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Hydrographic Nodality as Index for Predicting Fish Species Richness in West African Riverine Ecosystems

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ABSTRACT: The objective of this paper is to present the hydrographic nodality (N) and fish species richness (FSR) to evaluate the N-FSR relationships for West African riverine ecosystems using six Predictive Expressions (the Linear Line, Power Curve, Exponential Curve, Logarithmic Curve, Parabola and Cubic Curves). Of these models, the exponential curve, cubic curve, logarithmic curve and parabola curve were found to be adequate for FSR prediction in terms of their high degree of fitness to the data points and high forecasting efficiencies. These are given respectively as: $FSR = 47.811e^{0.0102N}$, $FSR = 0.0035N^3 – 1.0029N^2 +78.995N + 155.62$; $FSR = 16.02LnN +78.92$; and $FSR = 0.2191N^2 +48.118N + 292.92$.

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Riverine fish assemblages reflect the environmental conditions of their drainage basins (Larned *et al.*, 2011; Omoike, 2021; Oladipo *et al*, 2022; Daoudi *et al*., 2024; Rodmongkonkoldee *et al*., 2024). In ecology, species richness is defined as the number of species that occur in a given biological assemblage or habitat area (Leveque, 1997; King and Jonathan, 2003; Beamish *et al*., 2007; Olawusi-Peters and Ajibare, 2014). Species richness is a commonly invoked diversity index in ecological studies because it is uncomplicated, simple to evaluate and easily understood by both ecologists and nonecologists (Olawusi-Peters and Ajibare, 2014; Sani *et al.,* 2019; Onwude *et al*, 2019; Danba *et al*, 2021; Nazeef *et al*, 2021). Determination of the fish species richness (FSR) of a riverine ecosystem is essential in the understanding aspects of fish faunal community ecology and deciding on rational fish resources management options (Spellerberg, 1992; Danba *et al*., 2021; Asni *et al*, 2024). It is critical in developing guidelines for coordinated riverine fish and fisheries management. Knowledge of riverine FSR is also relevant in the development of fish–based biological indices of environmental impact assessment (Larned *et al*, 2015; Udoh and Okon, 2017; Boini and Bakshi, 2024). Some empirical FSR predictive models have been formulated for riverine ecosystems. One of the earliest A-FSR relationship was formulated by Welcomme (1979) for 25 African Rivers. Livingstone *et al* (1982) are of the notion that the annual mean discharge from a river mouth is a better FSR predictor than basin area, main channel length or stream order. Hugueny (1989) developed a multiple regression model for FSR prediction based on a combination of annual mean discharge, basin area, drainage basin, terrestrial habitat diversity and percent forest cover. Smith (1981) found that stream width was the principal determinant of FSR. The

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foregoing predictive models are fraught with constraints that limit their general application especially in the West African region. In any given riverine drainage basin, the nodality positively correlates with the number of tributaries. Therefore, the branching Complexity (network) of a watershed should, in principle, increase with nodality, a concept that is also noted in network geography (Udoidiong, 1991; King, 2013). Hence, a simple, rapid and relatively accurate prediction of the FSR of riverine ecosystems is imperative, therefore, the objective of this paper is to present the nodality (N) and fish species richness (FSR) to evaluate the N-FSR relationships for West African riverine ecosystems.

MATERIALS AND METHODS

Hydrographic maps (scale 1: 35,000 – 6,250,000) were used to derive the nodality values (N) of some west African riverine ecosystems (Table1) The selection of watersheds was largely based on the availability of reliable FSR data. Ancillary data such as basin area (A km^2) and annual mean discharge Q, m^3/s) were also taken from the relevant literature. Although different map scales were used to estimate nodality, each N – FSR data pair remained homogeneous.

Consequently, the minor variability in map scale had no significant and direct impact on the observed relationships. Two nodes were counted where two opposite tributaries join the main channel at the same point. For rivers that discharge directly into the Atlantic Ocean, the estuaries were regarded as nodes.

