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MULTIVARIATE ANALYSIS OF FISH SPECIES AND ENVIRONMENTAL FACTORS IN MARINE COASTAL WATERS OF THE GULF OF GUINEA, SOUTHWEST NIGERIA

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ABSTRACT

The multivariate relationship between fish species and environmental variables was studied at three landing sites along the coast of the Gulf of Guinea, Southwest Nigeria. Fish species were sampled for abundance once per month per site for twenty-four months and eight environmental variables were measured. Five fish species (*Sardinella maderensis, Ilisha africana, Pentanemus quinquarius, Chloroscombrus chrysurus, Ethmalosa fimbrata and Pterioscion peli*) were observed to be very abundant, which contributed 77.6% of the total abundance. Fish species composition depicted tropical waters fishery with few dominant species having large number of individuals. Dendogram of cluster analysis revealed five fish communities. Canonical correspondence analysis was used to elucidate the relationships between assemblages of fish species and their environment. *S. maderensis*, the most abundant species, was observed to be influenced by pH, total dissolved solids (TDS) and nitrate. Clustering and ordination techniques provided very similar results based on the fish species composition. Water pH, total dissolved solids (TDS), nitrate and conductivity were shown to be most influencing environmental variables in decreasing order of vector projections, influencing fish assemblages in marine coastal waters of the Gulf of Guinea, Southwest, Nigeria.

INTRODUCTION

Marine coastal waters provide valuable living and non-living resources which are in most cases being exploited by humans on a non-sustainable basis (Holligan, 1995). This ecosystem has the highest biological diversity and productivity compared to any part of the sea and it is estimated to contribute 25% of the global biological production and support most of the world's fisheries (Norse, 1993). Marine fish catch fluctuates in relation to human pressure, climatic conditions and physiological requirements (Beamish et al., 1999). Factors involved in the distribution and abundance of organisms are a fundamental challenge in community ecology (Schultz et al., 2012). However, there are major environmental challenges that threaten the sustainability of the goods and services provided by these systems to human beings. The most noticeable threats are the loss of fish diversity, decrease in individual weight and reduced number in fish catch culminating in over-exploitation. Such problems are a result of increased demand in economic and demographic growth which puts pressure on the coastal areas and their associated resources, especially fish production. Fish is the principal source of animal protein for over one billion people (Williams, 1996) and it provides many important nutritional and health benefits (FRDC, 2001). However, the overall well-being and viability of aquatic community are dependent on biochemical and environmental parameters of the system which invariably affect fish growth. Understanding factors structuring fish assemblages in a particular area is valuable to fishery management and species conservation (Schultz et al., 2012). Fish species have differing water quality requirements with decreasing population sizes distributed around their individual optimum values (Whittaker and Levin, 1975). Understanding of the response of these resources to environmental variation is of interest to fishery managers (Lyons, 1996). Multivariate gradient analysis are now frequently used to identify and explain how environmental gradients affect the distribution of fishes (Godinho et al., 2000; Moyle et al., 2003 and Erös et al., 2003). There has been a paucity of information on how physico-chemical parameters of coastal waters influence fish catch composition of marine resources. Therefore, the objective of this paper was to explore the relationship between fish assemblages and environmental variables in coastal waters of the Gulf of Guinea, Southwest Nigeria.

MATERIALS AND METHODS

Description of the study area

The study area is marine coastal water in the western coast of the Gulf of Guinea in Ogun State, Nigeria. Ogun State is situated between 06.36911ºN, 004.35458ºE and 06.34804ºN, 004.42901ºE. The state is bounded in the west and north by Lagos and Oyo States respectively. Ondo State is to the south, while the Gulf of Guinea of the Atlantic Ocean and part of Lagos State are to the south. Economic activities in the area include fishing, shipping, agriculture, lumbering, tourism, oil and gas exploration and exploitation. The area is characterized by tropical climate consisting of a rainy season (April – October) and a dry season (November – March) with high temperature and relative humidity. The vegetation is predominantly mangroves with red mangroves (*Rhizophora racemosa*) constituting 90% of the mangroves ecosystem.

