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Probabilistic model for explain spatial distribution in *Echinolittorina peruviana* (Lamarck, 1822) in rocky shore (23°S, Antofagasta, Chile)

Modelo probabilístico para explicar distribución espacial en *Echinolittorina peruviana* (Lamarck, 1822) en costa rocosa (23°S, Antofagasta, Chile)

Patricio R. De los Ríos-Escalante[1,2,3], Diego I. Gallardo[4], Héctor W. Gómez[5]

1 Departamento de Ciencias Biológicas y Químicas, Facultad de Recursos Naturales, Universidad Católica de Temuco, Casilla 15-D, Temuco, Chile. <prios@uct.cl>
2 Núcleo de Estudios Ambientales UC Temuco, Casilla, Temuco, Chile.
3 Estudiante programa de Magister en Estadística, Instituto de Estadística, Facultad de Ciencias, Pontificia Universidad Católica de Valparaíso, Av. Brasil 2830, Valparaíso, Chile.
4 Departamento de Estadística, Facultad de Ciencias, Universidad del Bío-Bío, Concepción 4081112, Chile. <dgallardo@ubiobio.cl>
5 Departamento de Estadística y Ciencias de Datos, Facultad de Ciencias Básicas, Universidad de Antofagasta, Av. Universidad de Antofagasta 02800, Antofagasta 124000, Chile. <hector.gomez@uantof.cl>

Abstract

The spatial patterns in benthic flora and fauna have three types: random, uniform and aggregated. Usually models to fit this are the Poisson, binomial or negative binomial distributions, respectively. However, for specific cases such models cannot be appropriated. The aim of the present study is to analyze data of gastropod *Echinolittorina peruviana* (Lamarck, 1822) obtained in rocky shore of Antofagasta north of Chile, with in order to determine a reasonable model for explain its spatial distribution. The results revealed that individuals have an aggregated pattern, but not all populations have negative binomial distribution, and it was proceeded to determine an alternative model to the negative binomial distributions family to explain the spatial distribution. The results revealed that population distribution can be adjusted to a

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Waring model. These results would agree with literature descriptions that negative binomial distribution is not the exclusive pattern that can explain the aggregated pattern in gregarious species.

Keywords: *Echinolittorina peruviana*, rocky shore, aggregated pattern, negative binomial distribution, Waring distribution.

Resumen

Los patrones espaciales en la flora y fauna bentónica tienen tres patrones aleatorios, uniformes y agregados. Generalmente los modelos que se ajustan a esto son las distribuciones de Poisson, binomial o binomial negativa, respectivamente. Sin embargo, para casos específicos tales modelos no pueden ser apropiados. El objetivo del presente estudio es analizar datos del gasterópodo *Echinolittorina peruviana* (Lamarck, 1822) obtenidos en la costa rocosa de Antofagasta al norte de Chile, con el objetivo de determinar un modelo razonable que explique su distribución espacial. Los resultados revelaron que los individuos tienen un patrón agregado, pero no todas las poblaciones tienen distribución binomial negativa, por lo que se procedió a determinar un modelo alternativo a la familia de distribuciones binomiales negativas para explicar la distribución espacial. Los resultados revelaron que la distribución de la población se puede ajustar a un modelo de Waring. Estos resultados estarían de acuerdo con las descripciones de la literatura de que la distribución binomial negativa no es el patrón exclusivo que puede explicar el patrón agregado en especies gregarias.

Palabras clave: *Echinolittorina peruviana*, costa rocosa, patrón agregado, distribución binomial negativa, distribución de Waring.

INTRODUCTION

The spatial distribution in flora and fauna can be explained with statistical and probabilistic models, first the main patterns are random when there is not a structured pattern, the second option is when the individuals have an spatial regular pattern, or uniform, and the third is not a option when the individuals have an aggregated pattern (Brower et al., 1998; Zar, 1999; Fernandes et al., 2003). The uniform pattern occurs when the individuals have territorial behaviour, whereas the aggregated pattern occurs when the individuals have gregarious behaviour (Brower et al., 1998; Fernandes et al., 2003).

