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HIERARCHICAL MODELS OF FISH ABUNDANCE AND OCCURRENCES IN SOUTHERN BASIN OF KAINJI LAKE NIGERIA

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ABSTRACT

Fish abundance is directly linked to species diversity, indicating the importance of maintaining rich fish communities for ecosystem stability and productivity. The aim of the study is to fit hierarchical models to modelled fish abundance through the following objectives: Evaluate fish abundance and occurrences using abundance formulae and their diversity index, fit hierarchical models, Investigate the variability of fish abundance and occurrences in different fishing locations and to identify the consequences of location specific management actions. Shannon weinner and Sampson diversity index reveals that Monai fishing location has the highest percentage of catch ranging to 30%. Cast net is found to be the most efficient method with highest count value of 1.9457, Poisson and negative binomial models reveal that, the locations have no significant difference and there is variability among fish catch over the years. Negative binomial reveals that Monai has the highest fish in abundance having the fish count value of 1.067 with a decrease in fish population by 7%. These results indicate significant variations in fish abundance and occurrence across the locations, years and methods. From the comparative regression and negative binomial model. Negative binomial model has the lowest log like hood of 7855874.07, with a deviance of 434.34. This infers that the negative binomial regression performs better than the Poisson regression in modelling fish abundance and occurrence. This study contributes valuable knowledge about dynamics of fish populations and basis for informed decision making in fisheries management and conservation.

Keywords: Fish abundance and occurrence, Diversity index, Abundance formulary, Shannon wiener, Simpson diversity index, Poisson model, Negative binomial model

INTRODUCTION

Fish abundance and occurrence refer to the population size and distribution of fish species within a particular ecosystem or geographical area. These terms are commonly used in the field of ecology and fisheries science to describe the number of fish individuals present in a given habitat and how frequently they are encountered. Fisheries scientists and managers are professionals who work in the field of fisheries management and conservation (Caddy and Mahon, 1995). Their primary goal is to study, understand, and responsibly manage aquatic resources, including fish populations, aquatic habitats, and related ecosystems. They play a crucial role in maintaining sustainable fisheries, ensuring the preservation of aquatic biodiversity, and supporting the livelihoods of communities that depend on fishing and related industries. Numerous studies have shown that fish abundance is directly linked to species diversity, indicating the importance of maintaining rich fish communities for ecosystem stability and productivity. Biodiversity hotspots and factors influencing species richness are explored in this section, emphasizing the need for comprehensive monitoring and conservation strategies (Mittermeier *et al.*, 2011). Fish abundance and occurrence can exhibit temporal and spatial variability due to natural and anthropogenic factors. Seasonal migration, reproductive cycles, and climatic influences can lead to fluctuations in fish populations. Additionally, habitat degradation, pollution, and overfishing may contribute to spatial disparities in fish distribution. Fish abundance and occurrence can exhibit temporal and spatial variability due to natural and anthropogenic factors. Seasonal migration, reproductive cycles, and climatic influences can lead to fluctuations in fish populations. Additionally, habitat degradation, pollution, and overfishing may contribute to spatial disparities in fish distribution. This study examines the dynamics of these fluctuations and their implications for fisheries management and conservation. Understanding the drivers behind fish abundance and occurrence is essential for effective management and conservation. This research work reviews the impact of various factors, such as water quality, habitat complexity, temperature, food availability, and human activities, on fish populations.(Halpern *et al.*, 2015). Moreover, the review explores the interactions between these drivers and their combined effects on fish communities. A fish population is a group of fish of the same species that live in a particular area. The size of a fish population can vary greatly, from a few individuals to millions of fish. The population size is determined by a number of factors, including the availability of food, habitat, and predators. A fish stock is a subpopulation of a fish population that is managed as a unit. Fish stocks are often defined by their location, life history, or behaviour. The terms "fish population" and "fish stock" are often used interchangeably, but there is a subtle difference between the two. A fish population is a more general term that refers to any group of fish of the same species, while a fish stock is a more specific term that refers to a group of fish that is managed as a unit. According to the Food and Agriculture Organization of the United Nations (FAO), the global fish population has declined by about 50% since 1970. This decline is due to a number of factors, including overfishing, climate change, and habitat loss. The FAO estimates that up to one third of all fish stocks are overfished. Overfishing is the most serious threat to fish populations. When fish are caught at a rate that is faster than they can reproduce, the population size declines. This can lead to the collapse of fish stocks, which can have a devastating impact on ecosystems and economies. The world fish production is about 167.2 million tons, out of which 146.3 million tons is used for human consumption and remaining is used as non-food purpose and discarded as waste material (Mekouar, 2018).