Data collection

The dataset consists of fish catches in three landing sites of commercial fisheries (Sparre and Venema, 1992) of artisanal fishermen operating in marine coastal waters in the Gulf of Guinea in Ogun State, Nigeria. Three sampling sites which were randomly selected included Igbeki (Site 1), Awodikora (Site 2) and Elefon (Site 3). The number of sampling sites was limited to three due to financial constraints. Artisanal fishermen operating in the study area make use of nylon monofilament and multifilament gillnets of mesh sizes 30, 40, 50, 60 and 70 mm. Samples were collected once a month in each site for twenty four months. Fish catch was identified to species level according to Schneider (1990). Each species was weighed with Salter hanging balance (to the nearest 1 g) and counted individually for abundance. At each sampling site, a set of water quality variables was recorded. Water samples were collected in 1-litre polyethylene sampling bottles from the surface, about 50 cm deep, of marine coastal water for analysis. Eight environmental variables were determined. Water temperature (^{0}C), pH, electrical conductivity, total dissolved solids (mgL^{-1}) and dissolved oxygen (mg/l) were measured in-situ, while phosphate (mgL^{-1}), nitrate (mgL^{-1}) and salinity (‰) were determined in the laboratory. Water temperature (^{0}C), pH, electrical conductivity (EC, mS/cm) and total dissolved solids (TDS, mgL^{-1}) were measured by using HANNA instrument (model HI 9810). Before the measurement of EC and TDS, water sample was diluted with de-ionized water (dilution factor = x10) to lower the concentration within the range of sensitivity of the instrument. Dissolved oxygen analyzer (Rex, model JPB-607) was used to determine dissolved oxygen in mgL^{-1}. Phosphate (mgL^{-1}) and nitrate (mgL^{-1}) were determined according to APHA (1998), and salinity (‰) by Swingle (1969) in the laboratory.

Data analysis

Data on total abundance of each fish species from the sampling sites were used to determine the percentage of relative abundance. PAST software, version 2.16, (Hammer et. al., 2001) was used for the ordination analyses by using the matrix table of site x species to ascertain species gradient within the marine coastal water ecosystem. Cluster analysis by hierarchical classification (Morisita index), using the option of unweighted pair group method average (UPGMA), was used to describe fish assemblage groupings based on fish abundances. Constrained ordination, correspondence analysis (CA) (ter Braak, 1995; Legendre and Legendre, 1998) was employed to show fish species gradient in relation to sampling sites. Rare species that contributed less than 0.01% to the total abundance were excluded in CA analysis (ter Braak and Prentice, 1988). Data set for species abundance and environmental factors, species matrix and an environmental matrix were used for canonical correspondence analysis (CCA) (ter Braak, 1986; ter Braak and Verdonschot, 1995; ter Braak and Šmilauer, 2002) to depict the influence of environmental parameters on fish species occurrence. CCA depicts distinct visualization of how the environment controls the species gradients. Since species are assumed to have unimodal response surfaces with respect to linear combinations of the environmental variables in CCA, species are logically represented by points and environmental variables by arrows indicating their direction and rate of change through the subspace (ter Braak and Prentice, 1988). The outcome of CCA (Mohammad, 2011) is highly dependent on the scaling of the explanatory variables.