The first descriptions in the literature mentioned these three general distribution patterns, random, uniform and aggregated can be fitted to Poisson, binomial and negative binomial (NB) distributions (Elliot, 1983; Fernandes et al., 2003). In relation to aggregated pattern, the literature mentioned that NB distribution is the main probabilistic model that adjust, but it is possible found other probabilistic models (Elliot, 1983), nevertheless the more recent literature give priority to NB distribution for explain aggregated patterns (Zar, 1999; Fernandes et al., 2003; De los Ríos-Escalante et al., 2023).

These probabilistic models are used to analyze aquatic benthic populations (Elliot, 1983), and although this first description was done for inland waters environments, it can be utilized for marine environments (De los Ríos-Escalante and Carreño, 2019; De los Ríos-Escalante et al., 2023). One benthic marine species that can be interesting for applied probabilistic distribution models is the gastropod *Echinolittorina peruviana* (Lamarck, 1822) that inhabits among rocky shores along chilean territory (Santelices, 1992; Lee et al., 2008), specifically in upper levels (Castillo and Brown, 2010) and southern Perú (Tejada-Perez et al., 2018), and it has aggregated patterns (De los Ríos-Escalante et al., 2023).

The aim of the present study is do determine the best model for explain the aggregated distribution pattern of *E. peruviana* adults specimens (10-15 mm total length) in a population from rocky intertidal environments in Antofagasta town, northern Chile, that had an aggregated pattern but it has not a NB distribution (see data from De los Ríos-Escalante et al., 2023).

MATERIAL AND METHODS

Data collection and analysis: it was used the data obtained from De los Ríos-Escalante et al. (2023), for was thrown out random, 10 * 10 cm quadrants (n = 40 for each site), considering the relative small size of considered species (Underwood, 2004; Underwood and Chapman, 2005; Ahmad et al., 2011). For those analyses where one site that has *E. peruviana* absence has not been considered. To each specie counting data (dislocated to zero, say M_iM_i), was obtained in first instance a variance mean ratio, as value was upper than 1, this corresponds to aggregated pattern (Brower et al., 1998; Zar, 1999; Fernandes et al., 2003). It was considered data of Coloso site (23°45'35.6"S; 70°27'41.9"W) that in according to literature has aggregated pattern, but it has not necessary NB distribution (Cf: De los Ríos-Escalante et al., 2023; Table 1). On these antecedents, we suggest that Waring distribution that is a model included in NB distributions group would be a potential probabilistic model that would explain the spatial distribution of this population.

We consider the NB distribution with probability mass function (pmf) given by

$$P(M=m)=\frac{\Gamma\left(m+\frac{\mu}{\sigma}\right)}{\Gamma\left(\frac{\mu}{\sigma}\right)\Gamma(m+1)}\sigma^{m}(1+\sigma)^{-\left(m+\frac{\mu}{\sigma}\right)}, m=0,1,2,\ldots,\mu,\sigma>0.$$

With this parametrization, $E(M)=\mu$ and $Var(M)=\mu(1+\sigma)$. On the other hand, the Waring distribution has pmf given by

$$P(M=m)=\frac{(1+\sigma)\Gamma\left(m+\frac{\mu}{\sigma}\right)\Gamma\left(\frac{(\mu+\sigma+1)}{\sigma}\right)}{\sigma\Gamma\left(m+\frac{(\mu+1)}{\sigma}+2\right)\Gamma\left(\frac{\mu}{\sigma}\right)},m=0,1,2,\ldots,\mu,\sigma>0,$$

Where $E(M)=\mu$ and $Var(M)=\mu(\mu+1)(1+\sigma)/(1-\sigma)$. To obtain the maximum likelihood estimation, we use the gamlss package (Rigby and Stasinopoulos 2005) of the R software (R Development Core Team, 2023).

We use as selection criteria according to AIC and BIC. Lower values for such criteria suggest a more appropriate model for a specific data set. Finally, we also perform a residual analysis based on the quantile residuals (Zuur et al., 2007), which also can be computed with the gamlss package. If the model were correctly specified, such residuals should be a random sample from the standard normal distribution, which can be validated, for instance, with traditional normality tests as the Shapiro-Wilks, the Cramer-Von-Mises and the Anderson-Darling tests (Zuur et al., 2007)

RESULTS AND DISCUSSION

The results confirmed that original data has aggregated pattern due the value of variance/mean ratio (7.62 that is upper than 1.0), but in spite of the of aggregated pattern it has not NB distribution:

$$\left(\chi \| obs^2=463.6168>\chi^2_{(\alpha=0.05;\, v=39)}=28.336\,; Fig.1\right)$$

On this basis, it was revised, and it had adjust to NB or Waring distribution models that are distribution models within the group of NB distribution, the results revealed that analyzed data is adjusted to Waring distribution (Tables 2 and 3, Fig. 2).