MATERIALS AND METHODS

The studies use sampling protocol taking N_i as unknown number of fish species captured within sample unit (i) and x_i denote observation vector. The catch at sample T yields 2^T -1 vector (1, 0) is used to represent catch or no catch where 1= catch in first occasion while 0 not catch in second occasion.

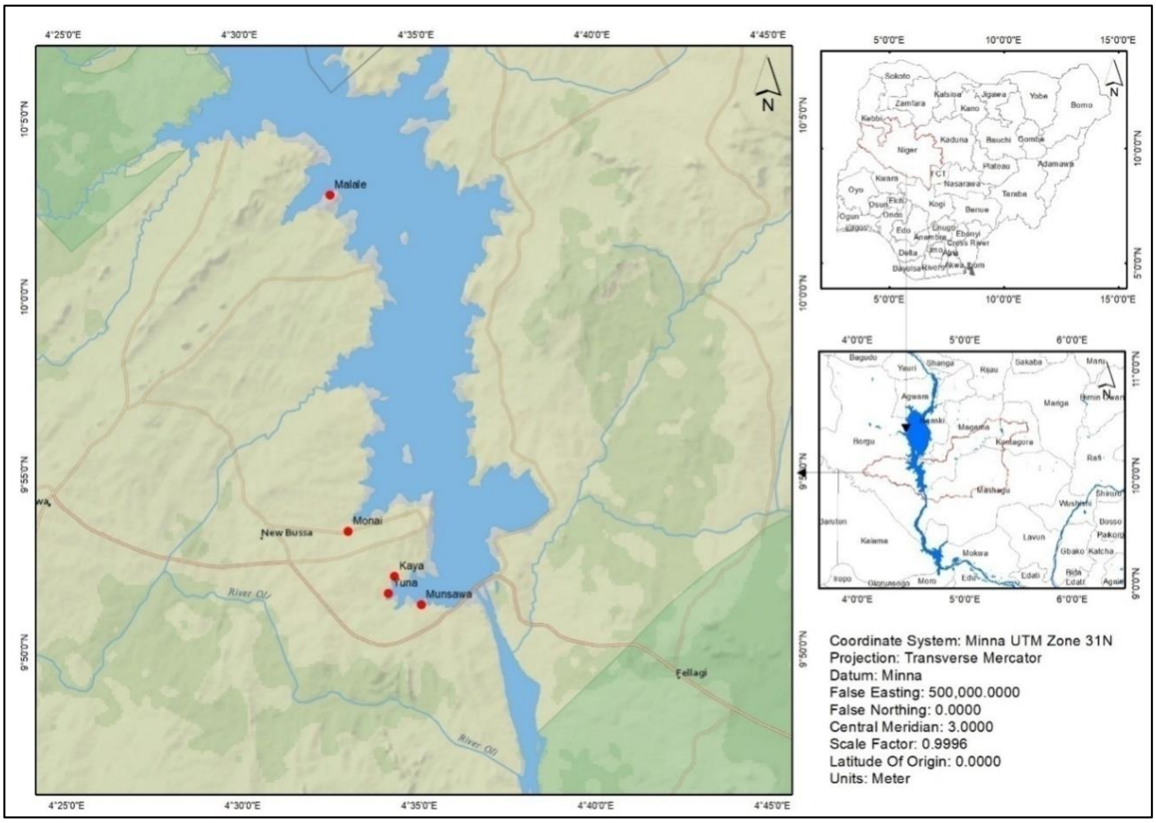

Figure 1: Map Shows the Study Area

Shannon diversity index (H') and Simpson's Diversity Index will be computed. Abundance formulae will be applied to detect differences in species occurrence among fishing locations.