RESULTS

In the study, 59 fish species belonging to 35 families were encountered (Table 1). Two fish families, Carangidae and Sciaenidae, were most represented in terms of species composition with 9 and 6 species, respectively. *Sardinella madarensis* (32%) and *Ilisha africana* (18.8%) members of Clupeid family, *Pentanemus quinquarius* (16.8%), *Chloroscombrus chrysurus* (8.1%) and *Ethmalosa fimbrata* (5.3%) were the most prominent fish species by abundance. Fifty-four (54) species were observed to contribute less than 5% of the total fish abundance. Fish species that contributed less than 0.005% of the total abundance, *Selene dorsalis, Hemiramphus brasiliensis, Ephippion guttifer, Lophius kempi, Echiophis creutzbergi, Trachinotus maxillosus, Lutjanus dentatus, Psettias sebae, Ophisurus serpens, Rhinobatus rhinobatus, Tarpon atlanticus, Coryphaena equiselis, Alutera scripta, Halobatrachus didactylus, Synaptura cadenati, Diodon hystrix* and *Istiophorus albicans* could be regarded as rare species. Site 3 has the highest number of species richness (51) decreasing through Site 3 to Site 2 with 46 and 45 species, respectively.

Table 1. List of fish species caught by artisanal fishermen in marine coastal waters of the Gulf of Guinea in Ogun State, Southwest Nigeria

Species name	Code	Percentage relative abundance
Sardinella maderensis	Sar.mad	32.030
Ilisha Africana	Ili.afr	18.800
Pentanemus quinquarius	Pen.qui	16.818
Chloroscombrus chrysurus	Chl.chr	8.139
Ethmalosa fimbrata	Eth. Fim	5.301
Pteroscion peli	Pte.pel	4.759
Pseudotolithus typus	Pse.typ	2.902
Trichiurus lepturus	Tri.lep	2.641
Lichia amia	Lic.ami	1.241
Pseudotolithus elongatus	Pse.elo	0.993
Pseudotolithus epipercus	Pse.epi	0.982
Brachydeuterus auritus	Bra.deu	0.858
Mugil cephalus	Mug.cep	0.856
Hemicaranx bicolor	Hem.bic	0.645
Galeoides decadactylus	Gal.dec	0.547
Caranx senegallus	Car.se	0.472
Cynoglossus browni	Cyn.bro	0.402
Arius latiscutatus	Ari.las	0.346
Caranx hippos	Car.hip	0.227
Scomberomorus tritor	Sco.tri	0.185
Elops larceta	Elo.lac	0.177
Pomadasys peroteti	Pom.per	0.162
Sphyraena afra	Sph.afr	0.121
Pomadasys jubelini	Pom.jub	0.050
Lutjanus goreensis	Lut.gor	0.039
Polydactylus quadrifilis	Pol.qua	0.034
Liza grandisquamis	Liz.gra	0.025
Dasyatis margarita	Das.mar	0.024
Cypselurus milleri	Cyp.mil	0.022
Caranx crysos	Car.cry	0.022
Lagocephalus laevigatus	Lag.lea	0.021
Strongylura senegalensis	Str.sen	0.020
Pseudotolithus senegalensis	Pse.sen	0.016
Pseudotolithus moori	Pse.mor	0.016
Albula vulpes	Alb.vul	0.014
Eucinostomus melanopterus	Euc.mel	0.013
Cynoponticus ferox	Cyn.fer	0.012
Euthynnus alletteratus	Eut.all	0.011
Lobotes surinamensis	Lob.sur	0.009
Caranx latus	Car.lat	0.009
Rhizoprionodon acutus	Rhi.acu	0.006
Drepane Africana	Dre.afr	0.005
Selene dorsalis	Sel.dor	0.004
Hemiramphus brasiliensis	Hem.bra	0.003
Ephippion guttifer	Eph.gutt	0.003
Lophius kempi	Lop.kemp	0.002
Echiophis creutzbergi	Ech.cre	0.002
Trachinotus maxillosus	Tra.max	0.002
Lutjanus dentatus	Lut.den	0.002
Psettias sebae	Pse.seb	0.002
Ophisurus serpens	Oph.ser	0.002
Rhinobatus rhinobatus	Rhi.rhi	0.002
Tarpon atlanticus	Tar.atl	0.001
Coryphaena equiselis	Cor.equ	0.001
Alutera scripta	Ale.scr	0.001
Halobatrachus didactylus	Hal.did	0.001
Synaptura cadenati	Syn.cad	0.001
Diodon hystrix	Dio.hys	0.001
Istiophorus albicans	Ist.alb	0.001
TOTAL		**100**