The exposed results revealed that the presence of Waring distribution that belongs to the NB distribution, agree with literature descriptions about that aggregated pattern has not as obligatory condition the NB distribution (Elliot, 1983; De los Ríos-Escalante, 2017; De los Ríos-Escalante et al., 2023). In this scenario this species has aggregated pattern as life strategy as protection against stressor effects of desiccation during lower tide, and efficient use of trophic resources (De los Ríos-Escalante et al., 2023), similar results had been observed for intertidal mollusks in northern Patagonian rocky shores (De los Ríos and Carreño, 2020).

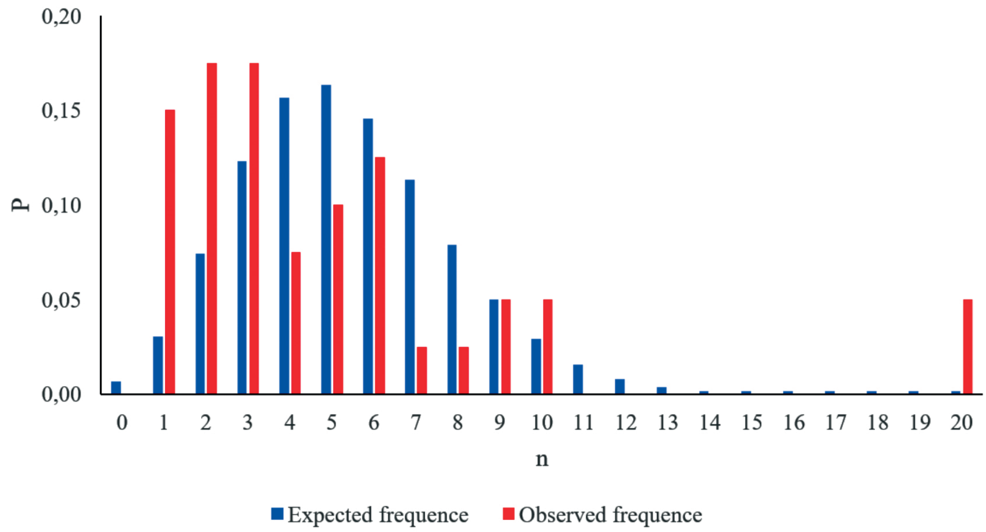

Fig. 1. Comparison of theoretically expected NB distribution and observed frequence of *Echinolittorina peruviana* for from Antofagasta rocky shore (Cf: De los Ríos-Escalante et al., 2023).

Fig. 1. Comparación teórica esperada para distribución NB y frecuencia observada para *Echinolittorina peruviana* for costa rocosa de Antofagasta (Cf: De los Ríos-Escalante et al., 2023).