Thirty seven of the FSR data were compiled from published sources (e.g. Sydenham, 1977; Teugels *et al*, 1988, 1992, 1994; Udoidiong, 1988, 1991; Hugueny, 1989; Nwadiaro and Okereke, 1993) and one from one of the author`s (R. P. King) unpublished field notes. Euryhaline fish species capable of free dispersion between the estuary and upper freshwater reaches of rivers were included in the species lists.

The FSR is here considered as a simple alpha diversity index that is uncomplicated by relative abundance and/or equitability data. The N – FSR relationship was explored with five regression expressions in the Excel package of Microsoft word 13 *viz*: linear line, power curve, exponential curve, logarithmic curve and parabola curve (i.e 2nd degree polynomial) in the Excel package of Microsoft word 13.

The degree of data fit in each expression was assessed by the coefficient of determination ($r^2$100) while the predictive strength of each model was evaluated by the index of forecasting efficiency (E) (Giulford and Fruchter, 1973).

RESULTS AND DISCUSSION

General features of Nodality: The basin areas, annual mean discharges, nodalities and fish species richnesses of the riverine ecosystems considered in this study are presented in Table 1.

Table 1. The basin area, mean annual discharge, nodality and fish species richness of West African riverine ecosystems considered in this study.

Riverinne ecosystems	A (km^2)	Q (m^3/s)	N	FSR
Bouo (Cote d`Ivore)	4690	32	1	46
Nero (Cote d`Ivore)	985	16	1	24
Dado (Cote d`Ivore)	850	-	1	21
Tabou (Cote d`Ivore)	800	-	1	18
Loffa (Liberia)	13199	-	1	35
Lokoundie (Cameroon)	5200	282	1	23
Udom (Nigeria)	-	-	1	17
Nung Oku (Nigeria)	-	-	1	19
Nworie (Nigeria)	-	-	1	19
Mission	-	-	1	22
Nipoue(Cote d`Ivore)	11920	-	2	63
Osun (Nigeria)	16000	-	2	23
Dibamba (Cameroon)	2400	125	2	19
San Pedro(Cote d`Ivore)	3320	31	3	32
Calvally (Cote d`Ivore)	28850	384	3	63
Mono (Togo)	22000	104	3	53
Otamini (Nigeria)	-	-	3	57
Mung (Cameroon)	4200	164	4	41
Me (Cote d`Ivore)	3920	32	5	55
Bia (Ghana)	6500	81	6	44
Agnebi (Cote d`Ivore)	8520	50	6	62
Mano (Sierra Leon)	7750	-	13	65
IKpoba (Nigeria)	-	-	11	58
Pra (Ghana)	22960	240	12	65
Wouri (Cameroon)	11700	308	13	69
Jong (Sierra Leon)	7750	-	13	65
IKpa (Nigeria)	516		16	68
Tano (Ghana)	1600	130	16	61
Sassandra (Guinea)	75000	513	17	78
Sombriero (Nigeria)	-	-	18	65
Nyong (Cameroon)	27800	443	21	107
Ntem (Cameroon)	31000	348	22	108
Comoe (Mali-Cote d`Ivore)	78000	206	28	92
Bandama (Cote d`Ivore)	75000	513	17	78
Ogun (Nigeria)	22370	-	30	91
Gambia (Gambia)	77000	170	47	91
Sanaga (Cameroon)	133000	2060	77	135
Cross(Nigeria–Cameroon)	75000	995	174	166

A = Basin area (km^2); Q = annual mean discharge (m^3/s); N = nodality; FSR = Fish species richness.

The basin area (A, km^2) varied 189 –fold, from a minimum A_{min} = 516km^2 in Ikpa River (Nigeria) to a maximum of A_{max} = 97500km^2 in Bandama River (Cote d`Ivore). Annual mean discharge (Q, $m^3/s$) varied 129 –fold, from a minimum $Q_{min}$ = 16$m^3/s$ in Nero (Cote d`Ivore) to a maximum Q_{max} = 2060 m^3/s in Sanaga (Cameroon). The amplitude of variation in nodality was high (174 –fold), from a minimum N_{min} =1 to a maximum N_{max} = 174. The present study elucidates the linkage of hydrographic nodalities (i.e. number of tributary junctions) of riverine watersheds to their fish species richnesses. This was inspired by Welcomme`s (1985) concept that spatial variations in faunal abundance often occur below stream junctions where abrupt changes inflow regime, sediment load and other hydrological conditions produce corresponding variations in the stream channel. This concept is also upheld by Spellerberg, (1992), Larned *et al*., (2011) and. King, (2013). As shown in Fig. 1 below, nodality significantly increased with basin area (r^2 = 0.4958, n= 30, P<0.002) producing the exponential equation:

$$N = 2.6496e^{3E\text{-}05A} \quad (1)$$

Which explained 49.6% of the variation in nodality.

Similar observations were earlier reported by Karr (1981), Karr, (1986) and King (2013).

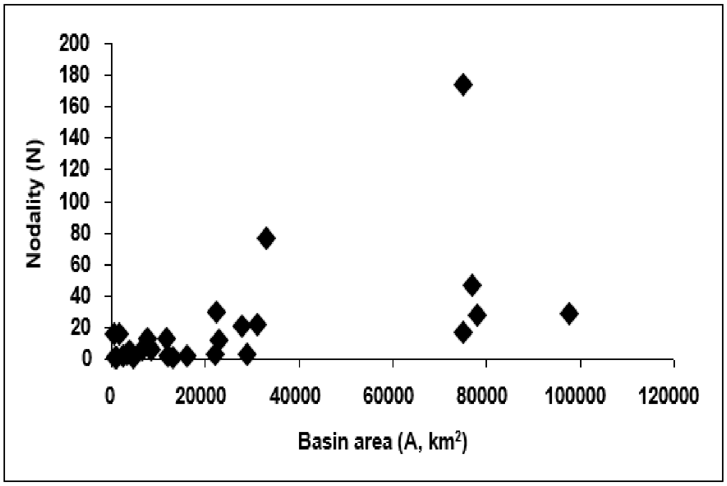

Fig.1. Relationship between river basin area and hydrographic nodality of some West African riverine ecosystems.

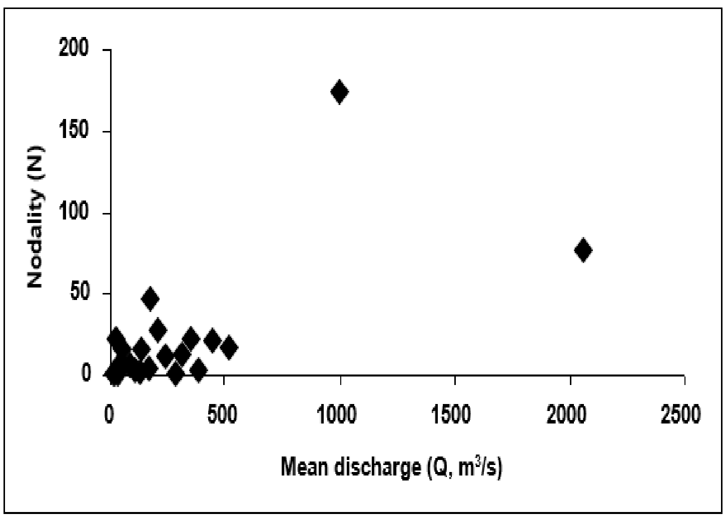

Fig.2. Relationship between annual mean discharge and the nodality of some West African riverine ecosystems

The annual mean discharge of the rivers also increased with nodality
(Fig. 2) (r^2 = 0.5401, n=23, P<0.002) as indicated in the parabola (2nd degree polynomial) curve, forming the equation:

$$N = -5E\text{-}05Q^2 + 0.1423Q - 9.291 \quad (2)$$

Which accounted for 54.0% of the changes in nodality.

The results of this study suggest a shift in ecological parameters favouring one faunal assemblage over another. This implies that habitat heterogeneity increases with nodality and hence, fish species richness. These findings are in consonance with the reports of Toham and Teugels, (1997); (1999); Udoidiong and king, (2000). This is probably because habitat diversity increases with the branching network of the watershed.