Cluster analysis by hierarchical classification of the identified fish species revealed five distinct groups (*Hemicaranx bicolor, Ethmalosa fimbrata, Dasyatis margarita, Drepane africana* and *Caranx hippos*) of fish assemblages at 0.72 - 84% similarity level as shown by dendogram in Figure 1. Members of each fish assemblage suggest closer similarities in ecological niche. Result of Correspondence analysis (CA) depicted relationship between the sampling sites and fish species (Figure 2). Each site point lies at the centroid of the points for species that occur in that site and a species is located in space where it was most abundant. Eigenvalues of axis 1 and 2 (0.246, 0.106) of the CA were significant as they accounted for 69.9% and 30% of the total correlation coefficient between species and site scores, respectively. Hence, higher axis might not be informative. The eigenvalue is a measure of how well the species scores correspond with the sample scores. The first component is usually related to important environmental gradients. The farther the fish species are from the centre of the ordination, the weaker their influence on the species distribution in the ecological system. E*ucinostomus melanopterus, Euthynnus alletteratus* and *Mugil cephalus* clustered at the extreme left, while *Liza grandisquamis* and *Drepane africana* were positioned at the extreme right of the first axis. These fish species had least influence on species distribution in marine coastal waters of the Gulf of Guinea, Ogun State Southwest, Nigeria. In canonical correspondence analysis (CCA), four categories of species are identifiable as shown in Figure 3. In this ordination, site scores were constrained to the linear combinations of environmental variables and the longer the vector, the stronger its effect on the distribution of the species as shown in Figure 3. The arrows, representing the environmental variables, indicate the direction of maximum change of that variable across the space. Further more, the length of the arrow is proportional to the rate of change, and the smaller the angle between the two environmental vectors, the more positive influence they have on species distribution. The species ordination diagram (Figure 3) reveals ordination pattern with continuous gradients along the first ordination axis with eigenvalue of 0.244. The triplot diagram gives an insight into the species with optimum abundance in each site, that is, the axis in which the species are located. Therefore, it can be inferred that *Pseudotolithus typus, Scomberomorus tritor, Pseudotolithus moori, Chloroscombrus chrysurus* have optimum abundance in Site 1, *Sardinella maderensis, Pseudotolithus elongatus, Dasyatis margarita*, and *Strongylura senegalensis* are most abundant in Site 2, while *Elops larceta, Pterioscion peli* and *Trichiurus lepturus* are optimum in abundance in Site 3.

It can be deduced from the result of CCA that changes in pH and TDS were strongly correlated with the ordination axes and thus with the community variation as shown in Figure 3. Phosphate level of marine coastal waters was orthogonal to pH and TDS. *Sardinella maderensis* (the most abundant fish species), *Dasyatis margarita, Pseudotolithus elongatus* and *Arius lasticulatus* were strongly positively correlated with increasing pH, TDS, nitrate and dissolved oxygen. Increasing change in water temperature positively influenced *Pseudotolithus typus* and *Scomberomorus tritor* but negatively correlated with *Ethmalosa fimbrata*, which was positively influenced by increasing phosphate level. While increased salinity gradient of marine coastal water played important role in the abundance of *Ilisha africana, Galeiodes decadactylus* and *Pentanemus quinquarius*.

