a: Morphometrics and meristic counts of fishes from river Vomvadung.

Morphometrics	*Barilius bendelisis* (n = 1)	*Devario aequipinnatus* (n = 1)	*Danio dangila* (n = 1)	*Esomus danrica* (n = 1)
Weight (g)	22.85	4.83	4.34	1.01
Total Length (cm)	12.5	8.1	8.1	4.8
Standard Length (cm)	10.6	6	6.3	3.8
Head Length (cm)	2.6	1.5	1.4	0.9
Head Depth (cm)	2.3	1.3	1.2	0.7
Head Breadth (cm)	1.4	0.8	0.8	0.5
Pre-Orbital Length (cm)	0.8	0.5	0.5	0.3
Post-Orbital Length (cm)	13	0.9	0.9	0.6
Snout Length (cm)	0.8	0.5	0.5	0.3
Eye Diameter (cm)	0.5	0.4	0.4	0.3
Pre-Dorsal Length (cm)	6	3.6	0.37	2.5
Post-Dorsal Length (cm)	5.5	3.5	3.5	2.0
Length of Dorsal fin base (cm)	1.5	1.3	1.1	0.5
Height of Dorsal fin (cm)	2.4	1.4	1.3	0.8
Pre-Pectoral Length (cm)	3.2	1.5	1.4	1.0
Post-Pectoral Length (cm)	9.8	6.4	6.5	3.7
Length of Pectoral fin base (cm)	0.8	0.3	0.4	0.2
Height of Pectoral fin (cm)	2.1	1.4	1.5	1.1
Pre-Pelvic Length (cm)	5.4	3	3.1	2.0
Post-Pelvic Length (cm)	7.4	4.9	5	2.6
Length of Pelvic fin base (cm)	0.5	0.2	0.2	0.1
Height of Pelvic fin (cm)	1.9	1	1	0.8
Pre-Anal Length (cm)	7.8	4.2	4.4	2.8
Post- Anal Length (cm)	3.9	2.8	2.6	1.6
Length of Anal fin base (cm)	1.7	1.1	1.1	0.4
Height of Anal fin (cm)	1.4	1.2	1.2	0.7
Body Depth (cm)	2.8	1.7	1.6	0.8
Length of Caudal Peduncle (cm)	1.7	1	1.1	0.6
Height of Caudal Peduncle (cm)	1.2	0.7	0.7	0.4
No. of Pectoral Fin Rays	10	12	12	8
No. of Spines in Pectoral Fin Rays	0	0	0	0
No. of Pelvic Fin Rays	7	7	7	5
No. of Spines in Pelvic Fin Rays	0	0	0	0
No. of Anal Fin Rays	8	12	13	6
No. of Spines in Anal Fin Rays	0	0	0	0
No. of Dorsal Fin Rays	7	11	11	7
No. of Spines in Dorsal Fin Rays	0	0	0	0
No. of Caudal Fin Rays	16	19	19	12
Shape of Caudal fin	Forked	Forked	Forked	Forked
No. Lateral Line Scales	42	33	34	24
No. of Scales above Lateral Line	7.5	6.5	6.5	3.5
No. of Scales below Lateral Line	4.5	2.5	2.5	3.5
No. of Nasal Barbels	0	0	0	0
No. of Rostral Barbels	0	2	2	2
No. of Maxillary Barbels	2	2	2	2
No. of Mandibulary Barbels	0	0	0	0
Pre-Dorsal Scales	17	12	12	11

Table 2b: Morphometrics and meristic counts of fishes from river Vomvadung.