Shannon diversity index (H)

The index (H) is commonly used to characterize species diversity in a community.

Accounts for both abundance and evenness of the species present.

Where $p=n/N$, n is the number of individual species while N is the total no of all species

Shannon wiener Index (H) $= -\sum_{i=1}^{s} P_i \, lin \, P_i$ (1)

Simpson index (D) $= \frac{1}{\sum_{i=1}^{s} Pi^2}$ (2)

Shannon index, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), in is the natural log, Σ is the sum of the calculations, and s is the number of species.

The Simpson index is a dominance index because it gives more weight to common or dominant species. In this case, a few rare species with only a few representatives will not affect the diversity.

In the Simpson index, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), Σ is still the sum of the calculations, and s is the number of species.

Total Abundance the area surveyed within each transect (A_i) was calculated by averaging transect width(W_i) estimates and multiplying by the smoothed transect length (L_i). Species densities for each transect were estimated by dividing the species count (C) by the transect area.

$$D = \sum_{i=1}^{N} \frac{c_i}{L_i \bar{w}_t} = \sum_{i=1}^{N} \frac{c_i}{A_t} \quad (3)$$

Total abundance (P) in number of individuals was estimated for each species by multiplying mean species density for each location.

Poisson regression

Y_i is the number of fish species for a particular fishing location. This will depend on the number of fish species caught, n_i, and other variables that affect θ_i, such as the number of fish caught in a location.

The subscript $i$is used to denote the different combinations of fish species population.

Then $Y_i \sim$ Poisson (μ_i) *and*

$E(Y_i) = \mu_i = n_i e^{\mathbf{x}T_i\beta}$; (4)

Log μ= log $n_i + \mathbf{x}^T{}_i \beta$. (5)

$$\log(\mu) = \log(n) + \beta_{i\,location_i} + \beta_{j\,method} + r\ years_i \quad (6)$$

The deviance for a Poisson model is given as

$$D = 2\sum\left[\boldsymbol{o_i}, \boldsymbol{log}\left(\frac{o_i}{e_i}\right) - (\boldsymbol{o_i} - \boldsymbol{e_i})\right] \quad (7)$$

The goodness of fit statistics X^2 and D are closely related. Using the Taylor series expansion

$$\sum \frac{(o_i - e_i)^2}{e_i} = X^2 \quad (8)$$

The statistics D and X^2 can be used directly as measures of goodness of fit, as they can be calculated from the data and the fitted model They can be compared with the central chi-

squared distribution with $N - p$ degrees of freedom, where p is the number of parameters that are estimated.
Negative Binomial model can be written as a Poisson-gamma mixture:
$y_i|\lambda_i \sim Poisson\ (\lambda_i\ )$
The Poisson mean λ_i is organised as:

$$\lambda_i = exp\ (x_i^T\beta + \varepsilon_i) \quad (9)$$

Negative binomial

The traditional Negative Binomial regression model is given by

$$\ln\mu = \beta_0 + \beta_1x_1 + \beta_2x_2 + \cdots + \beta_px_p \quad (10)$$

RESULTS AND DISCUSSION

Table 1: Statistics of the five fishing locations in southern basin of kainji lake, Nigeria

Fishing location	Species family	(H) Index	(SD) Index	Total abundance	Family no	Fish population
Monai	*Alestidae*	0.8118	0.4023			
	Latidae	0.0408	0.0359	1.0744	15	2101
Kaya	*Alestidae*	0.5270	0.3001			
	Channidae	0.2524	0.2816	0.3270	10	1239
Yuna	*Mormyridae*	0.2285	0.2010			
	Osteoglosidae	0.1025	0.0471			
	malapteruridae	0.0003	0.0002	0.4240	9	507
Malale	*Citharinidae*	0.3032	0.3021			
	Polypteridae	0.0013	0.0547	0.0390	11	1484
Musawa	*Alestidae*	0.5409	0.4503			
	Centropomidae	0.0030	0.0264			
	Clupeidae	0.0011	0.0003	0.5170	13	1793