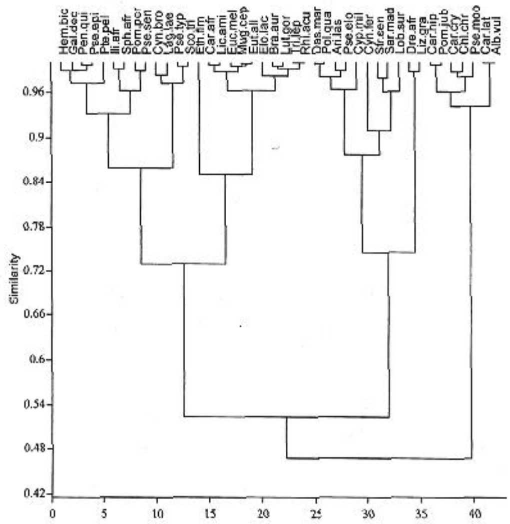

Fig 1. Dendogram of cluster analysis of fish species (*abundances*) in marine coastal waters of the Gulf of Guinea in Ogun State, Southwest Nigeria

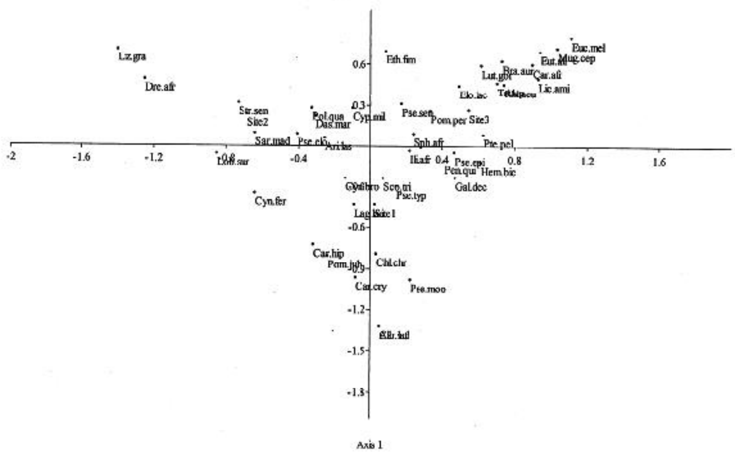

Fig 2. Biplot of the correspondence analysis of fish species in marine coastal waters of the Gulf of Guinea in Ogun State, Southwest Nigeria
See Table 1 for species codes. In this scaling of CA scores, the first two axes explained 69.9% and 30.0% of the total inertia.

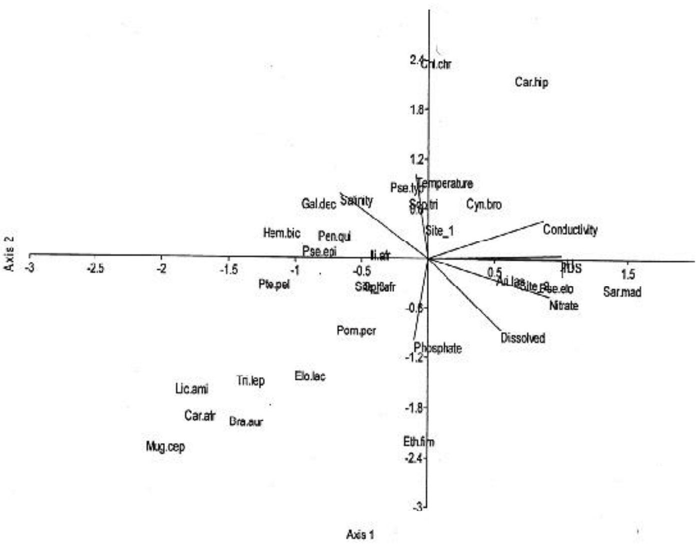

Fig 3. Triplot diagram of canonical correspondence analysis of fish species in marine coastal waters of the Gulf of Guinea in Ogun State, Southwest Nigeria
See Table 1 for species codes. Quantitative environmental variables are represented by lines. The length of the lines is proportional to the importance of the variables and the directions of the lines show their correlation with the axis. The eigenvalues of axis 1 (horizontal) and axis 2 (vertical) are 0.24 and 0.10, respectively. Species that contributed less than 0.05% are not shown in the diagram.