Fig. 3 shows a Logarithmic relationship between nodality and Fish Species Richness, while Fig. 4 represents a Second Degree Polynomial Relationship as indicated in the equations in Table 2. The two curves may look similar but the parameters are different.

The predictive models: The nodality –fish species richness relationship for the 38 riverine ecosystems is illustrated in Fig.3 while Table 2 is a display of the seven equations fitted to the points (Eqns 3 – 9). The cubic curve was the best fit to the data points ($r^2$100 = 85.7%). This was closely followed by the logarithmic and power curves (r^2 100= 82.6% and 80.6% respectively). The exponential curve was a poor fit while other models (Spellerberg (1992); Larned *et al*. (2011) were of intermediate fits. The exponential curves in Fig. 3, Fig. 4 and Fig. 5 had the best predictive capacity. The logarithmic curve had the least predictive capacity while other models had intermediate species richness forecasting capacities. This corroborates the findings of Karr (1981) and King (2013).

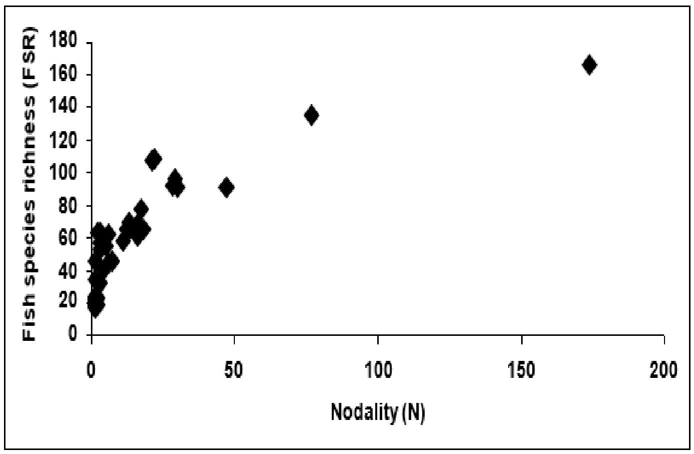

Fig. 3. Logarithmic Relationship between nodality and fish species richness of some West African riverine ecosystems

Table 2. Nodality –fish species richness predictive equations and related statistics for some West African riverine ecosystems.

Expression	**equation**	**$r^2$100**	**E (%)**	**Eq. No.**
Linear line	FSR = 0.9109N +42.549	68.2	56.5	3
Power curve	FSR = $24.771N^{0.3836}$	80.6	44.1	4
Exponential curve	FSR = $47.811e^{0.0102N}$	39.9	77.5	5
Logarithmic curve	FSR = 21.311lnN + 20.538	82.6	41.7	6
Exponential curve	FSR = $39.903e^{0.0127N}$	39.0	77.5	7
Parabola curve	FSR = $0.0078N^2$ +2.1122N+32.748	83.4	40.7	8
Cubic curve	FSR = $0.0001N^3$ $0.0375N^2$ + 3583N + 28.041	85.7	62.1	9

N= nodality; FSR = fish species richness; E = index of forecasting efficiency

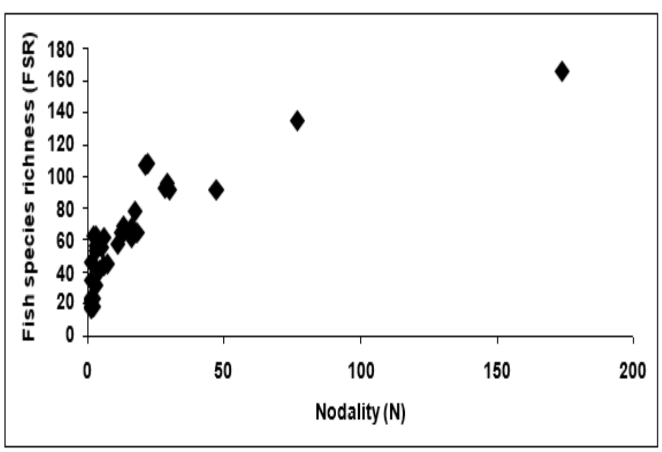

Fig. 4. Parabolic Relationship between nodality and fish species richness of some West African riverine ecosystems