Table 1 is the Statistical analysis of fish species abundance and occurrence in southern basin of Kainji lake, Nigeria for five fishing locations shows Shannon weinner (H) and Sampson (SDI). From the table we observed in Monai fishing location, from 15 family of 2101 fish populations. *Alestidae*have the high diversity index of 0.8118 from (H) index while 0.4023 in (SDI*), latidae* is low in abundance with (H) index of 0.0408 and (SDI) of 0.0359, *Alestidae* is more in abundance in Monai fishing location. The total abundance of the family is 1.0744 which indicate high diversity index of fish species in the location. In Kaya fishing location, from the family of 10 fish species having a total population of 1239, *Alestidae*also have higher diversity index of (H) as 0.5270 and (SDI) as 0.3001, while *channidae* have lower (H) index of 0.2524, and (SDI) as 0.2816. The result shows that *Alestidae* is more in abundance in this fishing location. The total abundance of the fish secies is 0.3270, in Yuna fishing location of 9 family with a total fish population of 504, *Mormyridae* have high diversity index of 0.2285 from (H) while (SDI) have 0.2010, *osteoglosidae* have lower (H) index as 0.1025 and (SDI) as 0.471, *malapteruridae*have the lowest (H) index of 0.0003 and (SDI) as 0.0002, the total abundance of the fish species is 0.4240 indicating low fish abundance and occurrence in this location. Malale fishing location with 11 family of fish species having a total fish population of 1484, *citharinidae*have high diversity index (H) of 0.3021 and (SDI) as 0.3021, *polypteridae*have low (H) index of 0.0013 and (SDI) as 0.0547, the total abundance is 0.0390 this indicates a low fish abundance and occurrence in this location. Musawa from the family of 13 fish species having a total fish population of 1793, *Alestidae* have the high diversity index of (H) as o.5409 and (SDI) as 0.4503, while *centropomidae*have low diversity index of (H) as 00030 and (SDI) as 0.0264, *clupeidae* have the lowest diversity index of (H) as 0.0011 and (SDI) as 0.0003, the total abundance of the fish species in this location is 0.5170. comparing fish abundance and occurrence in the five fishing locations, fish species abundance and occurrence is more in Monai than any other location while the location with the lowest fish abundance and occurrence is Malale.Roney *et al.* (2015). Comparative analysis of abundance occupancy relationships for species risk at both broad taxonomic and spatial scales. The finding revealed in the study, that area of occupancy is related to abundance within and among phylogenetically diverse groups of species across extensive spatial scales. With the exception of freshwater fishes and lichens, and in accordance with other work undertaken at broad taxonomic and spatial scales.

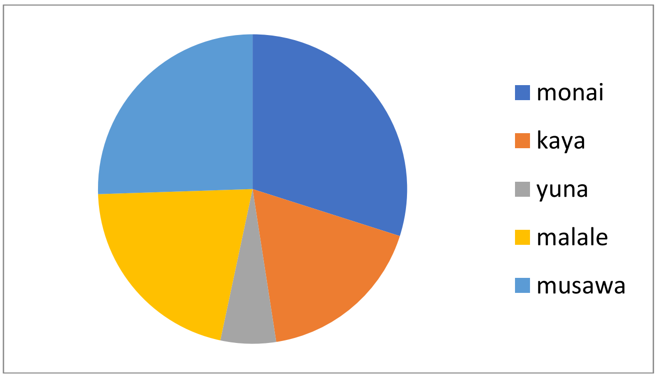

Figure 1: A pie chart for fish population size of each fishing location

Figure 1 shows the total number of fish catch assessment by method of each fishing location in southern basin of kainji lake, Nigeria. The chart shows that Monai fishing location has the highest percentage of catch ranging to 30%, followed by Musawa with 25%, then followed by Malale having 21%, followed by Kaya having 18%, Yuna fishing location have least percentage of catch assessment survey. The results showed that fish abundance and occurrence is more in Monai than the other fishing locations.