DISCUSSION

In this study, 59 fish species belonging to 35 families were encountered. Earlier studies by Odulate et al. (2006) reported 34 species belonging to 25 families, and Amadi (1991) reported 30 families of fish species comprising 120 species in the marine environment of Nigeria. The variation observed in species composition from the earlier studies may be due to differences in the time of fishing, type of gear and craft employed. The study area being in the tropical region, it may not be surprising that it has high species richness with few dominant species. This is corroborated by Morgan (1987) and Sparre and Venema (1992) who concluded that tropical fisheries are characterized by high species richness dominated by few species. DIVERSITAS (2001) noted that inventory of species richness is crucial to protect such a resource, and dominant species in a community (Ellenbroek, 1987) largely determine the structure and the functioning of that community. Species richness is dependent on the sampling methods and efforts. Whitfield and Marais (1999) recommended that abundance and catch composition of fishes be determined using different sampling methods that overlap in terms of selectivity. The basic aim of ordination and cluster analysis is to represent the (dis) similarity between sites or species based on the values of multiple variables associated with them so that similar objects are depicted near from each other and dissimilar objects are positioned further apart from each other (Ramette, 2007). Separation of species into four different assemblages by CCA corroborate ter Braak and Verdonschot (1995) who stated that this ordination method extracts from the measured environmental variable gradients that maximize the niche separation among species, as most multivariate analyses assume independence between sites (Ramette, 2007). Eigenvalues of the first axis of CA and CCA are of similar magnitude, suggesting that there is no dominant unmeasured gradient or that one or more of the variables measured are very closely correlated with that gradient. CCA has found wide-spread use in aquatic sciences (ter Braak and Verdonschot, 1995) and builds on the ordination method of reciprocal averaging (Hill, 1973; Hill, 1974; Hill and Gauch, 1980). CCA provides general framework for estimation and statistical testing of effects of environmental variables and other explanatory variables on biological communities and can unravel how a multitude of species simultaneously respond to external factors such as environmental variables using data from observational studies (ter Braak and Verdonschot, 1995). CCA is frequently used to identify environmental gradients in ecological data-sets (Barker, 1994), a means of studying seasonal and spatial variation in communities (Snoeijs and Prentice, 1989; Bakker et al., 1990; Anderson et al., 1994) and powerful in detecting relationships between species composition and environment (ter Braak and Prentice, 1988). According to Kautsky and van der Maarel (1990) and Soetaert et al. (1994), it is a means of assessing to what extent the observed variation can be explained by associated environmental variation.

Water quality attributes are prime factors that influence fish survival, abundance, reproduction, growth performance and overall biological production. Fish assemblages in coastal waters are largely structured by abiotic gradients (Kupschus and Tremain, 2001) which include dissolved oxygen (Eby and Crowder, 2004), salinity (Martino and Able, 2003) and temperature (Maes et al., 2006). Nitrate is the main nutrient supporting fish production in the open sea (Maruo et al., 2006). Nitrogen is essential in the synthesis of DNA and protein in organisms and photosynthesis in plants, while phosphorus is critical to metabolic process. Nitrate and phosphate are the key water quality parameters because they influence the overall biological productivity of the aquatic ecosystems (Moyle et al., 2003). Spellerberg (1991) stated that changes in the environmental variables, such as temperature and salinity, could result in a change in the species composition of the biotic community. According to Moyle et al. (2003), water temperature is a critical factor influencing chemical and biological processes. Temperature was positively correlated to abundance of *Anguilla anguilla, Sardinas pilchardus* and *Dicentrarchus labrax*, oxygen to *D. labrax*, while pH to the distribution of *S. bailloni* and *A. anguilla* in estuarine coastal lagoon, Ria de Aveiro, Portugal (Pombo et al., 2005). Thiel et al. (1995) found temperature to be the best predictor of temporal changes in fish abundance and species composition in the Elbe estuary (Germany). In the Humber (UK), temperature appeared to be the best predictor of total fish abundance, while salinity influenced species richness and total biomass (Marshall and Elliott, 1998). The most influential variable is salinity in the Agulhas Current influencing aggregate fish catch in the South Coast transition, South Africa (Jury, 2011). Selleslagh et al. (2008) argued that temperature and salinity are the most important environmental variables influencing species richness, abundance and fish assemblage in the Canche, France.