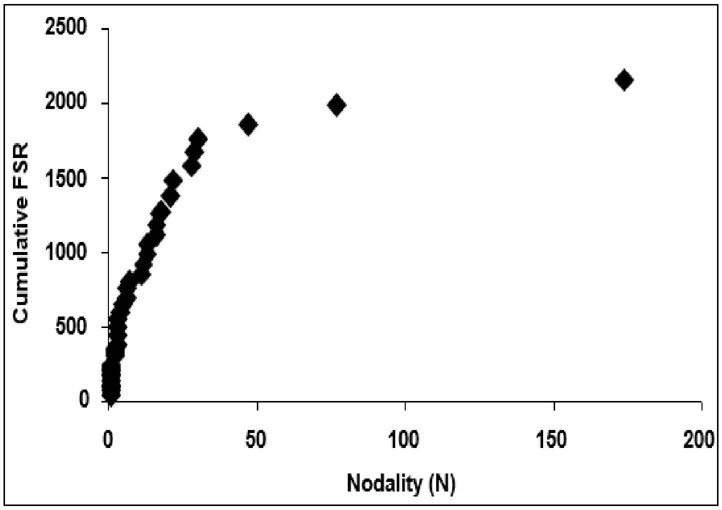

Fig. 5. Nodality and cumulative fish species richness of some West African riverine ecosystems

The nodality – cumulative fish species richness function (Fig.5) displays a typical logistic dispersion of points with an asymptote at N =200 and FSR = 2000. The nodality and cumulative fish species richness points were significantly correlated in terms of the following statistical expressions:

Linear line ($r^2 = 0.8294$, n=38, P< 0.002):

$$FSR = 14.571N + 569.91 \quad (10)$$

Power curve ($r^2 = 0.8625$, n=38, P<0.002):

$$FSR = 171.31N^{0.6597} \quad (11)$$

Exponential curve ($r^2 = 0.2829$, n=38, P<0.002):

$$FSR = 405.38e^{0.0179N} \quad (12)$$

Logarithmic curve ($r^2 = 0.9651$, n=38, P<0.002):

$$FSR = 16.02LnN + 78.92 \quad (13)$$

Parabola curve (r2 = 0.8927, n=38, P<0.002):

$$FSR = -0.2191N^2 + 48.118N + 292.92 \quad (14)$$

General assumptions apply to the

Cubic curve (r2 = 0.9775, n=38, P<0.002):

$$FSR = 0.0035N^3 - 1.0029N^2 + 78.995N + 155.52 \quad (15)$$

The respective coefficients of determination ($r^2$100) for the above relationships (i.e. Equations 10 – 15 were: 82.9%, 86.3%, 39.9%, 96.5%, 89.3% and 97.8%.

Therefore, the cubic curve exhibited the best fit to the data points. This was closely followed by the logarithmic curve and parabola curve while the exponential curve exhibited the worst fit to the data points.

The application of nodality to FSR prediction appears reasonable especially as nodality is significantly correlated with basin area (Eqn. 1) and discharge (Eqn2), which are two features previously known as determinants of the fish species richness of West African riverine ecosystems (Daget and Iltis, 1965; Welcome, 1979, 1985; Hugueney, 1989).

Assumptions of the predictive models: Certain general assumptions apply to the FSR predictive models proposed in this paper (*vide supra*). They include the following:

(a) The fishes of riverine ecosystems are associated to varying extents with distinct macro- and meso- habitat –types;

(b) The various mesohabitats of any given riverine ecosystem are sufficiently sampled. These include: surfacewater, midwater, bottomwater, pools.riffles raceways, sloughs, side channels, side streams, littoral zone, fringing swamps, Pools and swamps;

(c) a multi-gear sampling technique is adopted to minimize gear selectivity and thus improve on the overall FSR estimate

Conclusion: The present study has elucidated Hydrograpic Nodality as an index for prediction of Fish Species Richness (FSR) for West African Riverine ecosystems, as it correlates significantly with Basin Area and River discharge. The results of this study also showed that habitat heterogeneity increases with Nodality and hence, Species Richness.

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