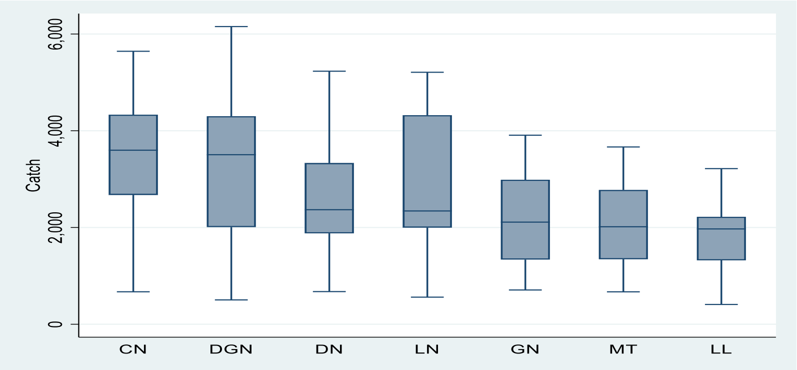

Figure 2: Box plot for the initial abundance of catch on each fishing gear

From figure 2 DGN has the highest catch with a maximum value of 6154 and a minimum value of 503, the mean value was observed to be 3235.88 and a standard error of 222.87, the fishing gear CN has a maximum catch of fish as 5643 and a minimum catch of 671 with a mean of 3405.76 and a standard error of 176.7. Method DN has a maximum catch of 6231 and a minimum catch of 675 with a mean value of 2622.94 and a standard error of 172.488. Method LN has a maximum catch of 5209 and a minimum catch of 560 with a mean value of 2959.58 and a standard error of 197.81. Method GN has a maximum catch of fish of 3908 and a minimum of 708 with a mean value of 2151.96 and a standard error of 128.101. Method MT has a maximum catch of 3665 and a minimum catch of 670 with a mean value of 2033.96 and a standard error of 118.579. Method LL has a maximum catch of 3217 and a minimum catch of 409, with a mean value of 1901.3 and a standard error of 106.359.

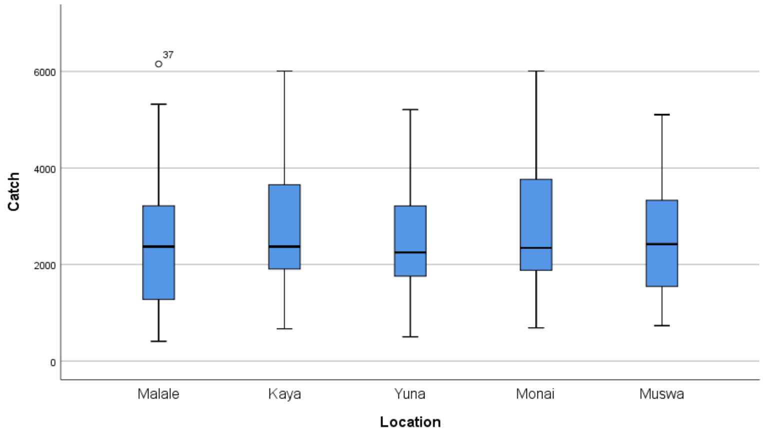

Figure 3: The five-fishing location and fishes catch

Figure 3 shows different fishing location and fishes catch, in Malale, the maximum catch was 6154 and the minimum catch was 409 with a mean value of 2506.73 and a standard error of 160.363 In Kaya, the maximum catch was 6008 while minimum catch was 670 with a mean value of 2730.29 and a standard error of 158.136. In Yuna, the maximum catch was 5208 whiles the minimum catch was 503 with a mean value of 2578.11 and a standard error of 150.151. In Monai, the maximum catch was 6008 while the minimum catch was 687 with a mean value of 2717.34 and a standard error of 160.724. In Musawa, the maximum catch was 5105 while the minimum catch was 732 with a mean value of 2547.09 and a standard error of 141.939. Location 1-4 (Malale,Kaya, Yuna, Monia and) has the highest catch using method DGN and the least catch using method LL while for Musawa location, the highest catch was observed using DN and the least using LL. Adimula *et al.* (2021) comparative study on the catch efficiency and size selection of entangling nets in kainji lake reported that, the catching efficiency of entangling nets that were experimented in Lake Kainji revealed that the multi-walled trammel net was more efficient in catch ability than that the single walled gillnet.Although there was a significant difference in the catch rates of the net types within the short fishing trials.