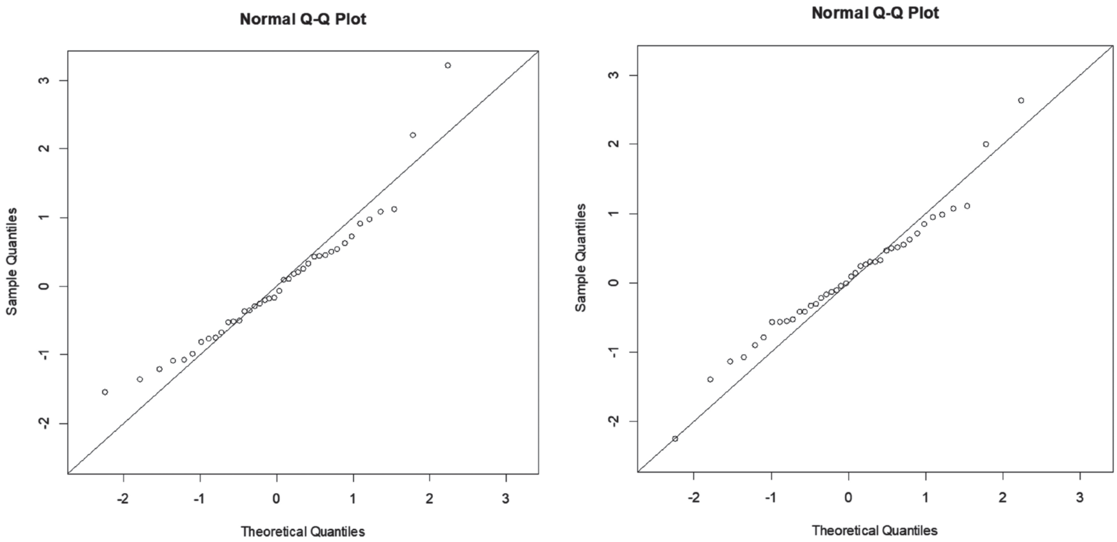

Fig. 2. Quantile residuals for NB (upper panel) and Waring (lower panel) models for Echinolittorina peruviana data set collected from Antofagasta rocky shore (Cf: De los Ríos-Escalante et al., 2023).

Fig. 2. Residuos de los cuantiles para modelos NB (panel superior) y Waring (panel inferior) para *Echinolittorina peruviana* for costa rocosa de Antofagasta (Cf: De los Ríos-Escalante et al., 2023).

Table 1. Original data on the abundance of *Echinolittorina peruviana* individuals per quadrant (10 x 10 cm) collected in Caleta Coloso (Cf: De los Ríos-Escalante et al., 2023) considered in the present study.

Tabla 1. Datos originales de abundancia de individuos de *Echinolittorina peruviana* por cuadrante (10 x 10 cm) colectados en Caleta Coloso (Cf: De los Ríos-Escalante et al., 2023) considerados en el presente estudio.

n	Individuals	n	Individuals	n	Individuals	n	Individuals
1	1	11	10	21	4	31	22
2	2	12	6	22	2	32	1
3	2	13	3	23	4	33	3
4	5	14	10	24	6	34	2
5	6	15	9	25	5	35	2
6	3	16	37	26	6	36	3
7	1	17	9	27	7	37	1
8	8	18	5	28	6	38	2
9	3	19	4	29	3	39	2
10	5	20	1	30	3	40	1

Table 2. Parameters estimated and selection criteria for NB and Waring models for *Echinolittorina peruviana* for the data set collected from Antofagasta rocky shore (Cf: De los Ríos-Escalante et al., 2023).

Tabla 2. Parámetros estimados y criterio de selección para modelos de distribución NB y Waring para el set de datos de *Echinolittorina peruviana* colectados para la costa rocosa de Antofagasta (Cf: De los Ríos-Escalante et al., 2023).

Parameter	NB	Waring
$log\ (\mu)$	1.4776 (0.1786)	1.4676 (0.2136)
$log\ (\sigma)$	1.5221 (0.3284)	-1.5980 (1.0950)
AIC	210.57	208.72
BIC	213.94	212.10

Table 3. P-values for normality test in for *Echinolittorina peruviana* data set collected from Antofagasta rocky shore (Cf: De los Ríos-Escalante et al., 2023) for NB and Waring models.

Tabla 3. Valores de P para la prueba de normalidad para el set de datos *Echinolittorina peruviana* colectados para la costa rocosa de Antofagasta (Cf: De los Ríos-Escalante et al., 2023) para los modelos NB y Waring.

Test	NB	Waring
Shapiro-Wilks	0.0055	0.6864
Cramer-Von-Mises	0.2432	0.7999
Anderson-Darling	0.0794	0.6652

The absence of NB distribution pattern was observed with these data, but the presence of other probabilistic model included in the group of "NB distribution" would be explained for other ecological characteristics such as predator exposure, trophic resources availability or topographic characteristics such as happens in rocky shores (Underwood, 2004; Aguilera & Navarrete, 2011, 2012; De los Ríos and Carreño, 2020; De los Ríos-Escalante et al., 2020). Then, it would be interesting based on counting data of flora and fauna, do a contrast if these counting data are adjusted to probabilistic models that are beyond than traditional models that explain spatial distribution such as binomial, NB or Poisson distribution. As conclusion, the analyzed data in the present study has not NB distribution, but it had Waring distribution that is included in the NB probabilistic distribution models, and would support the presence of aggregated pattern as response to ecological characteristics of the habitat of the studied population.

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