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Poisson Regression Model to Determine Factors of Microplastic Ingestion by African Catfish

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ABSTRACT

Poisson regression model is used to investigate the relationship among parameters when the response variable is a count data that follows Poisson distribution. The Poisson regression model is widely applied in various fields such as medical and epidemiological study. However, the application of this model in environmental science, particularly microplastic pollution is still limited. Small plastic particles with a size less than 5 mm or also known as microplastics are reported as an emerging pollutant in the aquatic environment. Microplastics have also been recognized as a serious threat to commercial fish through ingestion. Thus, the Poisson regression model was applied to determine factors that are contributed to the microplastic ingestion by African catfish. Three Poisson regression models were separately developed for each factor such as color, morphology, and environments. Based on the models, the significant difference was observed for all microplastic colors and morphology except for bead. Meanwhile, only two variables of water quality factor were significant and affected the number of ingested microplastics. In conclusion, the relationships between ingested microplastics and its factors was successfully represented using Poisson regression model.

Keywords: Poisson regression, microplastic ingestion, water quality, monsoon, environmental pollution.

1. Introduction

It is noted that the generalized linear model (GLM) with Poisson regression has been widely applied in various fields of study, where most of the research context is in biomedical research. For example, the model is extensively used to investigate the occurrence of several diseases and the effects of clinical treatments Parodi and Bottarelli (2006). However, in environmental study, most of the research scope was only focused on the particulate air pollution Zou (2004). Nonetheless, the application of this model in other pollution studies such as microplastics is still lacking, notably on their occurrence in the environments. Indeed, selection of the model is important as the model must fit the datasets. In general, Poisson regression is a common model to investigate the relationships among predictor variables and unknown parameters. In fact, this model is more appropriately applied to untransformed count data with a sample mean is equal to the sample variance (Hutchinson and Holtman (2005)). In this paper, the obtained dataset used for modelling is a count data and modelled in GLM using Poisson distribution. Therefore, due to this property, the Poisson regression model is employed to investigate the significant factors that influence to the ingestion of microplastics by African catfish.

2. Microplastics

Microplastics are formed through the breakdown of larger plastics into a smaller particle with size less than 5 mm. In general, microplastics are classified into two categories, namely the primary and secondary microplastics. The primary microplastics are comprised of raw resin pellet and beads. Most of this microplastics category is used for plastic goods manufacturing and as cleanser scrubbers. Primary microplastics are also used in industrial applications, such as air blasting. Contrariwise, the secondary microplastics are derived from the segmented plastic products as well as textile fibers (Frias and Nash (2019)). The investigation on the impact of microplastics in the environment has been reported by many studies. Regrettably, the ubiquity of microplastics have not only impacted the environment but also human health. For instance, the exposure of airborne microplastics can cause occupational disease, which can induce respiratory failure after inhalation of high concentration of synthetic plastic particles (Prata (2018)).

Interestingly, microplastics have also been found in honey, table salt, bottled water, dried and canned food (Rist et al. (2018)). In fact, the occurrence of microplastics has been reported as a hot topic worldwide due to its abundance and fate (Herrera et al. (2019) Zhang et al. (2018)). As of today, the ingestion of microplastics by various fish species have been reported by several studies. Indeed, this investigation is pertinent especially when the edible fish are economically important species and commonly consumed by human. Besides that, the accumulation of microplastics in their stomach has also drawn the attention of many researchers due to their adverse effect which can cause false satiation and starvation (Rummel et al. (2016)). Meanwhile, previous studies have also reported on the significant relationships of microplastic abundance and other factors such as based on seasons, extreme events, and water quality (Kataoka et al. (2019)).

3. Methods

The primary data was obtained by collecting 287 African catfish all year round (September 2017 to August 2018) from Skudai and Tebrau River. The selection of these rivers was considered based on previous report from the Department of Environment and Department of Irrigation and Drainage, Malaysia on rubbish pollution. Besides, a previous study has also reported on the occurrence of microplastics from surface sediment and different fish in both rivers as in Sarijan et al. (2018) and Sarijan et al. (2019). Microplastics were obtained from their gastrointestinal tract by digesting the whole tract in 10% potassium hydroxide (KOH). The reaction was left standing for 2 days at room temperature and filtered through 22 μm filter membrane. The filter was then transferred into 10 mL of saturated sodium chloride (NaCl) solution and shaken for 2 min by using orbital shaker. The solution was filtered again, oven dried at 30 $^{\circ}C$ for 2 min and ready to be observed under light microscopy (Sarijan et al. (2019)). In this study, the number of ingested microplastics by fish are represented as response variable (y). Three Poisson models were developed based on microplastic colour, morphology as well as environmental factors, where all these factors are denoted as predictor variables. The colours of microplastics are segregated into six variables such as blue, red, yellow, black, transparent, and white. Meanwhile, four microplastic morphology variables are film, fibre/line, foam and bead. There are two environmental factors investigated namely water quality and monsoon period. As for water quality, six variables are turbidity, pH, dissolved oxygen (DO), total dissolve solid (TDS), salinity and temperature. On the other hand, monsoon periods are segregated into southwest, northeast, and transitional period. The steps of analysis are as follow:

The Poisson regression model (Parodi and Bottarelli (2006)) is:

$$Y = e^{b_1 x_1 + b_2 x_2 + \cdots + b_k x_k}. \tag{1}$$

The probability density function of Poisson distribution is:

$$Pr(Y_i = y_i) = \frac{\mu_i^{y_i} \exp(-\mu_i)}{y!}, y_i = 0, 1, 2, \ldots \tag{2}$$

where Y_i is the random variable for Poisson distribution, with mean and variance are equal, $E(Y_i) = Var(Y_i) = \mu_i$. The multi predictor variables of Poisson regression model in this study was observed through:

$$\mu_i = \exp(\mathbf{x}_i^T, \beta); i = 1, 2, \ldots, k, \tag{3}$$

where x_i is a vector of covariates and β is the vector of regression parameters. The estimates of β may be obtained by using the maximum likelihood method. In this model, the maximum likelihood estimation $L(\beta)$ function is:

$$L(\beta) = \prod_{i=1}^{n} \frac{\mu_i^{y_i} \exp(-\mu_i)}{y!} \tag{4}$$

where, n is the number of sample variable.

4. Results and Discussion

The analyses were conducted using R statistical packages. The number of ingested microplastics in African catfish GI tract from both rivers ranged from 0 to 10. The preliminary analysis shows that the dependent variable was highly skewed distributed (Figure 1). Meanwhile, the output of the Poisson regression model has been shown in Table 1. The study intends to describe the effect of colour (Model 1) and shape (Model 2) separately as to understand their influence on the ingestion of microplastics by fish. It is pertinent since some fish species preferably consume particles based on different morphological and colours appearance. Thus, none of the morphology nor colour variable was selected as a reference group in both models. On the other hand, environmental factors and seasonality are combined together as the third model, therefore, a comprehensive effect of water quality and monsoon period to the number of ingested microplastics by catfish could be obtained.

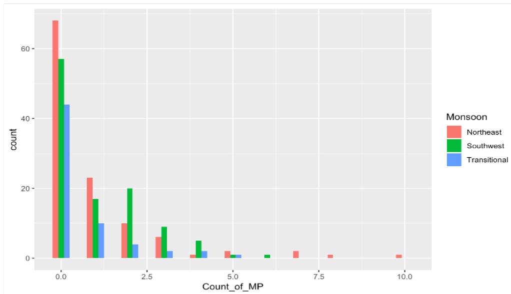

Figure 1: The concentration of ingested microplastics by fish follows Poisson distribution based on monsoon period.

Table 1: The output for Poisson regression Model 1, Model 2, and Model 3.

Coefficients: Model	Estimate	Std. Error	z value	Pr $(>\|z\|)$
Model 1				
(Intercept)	−0.95993	0.09408	−10.203	< 2e-16***
Red	0.50702	0.09527	5.322	1.03e-07 ***
Yellow	0.59737	0.10326	5.785	7.26e-09 ***
Blue	0.51665	0.06065	8.518	< 2e-16 ***
Black	0.34105	0.08207	4.156	3.24e-05 ***
White	0.21320	0.07196	2.963	0.00305 **
Transparent	0.59819	0.06713	8.911	< 2e-16 ***
Model 2				
(Intercept)	−1.04500	0.09872	−10.586	< 2e-16 ***
Fiber	0.67876	0.04853	13.985	< 2e-16 ***
Film	0.48279	0.04105	11.762	< 2e-16 ***
Fragment	0.31663	0.05507	5.750	8.93e-09 ***
Foam	0.45544	0.11724	3.885	0.000102 ***
Bead	1.05939	0.71162	1.489	0.136564
Model 3				
(Intercept)	−1.06888	3.30289	−0.324	0.74623
Southwest	0.35177	0.20092	1.751	0.07999 .
Transitional	−0.32092	0.20076	−1.598	0.10993
Turbidity	0.01426	0.00753	1.892	0.05844 .
pH	1.23155	0.82138	1.499	0.13378
DO	0.15967	0.12411	1.286	0.19829
TDS	0.00550	0.00155	3.551	0.00038***
Salinity	− 5.15084	1.62949	−3.161	0.00157 **
Temperature	−0.31896	0.17858	−1.786	0.07408 .