Table 2: Dependent variable count for Poisson regression

	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	155	518504359.6	3345189.4	5.14	<.0001
Error	264	171776233.1	650667.5		
Corrected Total	419	690280592.7			

The table 2 shows that the Poisson model with 155 degrees of freedom, explains a substantial amount of the variance, as indicated by the Sum of Squares (518504359.6) and a high Mean Square value (3345189.4). The F-value of 5.14, coupled with a very small p-value (Pr> F <.0001), suggests that the model is statistically significant, meaning the predictors account for a meaningful portion of the total variance in the data. However, the Error Sum of Squares (171776233.1) and its associated degrees of freedom (264) indicate that a considerable amount of the variance remains unexplained by the model. This balance between explained and unexplained variance implies that while the model is significant, further improvements could be made, possibly by adding more relevant predictors or refining the current ones.

Table 3: The R- square, Coefficient, MSE and Count Mean

R-Square	Coeff. Var	Root MSE	count Mean
0.751150	30.22413	806.6397	2668860

The table 3 shows R-Square value of 0.751150 indicating that approximately 75.12% of the variance in the dependent variable is explained by the model, signifying a moderately strong fit. The Coefficient of Variation (30.22%) reflects the extent of variability in relation to the mean, suggesting that while there is variation, the model is reasonably consistent. The Root Mean Square Error (806.6397) represents the average deviation of the predicted values from the observed values, with smaller values indicating better predictive accuracy. Lastly, the Count Mean (2491.809) provides a reference point for the average value of the dependent variable, helping to contextualize the model's predictions.

Table 4: Interaction between the years, location (site) and methods

	DF	Type I SS	Mean Square	F Value	Pr > F
Years	11	63933362.3	5812123.8	8.93	<.0001
Site	4	4394762.4	1098690.6	1.69	0.1529
Method	6	138515382.7	23085897.1	35.48	<.0001
site*method	24	3997330.5	166555.4	0.26	0.9999
years*site	44	32468730.3	737925.7	1.13	0.2715
years*method	66	275194791.4	4169618.1	6.41	<.0001

The table 4 shows that the sums of square of the years 63933362.3 with 11 degrees of freedom, explains a substantial amount of the variance, as indicated by the Sum of Squares (518504359.6) and a high Mean Square value 5812123.8. The F-value of 8.93, has a very small p-value (Pr> F <.0001), suggests that the model is statistically significant. The sums of squares for the location having sums of squares of 4394762.4 with degree of freedom 4. Has F-value 1.69 with a p-value of 0.1529 which is not statistically significant. The methods have a sum of squares of 138515382.7 with 6 degrees of freedom having a means of squares 23085897.1 with F-value of 35.48 has a P-value (Pr> F <.0001), shows a significant statistical value. The interaction between (locations) site and method has a sum of squares 3997330.5 with 24 degrees of freedom contained 166555.4 means of squares. The F-value is 0.26 with a p-value of 0.9999 which is not statistically significant. The interactions between years and site have a sums of squares value of 32468730.3 with 44 degrees of freedom has a means of squares value of 737925.7, contain 1.13 F-value with a P- value of 0.2715 which is not statistically significant. The interactions between years and method have a sum of squares of 275194791.4 with 66 degrees of freedom, has a means of squares 4169618.1 with F-value of 6.41, the P-value is 0.0001 which statistically significant. These results are achieved using Type I error the same results are also obtainable using Type iii error refer to the Appendix C for more detail.

