PROBABILITY MODELS FOR THE DISTRIBUTION OF COPEPODS IN DIFFERENT COASTAL ECOSYSTEMS ALONG THE STRAITS OF MALACCA

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Copepods are the most abundant microcrustaceans in the marine waters and are the major food resource for many commercial fish species. In addition, changes in the distribution and population composition of copepods may also serve as an indicator of global climate changes. Therefore, it is important to model the copepod distribution in different ecosystems. Copepod samples were collected from three different ecosystems (seagrass area, cage aquaculture area and coastal waters off shrimp aquaculture farm) along the coastal waters of the Malacca Straits over a one year period. In this study the major sta-

tistical analysis consisted of fitting different probability models. This paper highlights the fitting of probability distributions and discusses the adequateness of the fitted models. The usefulness of these fitted models would enable one to make probability statements about the distribution of copepods in three different ecosystems.

Keywords: Probability models; Copepods; Coastal ecosystems.

Mathematics subject classification: 62P10

1. Introduction

Copepods are considered to be the most important metazoan secondary producers in marine ecosystems both in terms of abundance and biomass. They play a vital role serving as a link between phytoplankton and higher trophic levels. Studies of zooplankton in coastal and even oceanic waters of the world have shown that copepods constitute the most important group in marine zooplankton communities. Copepods dominate the zooplankton of most tropical waters including Malaysia. In fact, studies in the coastal and neritic waters along the Straits of Malacca show that copepods accounted for more than 60% of the zooplankton collected.¹ Copepods have ubiquitous distribution and high relative abundance; therefore, they constitute the most important group in marine zooplankton communities.

In describing the distribution and estimating the abundance of copepods in the marine ecosystems, it has become increasingly evident that individuals are seldom, if ever, randomly distributed in space. Most commonly, the distribution of sample counts' variance is in excess of random expectation (i.e. greater than their mean) or the distribution of samples are not normal. In fact, most biological communities tend to aggregate in the seas due to their natural behaviour. In such cases, it may be regarded that the precision of the estimate is correspondingly reduced. However, if the data set is not normally distributed or there is excess variance, these may imply that the distribution of individuals has a partially determined pattern, and thus may be regarded as a reservoir of information about the behaviour of the organisms concerned. Suitable mathematical models, which describe this pattern, may be an aid to the extraction of many important information.

Therefore, in this study, different probability models were fitted to the data set to find the most suitable fit, which in turn may enable one to make probability statements about the distribution of copepods in different ecosystems.

2. Materials and Methods

2.1. Location of the study

Three different habitats in three different locations along the coastal zone of the Straits of Malacca were selected (Fig. 1); these are the coastal waters off a shrimp aquaculture farm (SF), sea grass beds/meadow (SG) and cage mariculture area (CA).

Fig. 1. Map of the Straits of Malacca. Arrows indicate the sampling locations along the coastal zones of the Straits.

2.1.1. Coastal waters of shrimp aquaculture farm

Kuala Selangor is a fishing village located in Sungai Selangor estuary and is also popularly known for the firefly habitat, associated with mangrove species, *Sonneratia caseoloris*. Kuala Selangor estuary is the end point of several rivers that received both the domestic and industrial waste discharges before entering the Malacca Strait. The sampling stations were located 1 km away from the thinned mangrove forest which can barely hide the shrimp aquaculture farm from the view.

2.1.2. Seagrass bed/meadow

The seagrass meadow popularly known as Merambong shoal is approximately 40-ha oval shaped meadow (it stretches almost 2 km long at the largest patch) located between the Causeway second link and the Pulau Merambong, Southwest of Johore in Peninsular Malaysia and is the most extensive seagrass covered subtidal shoal in Malaysian waters.² The seagrass bed is vegetated by seagrass species which were mainly *Enhalus acroides*, *Halopila* spp. and *Syringodium* spp among others. Around the area nearby the seagrass meadow is slated for heavy industry (a large port, chemical processing plants, oil and gas refineries and storage and a power-plant).

2.1.3. Cage mariculture area

Pulau Ketam cage mariculture area is located along the coastal waters of the Straits of Malacca, which is 12 nautical miles away from the Port Klang (one of the major Malaysian industrial ports). Floating cages are set up in calm water, which is situated behind an island (Pulau Ketam) near a river mouth. The water depth is at average 8 m during the highest high tide and 5-6 m during low tide. The

site is relatively free from domestic, industrial and agricultural wastes and other environmental hazards.