Morphometrics	*Neolissochilus hexastichus* (n = 1)	*Pethia conchonius* (n = 2)	*Garra lamta* (n = 2)	*Mystus bleekeri* (n = 1)
Weight (g)	11.55	3.27-5.14	12.85-17.99	14.48
Total Length (cm)	11.1	6.4-7.0	9.9-11.4	11.9
Standard Length (cm)	8.6	4.8-5.3	7.8-8.9	9.3
Head Length (cm)	2.2	1.3-1.4	2.0-2.3	2.4
Head Depth (cm)	1.6	1.2-1.4	1.4-1.5	1.7
Head Breadth (cm)	1.1	0.7-0.9	1.5-1.7	1.8
Pre-Orbital Length (cm)	0.7	0.3	0.9-1.1	1
Post-Orbital Length (cm)	1.2	0.7	1.3-1.5	1.5
Snout Length (cm)	0.7	0.3	0.9-1.1	1
Eye Diameter (cm)	0.5	0.4	0.4	0.4
Pre-Dorsal Length (cm)	4.3	2.5-2.7	3.6-4.4	3.6
Post-Dorsal Length (cm)	5.7	3.5-3.6	5.4-6.0	7.9
Length of Dorsal fin base (cm)	1.3	0.8-1.0	1.3-1.6	1.4
Height of Dorsal fin (cm)	2.4	1.1-1.2	1.9-2.4	2.1
Pre-Pectoral Length (cm)	2.1	1.3	1.7-2.0	2.2
Post-Pectoral Length (cm)	9.1	5.0-5.4	8.0-9.2	9.8
Length of Pectoral fin base (cm)	0.3	0.3	0.5-0.6	0.4
Height of Pectoral fin (cm)	1.8	1.1	1.6	1.7
Pre-Pelvic Length (cm)	4.4	2.4-2.5	4.1-4.7	4.5
Post-Pelvic Length (cm)	6.8	4.0-4.3	5.5-6.4	7.4
Length of Pelvic fin base (cm)	0.4	0.3	0.4	0.3
Height of Pelvic fin (cm)	1.6	1.0-1.1	1.5-1.6	1.6
Pre-Anal Length (cm)	6.8	3.5-4.0	5.8-6.9	6.4
Post- Anal Length (cm)	4.0	2.5	3.3-3.7	4.5
Length of Anal fin base (cm)	0.6	0.5-0.6	0.6-0.7	1
Height of Anal fin (cm)	1.6	0.8	1.5-1.7	1.8
Body Depth (cm)	1.9	1.7-2.0	1.8-2.0	2.1
Length of Caudal Peduncle (cm)	1.6	0.9-1.0	1.6-1.7	2
Height of Caudal Peduncle (cm)	1	0.7	1.1-1.3	1.1
No. of Pectoral Fin Rays	12	11	14	7
No. of Spines in Pectoral Fin Rays	0	0	0	1
No. of Pelvic Fin Rays	9	8	9	6
No. of Spines in Pelvic Fin Rays	0	0	0	0
No. of Anal Fin Rays	6	6	6	7
No. of Spines in Anal Fin Rays	0	0	0	
No. of Dorsal Fin Rays	9	8	9	7
No. of Spines in Dorsal Fin Rays	1	1	0	1
No. of Caudal Fin Rays	19	18	18-19	14
Shape of Caudal fin	Forked	Forked	Forked	Forked
No. Lateral Line Scales	28	23-24	34	0
No. of Scales above Lateral Line	3.5	4.5	3.5	0
No. of Scales below Lateral Line	3.5	5.5	5.5	0
No. of Nasal Barbels	0	0	0	2
No. of Rostral Barbels	2	0	2	0
No. of Maxillary Barbels	2	0	2	2
No. of Mandibulary Barbels	0	0	0	4
Pre-Dorsal Scales	8	7	9-10	0

Table 2c: Morphometrics and meristic counts of fishes from river Vomvadung.