Marine organisms are adapted to specific ranges of temperature and salinity, and changes in temperature influence the metabolism and can alter ecological processes such as productivity and species interactions (Kennedy et al., 2002; Hansen, 2003). Development of eggs and gonads in most of the fish species are influenced by temperature and salinity (Vicente et al., 2004). Water temperature influences the rate of plant photosynthesis, the metabolic rates of aquatic organisms and the sensitivity of organisms to pollutants, susceptibility to parasites and diseases, and other stresses. The dissolved oxygen level is influenced by mixing at the air/water interface, temperature and salinity, the level of photosynthesis and decomposition of organic material (Moyle et al., 2003). Water pH provides insight into changing water quality conditions and it is important to ecosystem health. Jayachandran et al. (2013) reported the importance of salinity in determining the abundance, diversity and distribution of ichthyofauna in the Kodungallur-Azhikode estuary in India.

Statistical analysis of available time-series (Heath, 2007) revealed changes in distribution and abundance of fish species that correlate with environmental variables. Bennet et al. (2004) identified monitoring of coastal waters as the key issue in coastal management. There are many factors that could cause a change of nutrient concentration in seawater such as anthropogenic impacts, terrestrial inputs, rain vertical mixing, upwelling and biological processes. Fish abundance and species richness can provide managers with a good indication of the health of a particular system (Whitfield, 1996). Understanding the fluctuations in marine fish stocks and knowledge of this role is important for sustainable production, management and conservation of this coastal fisheries.

Sažetak

MULTIVARIJATNE ANALIZE RIBLJIH VRSTA I OKOLINSKIH FAKTORA U VODI MORSKE OBALE GVINEJSKOG ZALJEVA U JUGOZAPADNOJ NIGERIJI

Ovim istraživanjem proučavan je multivarijatni odnos vrsta riba i varijabli iz okoline na tri mjesta duž obale Gvinejskog zaljeva u jugozapadnoj Nigeriji. Uzorci riba prikupljani su jednom mjesečno na odabranim lokacijama tijekom 24 mjeseca, pri čemu je mjereno i osam varijabli iz okoline. Najčešće vrste riba, sa 77,6 % udjela ukupne riblje populacije, bile su: *Sardinella maderensis, Ilisha africana, Pentanemus quinquarius, Chloroscombrus chrysurus, Ethmalosa fimbrata* i *Pterioscion peli*. Sastav ribljih vrsta prikazuje ulov u tropskim vodama s nekoliko dominantnih vrsta koje imaju veliki broj jedinki. Dendrogram klaster analize prikazuje pet ribljih zajednica. Kanonička korelacijska analiza korištena je kako bi se razjasnio odnos između sastava vrsta riba i njihove okoline. Utvrđen je vidljiv utjecaj pH, ukupnih otopljenih tvari (TDS) i nitrata na *S. maderensis*, najbrojniju riblju vrstu. Tehnike grupiranja i koordinacije dale su vrlo slične rezultate temeljene na sastavu ribljih vrsta. pH vrijednost vode, ukupne otopljene tvari (TDS), nitrati i provodljivost najutjecajnije su varijable okoline u opadajućem redoslijedu vektorske projekcije, a znatno utječu na riblji sastav u moru na obalama Gvinejskog zaljeva u jugozapadnoj Nigeriji.

Ključne riječi: klaster, ordinacijski dijagram, svojstvene vrijednosti, okolinske varijable

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