Table 5: Assessment of goodness of fit

Criterion	DF	Value	Value z/DF
Deviance	398	190624.8800	478.9570
Scaled Deviance	398	190624.8800	478.9570
Pearson Chi-Square	398	177755.2742	446.6213
Scaled Pearson X^2	398	177755.2742	446.6213
Log Likelihood		7762079.8080	

The table 5 show the data set deviation from the Poisson regression model of value190624.8800 with 398 degrees of freedom having the value to DF ratio of 478.9570. The scale deviance of 190624.8800 with a degree of freedom 398 contain value to the DF ratio of 478.9570. Pearson chi-square has a value of 177755.2742 with 398 degrees of freedom has the value to DF ratio of 446.6213, scale Pearson chi-square has a value of 177755.2742 with 398 degree of freedom and also has the value to DF ratio of 446.6213, lastly the log like hood value of 7762079.8080, higher log like hood indicates better fit of the model.

Table 6: Comparative Analysis of Poisson Regression and Negative Binomial Regression for Modelling Fish Abundance and occurrence in southern basin of kainji lake, Nigeria

Poisson	Df	Value	Value/Df
Deviance	398	190624.8800	478.9570
Scale Deviance	398	190624.8800	478.9570
Pearson chi-square	398	177755.2742	446.6213
Scale Pearson chi-square	398	177755.2742	446.6213
Log like hood			**7762079.8080**
Negative Binomial			
Deviance	398	434.3440	1.0913
Scale Deviance	398	434.3440	1.0913
Pearson chi-square	398	344.0092	0.8643
Scale Pearson chi-square	398	344.0092	0.8643
Log like hood			**7855874.0693**

Table 6 shows the comparison between Poisson and negative binomial model at 398 degrees of freedom. Binomial model is found to be the better fit model compare to Poisson regression model. Negative binomial model has a lower deviance and scale deviance than Poisson model. The lower deviance of a model the better the fit negative binomial has deviance and scale deviance value of 434.3440 while Poisson model have deviance and scale deviance value of 190624.8800, the Pearson chi-square and scale Pearson chi-square of negative binomial is344.0092**,** while that of Poisson model is 177755.2742. the smaller the values of Pearson chi-square and scale Pearson chi-square the better the model. The larger the log like hood of a model the better the fit. Binomial model has a log like hood of7855874.0693 while negative Poisson model has the value as 7762079.8080, the log like hood of negative binomial is larger

than the Poisson model and so negative binomial has the better fit. Looking also at the ratio of degree of freedom the smaller the value the better the fit negative binomial has the values as 1.0913 and0.8643 while poison has the values as 478.9570 and446.6213. conclusively negative binomial model is the best fit model for fish abundance and occurrence

CONCLUSION

In this research work, Shannon wiener and Sampson diversity index and abundance formular were used and applied to data collected for fish catch sampling survey and Generalise Linear regression model and negative binomial model were adopted for fish catch sampling survey of five different fishing location over the period of twelve years in southern basin of kainji lake Nigeria. The data is obtained from Artisanal fisheries, Research operation department National institute of freshwater fisheries research (NIFFR), Niger State. The result shows that, location does not have effect on fish catch ability. In this research, it was found that negative binomial model has a perfect result and best model for modelling fish abundance and occurrence.

REFERENCES

Adimula, AB, Fasakin, EA, & Adebayo, OT. (2021). Comparative study on the catch efficiency and size selection of entangling nets in Lake Kainji, Nigeria.

Amarasinghe, Upali S, & De Silva, Sena S. (2015). Fishes and fisheries of Asian inland lacustrine waters. Freshwater fisheries ecology, 384-403.

Bennett, Elizabeth. (2005). Gender, fisheries and development. Marine policy, 29(5), 451-459.

Bogstad, Bjarte, Hauge, KjellrunHiis, &Ulltang, Oyvind. (1997). MULTSPEC-A multi-species model for fish and marine mammals in the Barents Sea. Journal of Northwest Atlantic Fishery Science, 22.

Bohnett, Eve, Schulz, Jessica, Dobbs, Robert, Hoctor, Thomas, Hulse, Dave, Ahmad, Bilal, Waddle, Hardin. (2023). Shorebird Monitoring Using Spatially Explicit Occupancy and Abundance. Land, 12(4), 863.