Morphometrics	*Olyra longicaudata* (n = 1)	*Badis badis* (n = 1)	*Channa gachua* (n = 2)
Weight (g)	2.04	1.55	16.13-17.81
Total Length (cm)	8.2	4.7	12.1-12.3
Standard Length (cm)	7.1	3.7	9.8-10.3
Head Length (cm)	1.2	1.1	3.1-3.2
Head Depth (cm)	0.6	0.9	1.5-1.6
Head Breadth (cm)	0.9	0.6	2.0-2.1
Pre-Orbital Length (cm)	0.4	0.2	0.6-0.8
Post-Orbital Length (cm)	0.5	0.5	1.1-1.3
Snout Length (cm)	0.4	0.2	0.8
Eye Diameter (cm)	0.1	0.3	0.5
Pre-Dorsal Length (cm)	2.5	1.1	3.6-3.7
Post-Dorsal Length (cm)	5.2	1.4	2.5-3.0
Length of Dorsal fin base (cm)	0.7	2.3	5.1-5.7
Height of Dorsal fin (cm)	0.7	0.9	1.1-1.3
Pre-Pectoral Length (cm)	1.2	1.2	3.1-3.3
Post-Pectoral Length (cm)	7.0	3.5	9.1-9.3
Length of Pectoral fin base (cm)	0.2	0.2	0.5-0.6
Height of Pectoral fin (cm)	0.7	0.7	1.9-2.2
Pre-Pelvic Length (cm)	2.5	1.2	3.6-3.8
Post-Pelvic Length (cm)	5.6	3.3	5.7-9.1
Length of Pelvic fin base (cm)	0.2	0.2	0.2
Height of Pelvic fin (cm)	0.8	0.8	0.8-0.9
Pre-Anal Length (cm)	3.9	2.6	5.4-5.8
Post- Anal Length (cm)	2.2	1.6	3.4-3.5
Length of Anal fin base (cm)	2.3	0.7	3.3-3.9
Height of Anal fin (cm)	0.7	0.8	0.8-1.2
Body Depth (cm)	0.7	1.0	1.6-1.8
Length of Caudal Peduncle (cm)	1.1	0.7	1.2-1.5
Height of Caudal Peduncle (cm)	0.5	0.6	1.0-1.1
No. of Pectoral Fin Rays	6	10	11
No. of Spines in Pectoral Fin Rays	1		0
No. of Pelvic Fin Rays	7	6	6
No. of Spines in Pelvic Fin Rays			0
No. of Anal Fin Rays	13	6	32
No. of Spines in Anal Fin Rays		3	0
No. of Dorsal Fin Rays	5	16	37
No. of Spines in Dorsal Fin Rays		4	0
No. of Caudal Fin Rays	12	14	14
Shape of Caudal fin	Rounded	Rounded	Rounded
No. Lateral Line Scales	0	32	40-44
No. of Scales above Lateral Line	0	2.5	4.5
No. of Scales below Lateral Line	0	6.5	5.5
No. of Nasal Barbels	2	0	0
No. of Rostral Barbels	0	0	0
No. of Maxillary Barbels	2	0	0
No. of Mandibulary Barbels	4	0	0
Pre-Dorsal Scales	0	6	10

Table 3a: Morphometrics and meristic counts of fishes from river Khualzangvadung.