Signif. Codes : 0 '***' , 0.001 '**', 0.01 '*', 0.05 '.' , 0.1 ' ' , 1

Table 2 summarizes the significant factors that contribute to the number of ingested microplastics by African catfish. The results showed that most of the variables in Model 1 and 2 have a significant p-value less than 0.05. Conversely, only five variables were significant in Model 3. Hence, in this study, three models have been proposed based on the estimation value where the proposed models are as follow:

Model 1: Microplastics Color

$$\ln(number\, of\, MP) = -0.960 + 0.507(red) + 0.597(yellow) + 0.517(blue) + 0.341(black) + 0.213(white) + 0.598(transparent) \quad (5)$$

Model 2: Microplastics Morphology

$$\ln(number\, of\, MP) = -1.045 + 0.679(fiber) + 0.483(film) + 0.317(fragment) + 0.455(foam) \quad (6)$$

Model 3: Water Quality and Monsoon Period

$$\ln(number\, of\, MP) = -1.069 + 0.005(TDS) - 5.151(salinity). \quad (7)$$

Table 2: Factors that affect the number of ingested microplastics by fish based on different models.

Factor	Model 1	Model 2	Model 3
Color			
Red	***		
Yellow	***		
Blue	***		
Black	***		
White	**		
Transparent	***		
Morphology			
Fiber		***	
Film		***	
Fragment		***	
Foam		***	
Bead			
Water quality			
Turbidity			
pH			
DO			
TDS			**
Salinity			*
Temperature			
Monsoon period			
Northeast			
Southwest			
Transitional			

Signif. Codes : *** 0.00, **0.001, and * 0.01, respectively.

In the present study, the significant of particle characters to influence the number of ingested microplastics by African catfish can be observed through the proposed models. Thus, it reveals that the ingestion of microplastic characters by the studied fish was selectively based. Nonetheless, a previous study of the polysensory bases of the feeding behaviour has indicated that African catfish have shown a well-developed visual reception in light, where the fish able to selectively consume food items by colour (Fatollahi and Kasumyan (2006)). To indicate this, in Model 1, the analyses showed that the estimate for transparent was higher compared to yellow, blue and red colours. Meanwhile, black and white were the least particles ingested by the studied fish. The present result is also in a good agreement with previous studies of which reported that the transparent and blue microplastics often found in fish stomach obtained from the environment (Ory et al. (2018)). In general, the African catfish is regarded as a predator and able to consume all types of feed (Yalçin et al. (2001)).

On the other hand, the estimate for fibre, film and foam were higher than of fragment, indicating the most predicted characters ingested by the African catfish (Model 2). It is because most of the fish species preferably ingest soft rather than harder particles, per se (Tanaka and Takada (2016)). Besides, Ory et al. (2018) reported that hard fragment particles rarely swallowed by the fish. In contrast, only microbead was not significant in this model. The possible reason is that the number of microbeads found in the present study was too small as most of them are efficiently removed in sewage treatment plant through the sedimentation process (Tanaka and Takada (2016)). Nevertheless, the presence of microbeads in the aquatic biome is of major concern because of their non-biodegradable property and able to stay for a long time in the environment (Tanaka and Takada (2016)).

Meanwhile, other statistical information from this method can be perceived where most of the continuous variables showed significant results. Based on Model 3, the increment of 1 mg/L (TDS unit) would increase one particle of ingested microplastics by African catfish. It is noted that the high concentration of TDS in the water column may reduce water clarity. Indeed, the event can lead to visual disturbance for fish in recognising food items. It has been reported that, most of the fish relying mainly on vision to search and assess the food items in the aquatic environments. Nonetheless, when the environmental condition is under a minimum illumination due to limited penetration of light, hence it inhibits the assessment of food items edibility. Interestingly, African catfish have the alternative sensory systems such as a tactile sense of which able to sense smell and taste via their skin and barbels even in a dark surrounding (Fatollahi and Kasumyan (2006)). Thus, this indicated that, besides colour, the scent of microplastics has also influenced the fish food preferences

(Savoca et al. (2017)). Therefore, without discriminating colours, the ingestion of microplastic particles indirectly during the feeding period through its scent could also occur in the environment.

Contrariwise, salinity do not give much effect to the number of microplastics. However, the number of ingested microplastics by benthopelagic species may possibly increase when their population area is farther away from the high salinity environment. Since freshwater has a lower density, sedimentation of several plastic polymers in rivers is higher compared to the marine environment (Filella (2015)). Thus, besides the possibility to ingest microplastics through water column, the incident of microplastic ingestion while foraging surface sediment for benthic organisms could also be one of the possible factors.

5. Conclusion

The study has successfully proposed the Poisson regression model on the microplastics pollution data. In this study, all microplastics colour and morphology influenced the ingestion of microplastics by the African catfish except the microbead. Meanwhile, the third model shows that only TDS influenced the number of ingested microplastics.

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