Brummett, Randall E, Beveridge, Malcolm CM, &Cowx, Ian G. (2013). Functional aquatic ecosystems, inland fisheries and the Millennium Development Goals. Fish and Fisheries, 14(3), 312-324.

Bucher, Heiner C, Hengstler, Peter, Schindler, Christian, & Meier, Gabriela. (2002). N-3 polyunsaturated fatty acids in coronary heart disease: a meta-analysis of randomized controlled trials. The American journal of medicine, 112(4), 298-304.

Caddy, John F, & Mahon, Robin. (1995). Reference points for fisheries management.

Cameron, A Colin, & Trivedi, Pravin K. (2001). Essentials of count data regression. A companion to theoretical econometrics, 331.

Choudhary, Poonam, Khade, Monika, Savant, Sandip, Musale, Amar, Chelliah, Meenakshi Sundaram, & Dasgupta, Santanu. (2021). Empowering blue economy: From underrated ecosystem to sustainable industry. Journal of environmental management, 291, 112697.

Collen, Ben, Whitton, Felix, Dyer, Ellie E, Baillie, Jonathan EM, Cumberlidge, Neil, Darwall, William RT, Böhm, Monika. (2014). Global patterns of freshwater species diversity, threat and endemism. Global ecology and Biogeography, 23(1), 40-51.

Damsgaard, Jesper, Hjerrild, Simon, Andersen, Henning, &Leutscher, Peter Derek Christian. (2015). Long-term neuropsychiatric consequences of aseptic meningitis in adult patients. Infectious Diseases, 47(6), 357-363.

Dudgeon, D. (2011). Asian river fishes in the Anthropocene: threats and conservation challenges in an era of rapid environmental change. Journal of Fish Biology, 79(6), 1487-1524.

Fafioye, OO. (2011). Preliminary studies on water characteristics and bacterial population in high yield Kajola fish ponds. Journal of Agricultural Extension and Rural Development, 3(3), 68-71.

Faleke, Sunday Akinola, Nwabeze, Godfrey Onyechukwu, & Buhari, Habeeb Lola. (2023). Characteristics of Capture and Culture Fishery Production in Kainji Lake Basin, Nigeria. Journal of Agricultural Extension, 27(3), 35-40.

Faulks, Leanne, Svanbäck, Richard, Ragnarsson-Stabo, Henrik, Eklöv, Peter, &Östman, Örjan. (2015). Intraspecific niche variation drives abundance-occupancy relationships in freshwater fish communities. The American Naturalist, 186(2), 272-283.

Foster, Scott D, &Bravington, Mark V. (2013). A Poisson–Gamma model for analysis of ecological non-negative continuous data. Environmental and ecological statistics, 20(4), 533-552.

Geedipally, Srinivas Reddy, Lord, Dominique, &Dhavala, Soma Sekhar. (2012). The negative binomial-Lindley generalized linear model: Characteristics and application using crash data. Accident Analysis & Prevention, 45, 258-265.

Gerstenkorn, Tadeusz. (2006). Limit Property of The Compound Distribution Binomial-Generalized Two-Parameter Gamma.

Hall, Carolyn J, Jordaan, Adrian, & Frisk, Michael G. (2012). Centuries of anadromous forage fish loss: consequences for ecosystem connectivity and productivity. BioScience, 62(8), 723-731.

Halpern, Benjamin S, Frazier, Melanie, Potapenko, John, Casey, Kenneth S, Koenig, Kellee, Longo, Catherine, Selkoe, Kimberly A. (2015). Spatial and temporal changes in cumulative human impacts on the world’s ocean. Nature communications, 6(1), 1-7.

Hardin, James W, &Hilbe, Joseph M. (2014). Regression models for count data based on the negative binomial (p) distribution. The State Journal, 14(2), 280-291.

Royle, J Andrew, &Dorazio, Robert M. (2006). Hierarchical models of animal abundance and occurrence. Journal of Agricultural, Biological, and Environmental Statistics, 11, 249-263.