Morphometrics	*Barilius bendelisis* (n = 3)	*Pethia conchonius* (n = 2)	*Garra lamta* (n = 2)	*Psilorhync husbalitora* (n = 1)
Weight (g)	2.76-3.27	1.92-5.03	3.29-5.09	1.23
Total Length (cm)	6.4-6.8	5.2-6.7	6.4-7.7	5.1
Standard Length (cm)	5.0-5.4	3.9-5.0	4.9-5.8	4
Head Length (cm)	1.3-1.5	1.0-1.4	1.4-1.6	1
Head Depth (cm)	0.9-1.0	1.0-1.5	0.9-1.0	0.6
Head Breadth (cm)	0.6-0.8	0.6-0.8	1.1-1.2	0.7
Pre-Orbital Length (cm)	0.4	0.3-0.4	0.7-0.8	0.4
Post-Orbital Length (cm)	0.8	0.6-0.8	1	0.7
Snout Length (cm)	0.4	0.3-0.4	0.7-0.8	0.4
Eye Diameter (cm)	0.4	0.3-0.4	0.3	0.4
Pre-Dorsal Length (cm)	2.9-3.2	2.1-2.6	2.5-2.7	1.9
Post-Dorsal Length (cm)	2.8-3.1	2.4-3.3	3.0-3.8	2.5
Length of Dorsal fin base (cm)	0.5-0.6	1.1	0.9-1.1	0.5
Height of Dorsal fin (cm)	0.9-1.1	1.0-1.1	1.1-1.4	0.9
Pre-Pectoral Length (cm)	1.3-1.5	1.1-1.3	1.3-1.5	0.9
Post-Pectoral Length (cm)	5.0-5.5	4.0-5.2	4.9-6.2	4.2
Length of Pectoral fin base (cm)	0.3	0.2-0.3	0.4	0.4
Height of Pectoral fin (cm)	1.1-1.2	0.8-1.0	1.1-1.2	0.9
Pre-Pelvic Length (cm)	2.7-3.1	2.0-2.6	2.6-3.2	2.1
Post-Pelvic Length (cm)	3.6-4.2	3.1-4.0	3.4-4.3	3.8
Length of Pelvic fin base (cm)	0.2	0.2-0.3	0.3	0.2
Height of Pelvic fin (cm)	0.7-0.8	0.8-1.0	1.0-1.2	0.8
Pre-Anal Length (cm)	3.8-4.1	2.9-3.6	3.8-4.7	3.3
Post- Anal Length (cm)	2.1-2.4	1.9-2.3	2.0-2.6	1.5
Length of Anal fin base (cm)	0.5-0.6	0.2-0.3	0.4-0.5	0.2
Height of Anal fin (cm)	0.8	0.9-1.0	1.0-1.2	0.6
Body Depth (cm)	1.3-1.5	1.5-2.3	1.1-1.3	0.7
Length of Caudal Peduncle (cm)	0.9-1.1	0.9-1.0	1.0-1.1	0.5
Height of Caudal Peduncle (cm)	0.4-0.5	0.4-0.5	0.5-0.8	0.3
No. of Pectoral Fin Rays	12	12	13	13
No. of Spines in Pectoral Fin Rays	0	0	0	0
No. of Pelvic Fin Rays	8	8	9	8
No. of Spines in Pelvic Fin Rays	0	0	0	0
No. of Anal Fin Rays	9	6	6	5
No. of Spines in Anal Fin Rays	0	0	0	0
No. of Dorsal Fin Rays	8	8	9	8
No. of Spines in Dorsal Fin Rays	0	1	0	0
No. of Caudal Fin Rays	18	18	18	14
Shape of Caudal fin	Forked	Forked	Forked	Forked
No. Lateral Line Scales	37-40	23	29	35
No. of Scales above Lateral Line	7.5-8.5	4.5	3.5	3.5
No. of Scales below Lateral Line	4.5-5.5	4.5	4.5	3.5
No. of Nasal Barbels	0	0	0	0
No. of Rostral Barbels	2	0	2	0
No. of Maxillary Barbels	2	0	2	0
No. of Mandibulary Barbels	0	0	0	0
Pre-Dorsal Scales	16-18	9	9	10

Table 3b: Morphometrics and meristic counts of fishes from river Khualzangvadung.

Morphometrics	*Paracanthocobiti sbotia* (n = 1)	*Schistura* sp. (n = 1)	*Mastacembelusar matus* (n = 1)
Weight (g)	7.23	1.48	6.73
Total Length (cm)	9.3	5.9	13.2
Standard Length (cm)	3.6	4.8	12.5
Head Length (cm)	1.8	1.2	2.4
Head Depth (cm)	1	0.6	0.9
Head Breadth (cm)	1	0.7	0.6
Pre-Orbital Length (cm)	0.8	0.5	0.9
Post-Orbital Length (cm)	0.6	0.7	0.7
Snout Length (cm)	0.8	0.5	0.9
Eye Diameter (cm)	0.3	0.2	0.3
Pre-Dorsal Length (cm)	3.7	2.6	2.8
Post-Dorsal Length (cm)	4.4	2.7	0.8
Length of Dorsal fin base (cm)	1.2	0.8	10
Height of Dorsal fin (cm)	1.4	0.8	0.5
Pre-Pectoral Length (cm)	1.7	1.2	2.5
Post-Pectoral Length (cm)	7.5	4.7	10.5
Length of Pectoral fin base (cm)	0.4	0.2	0.4
Height of Pectoral fin (cm)	1.4	0.9	0.6
Pre-Pelvic Length (cm)	4	2.7	0
Post-Pelvic Length (cm)	5.2	3.2	0
Length of Pelvic fin base (cm)	0.3	0.2	0
Height of Pelvic fin (cm)	1.1	0.8	0
Pre-Anal Length (cm)	5.8	3.9	7.7
Post- Anal Length (cm)	2.9	1.7	0.7
Length of Anal fin base (cm)	0.6	0.4	0.3
Height of Anal fin (cm)	1.0	0.7	0.5
Body Depth (cm)	1.4	0.7	1.2
Length of Caudal Peduncle (cm)	1.4	0.8	0.2
Height of Caudal Peduncle (cm)	0.4	0.6	0.6
No. of Pectoral Fin Rays	13	10	15
No. of Spines in Pectoral Fin Rays	0	0	0
No. of Pelvic Fin Rays	7	8	0
No. of Spines in Pelvic Fin Rays	0	0	0
No. of Anal Fin Rays	5	6	60
No. of Spines in Anal Fin Rays	0	0	2
No. of Dorsal Fin Rays	11	9	73
No. of Spines in Dorsal Fin Rays	0	0	37
No. of Caudal Fin Rays	19	18	14
Shape of Caudal fin	Rounded	Forked	Rounded
No. Lateral Line Scales	160	95	275
No. of Scales above Lateral Line	15	13	10
No. of Scales below Lateral Line	19	14	15
No. of Nasal Barbels	4	4	0
No. of Rostral Barbels	0	0	0
No. of Maxillary Barbels	2	2	0
No. of Mandibulary Barbels	0	0	0
Pre-Dorsal Scales	48	38	19

Table 4: Morphometrics and meristic counts of fishes from river Tuikoi.

Morphometrics	*Barilius bendelisis* (n = 2)	*Barilius barila* (n = 1)
Weight (g)	13.07-13.10	17.36
Total Length (cm)	11.3	12.6
Standard Length (cm)	8.5	9.5
Head Length (cm)	2.4-2.5	2.8
Head Depth (cm)	1.8-1.9	2.1
Head Breadth (cm)	1.3-1.4	1.4
Pre-Orbital Length (cm)	0.8	0.9
Post-Orbital Length (cm)	1.3	1.6
Snout Length (cm)	0.8	0.9
Eye Diameter (cm)	0.5	0.7
Pre-Dorsal Length (cm)	4.0-4.3	4.7
Post-Dorsal Length (cm)	5.8-6.0	6.7
Length of Dorsal fin base (cm)	1.3	1.6
Height of Dorsal fin (cm)	2.3-2.4	2.6
Pre-Pectoral Length (cm)	2.3-2.4	2.5
Post-Pectoral Length (cm)	8.6-9.1	10
Length of Pectoral fin base (cm)	0.4	0.4
Height of Pectoral fin (cm)	1.9-2.1	2.2
Pre-Pelvic Length (cm)	4.5	4.9
Post-Pelvic Length (cm)	6.3-6.8	7.5
Length of Pelvic fin base (cm)	0.3	0.4
Height of Pelvic fin (cm)	1.8	1.9
Pre-Anal Length (cm)	6.6-6.7	7.4
Post- Anal Length (cm)	3.8-4.1	4.6
Length of Anal fin base (cm)	0.6-0.7	0.8
Height of Anal fin (cm)	1.7-1.8	2.0
Body Depth (cm)	2.3	2.5
Length of Caudal Peduncle (cm)	1.6	1.8
Height of Caudal Peduncle (cm)	0.9-1.0	1.2
No. of Pectoral Fin Rays	14	14
No. of Spines in Pectoral Fin Rays	0	0
No. of Pelvic Fin Rays	9	9
No. of Spines in Pelvic Fin Rays	0	0
No. of Anal Fin Rays	7	7
No. of Spines in Anal Fin Rays	0	0
No. of Dorsal Fin Rays	9	9
No. of Spines in Dorsal Fin Rays	1	1
No. of Caudal Fin Rays	20	20
Shape of Caudal fin	Forked	Forked
No. Lateral Line Scales	28-29	27
No. of Scales above Lateral Line	4.5	4.5
No. of Scales below Lateral Line	4.5	4.5
No. of Nasal Barbels	0	0
No. of Rostral Barbels	2	2
No. of Maxillary Barbels	2	2
No. of Mandibulary Barbels	0	0
Pre-Dorsal Scales	10-11	11

Table 5: Morphometrics and meristic counts of fishes from river Mahur.

Morphometrics	*Barilius bendelisis* (n = 6)	*Neolissochilus hexastichus* (n = 1)	*Systomus clavatus* (n = 1)
Weight (g)	5.89-16.32	3.99	11.87
Total Length (cm)	8.4-12.4	7.6	10.5
Standard Length (cm)	6.8-9.9	5.8	8.2
Head Length (cm)	1.8-2.4	1.7	2.1
Head Depth (cm)	1.2-2.0	1.2	1.8
Head Breadth (cm)	0.9-1.2	0.9	1.2
Pre-Orbital Length (cm)	0.5-0.8	0.4	0.7
Post-Orbital Length (cm)	0.9-1.2	1	1.2
Snout Length (cm)	0.5-0.8	0.4	0.7
Eye Diameter (cm)	0.4-0.5	0.5	0.5
Pre-Dorsal Length (cm)	3.9-5.8	2.9	3.9
Post-Dorsal Length (cm)	3.5-5.2	3.7	5.5
Length of Dorsal fin base (cm)	0.9-1.3	1.1	1.6
Height of Dorsal fin (cm)	1.4-2.3	1.7	2.4
Pre-Pectoral Length (cm)	1.7-2.8	1.6	2
Post-Pectoral Length (cm)	6.3-9.6	6	8
Length of Pectoral fin base (cm)	0.3-0.5	0.2	0.4
Height of Pectoral fin (cm)	1.5-2.1	1.3	2.0
Pre-Pelvic Length (cm)	3.4-5.1	3.0	4.1
Post-Pelvic Length (cm)	4.4-7.1	4.4	5.9
Length of Pelvic fin base (cm)	0.3	0.3	0.4
Height of Pelvic fin (cm)	1.0-1.8	0.1	1.6
Pre-Anal Length (cm)	4.9-7.3	4.5	6
Post- Anal Length (cm)	2.2-3.9	2.8	3.6
Length of Anal fin base (cm)	0.8-1.4	0.5	0.7
Height of Anal fin (cm)	1.0-1.5	0.9	1.5
Body Depth (cm)	1.9-2.5	1.6	2.2
Length of Caudal Peduncle (cm)	1.2-1.7	0.9	1.5
Height of Caudal Peduncle (cm)	0.7-1.0	0.7	1
No. of Pectoral Fin Rays	13	12	13
No. of Spines in Pectoral Fin Rays	0	0	0
No. of Pelvic Fin Rays	8-9	9	8
No. of Spines in Pelvic Fin Rays	0	0	0
No. of Anal Fin Rays	9-10	7	6
No. of Spines in Anal Fin Rays	0	0	0
No. of Dorsal Fin Rays	8-9	9	7
No. of Spines in Dorsal Fin Rays	0	1	1
No. of Caudal Fin Rays	18	19	18
Shape of Caudal fin	Forked	Forked	Forked
No. Lateral Line Scales	40-43	29	38
No. of Scales above Lateral Line	7.5-8.5	3.5	6.5
No. of Scales below Lateral Line	4.5-5.5	3.5	4.5
No. of Nasal Barbels	0	0	0
No. of Rostral Barbels	2	2	0
No. of Maxillary Barbels	2	2	2
No. of Mandibulary Barbels	0	0	0
Pre-Dorsal Scales	18-19	9	11

CONCLUSIONS

The taxonomic study of fish collected from five rivers in the Dima Hasao District of Assam, namely Diyung, Vomvadung, Khualzangvadung, Tuikoi, and Mahur, resulted in the first record of 21 species of fish belonging to 19 genera, eight families and four orders. The species composition is highest in Vomvadung River with 11 species followed by Diyung with eight species, Khualzangvadung with six species, Mohur with three species and Tuikoi with two species. The conservation status of *Systomus clavatus*, *Tor tor*, *Neolissochilus hexagonolepis*, and *Neolissochilus hexastichus* are near threatened and *Pterocryptis barakensis* is endangered. The micro-habitats and substrata in the rivers surveyed are essential breeding grounds for these hill stream fishes and need protection.

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