2.2. Copepod sample collection

Samples were collected using conical shaped (with mouth opening size of 0.30 m and 1.00 m length) plankton net with 100 mesh with an acrylic plastic cod end. Triplicate samples from four randomly selected stations from different ecosystems were collected. Samples were carefully transferred in labeled sample bottles and immediately preserved with 5% buffered (pH 8.0-8.2) formalin.³

2.3. Copepod density estimation

Samples were filtered in a 350 m mesh size net filter to separate the bigger organisms (in this case the entire copepod portion passed through the net due to their smaller size). Then the remaining portion was sorted out under dissecting microscope (Nikon model SMZ645) to separate the copepod from non-copepod portions. For the highly concentrated samples, dilution was performed before sub sampling was done. The samples were first poured in the 500 ml graduated cylinder and diluted with filtered sea water to 200-500 ml volume depending on how concentrated the sample was. Using a Stempel pipette, 10 ml of the sample was drawn and transferred into a Bogorov counting chamber and counted under the Nikon dissecting microscope (Nikon model SMZ645). The copepod density was calculated according to the formula:⁴

$$N = \frac{nS}{w}$$

where N is the number of individuals per cubic meter of water filtered, n is the number of individuals in the subsample (10ml), S is the fraction number of the subsample (250/10) and w is the volume of water filtered. Note that volume of water filtered was calculated following Ref. 5 as,

$$\text{Volume of water filtered } (w) = As$$

where A is the mouth area of the net and s is the depth of tow.

2.4. Statistical analysis

The main statistical analysis done in this study is to fit probability models to the copepods data observed at the above-mentioned ecosystems. We fitted several types of distributions to the data set and then compared how well they fit the data. Three probability distributions namely, *Normal*, *Gamma* and *Log-normal*, were considered in this study. The probability densities of these distributions are respectively listed below,

$$f(y) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(y-\mu)^2}{2\sigma^2}}, \quad y \in \mathbb{R}, \mu \in \mathbb{R}, \sigma^2 > 0$$

$$f(y) = \frac{1}{\Gamma(\alpha)\beta^\alpha} y^{\alpha-1} e^{-\frac{y}{\beta}}, \quad y > 0, \alpha > 0, \beta > 0$$

$$f(y) = \frac{1}{y\sqrt{2\pi}\sigma} e^{-\frac{(\ln y - \mu)^2}{2\sigma^2}}, \quad y > 0, \mu \in \mathbb{R}, \sigma^2 > 0$$

Since the values of the original data $\{x_1, x_2, \dots, x_n\}$, were very large, they were transformed to $y_i = x_i/c$, $\{i = 1, \dots, n\}$, where $c = 300,000$ (for SF) and $20,000$ (for SG and CA). This transformation was done in order to avoid numerical difficulties.

To the transformed data $\{y_i\}$, we fitted the *Normal*, *Gamma* and *Log-normal* distributions. Since $y_i = x_i/c$, we have $x_i = cy_i$. Using the *moment generating function*, it can be shown that if $Y_i \sim \text{Normal}(\mu, \sigma^2)$, then $X_i \sim \text{Normal}(c\mu, c^2\sigma^2)$. Similarly, it can be shown that if $Y_i \sim \text{Gamma}(\alpha, \beta)$, then $X_i \sim \text{Gamma}(\alpha, c\beta)$. However, the *moment generating function* does not exist for the *Log-normal* random variable but by using the *characteristic function*, we can still show that if $Y_i \sim \text{Log-Normal}(\mu, \sigma^2)$, then X_i is also *Log-Normal* $(\mu + \ln c, \sigma^2)$.

Finally the adequateness of the models were accessed by Q-Q plots, goodness-of-fit tests (Chi-square test and Kolmogrov-Smirnov test) and *AIC* statistic.⁶ A somewhat straight Q-Q plot indicates a good fit. The null hypothesis of the goodness-of-fit test is that the data is consistent with the hypothesized distribution. The higher the *p*-value of these tests, the closer the fitted distribution appears to match the data. The *AIC* statistic is defined as,

$$AIC = 2k - 2 \ln L$$

where k is the number of parameters in the statistical model, and L is the maximized value of the likelihood function for the estimated model. Given a set of candidate models for the data, the preferred model is the one with the minimum *AIC* value.

The entire statistical analysis was done using the *R* statistical package.

3. Results and Discussion

In this section the results are discussed. In subsection 3.1 the results for *coastal waters of shrimp aquaculture farm* are discussed. In subsections 3.2 and 3.3 the results for *sea grass bed* and *cage mariculture area* are presented, respectively.

3.1. Coastal waters of shrimp aquaculture farm

In Table 1 the results for the fitted distributions are shown. Using Chi-square test, it shows that the *Normal* distribution is not suitable to the data because of the very small *p*-value of 0.00000635 (Table 1). Similarly, the Kolmogrov-Smirnov test also rejects the null hypothesis that the data is *Normal* at 0.05 α -level. On the other hand, the *p*-value of both the Chi-square and Kolmogrov-Smirnov tests for the *Log-normal* distribution is larger than the *Gamma* distribution. In addition, the *AIC* statistics for the *Log-normal* distribution is less than the *Gamma* distribution,

Table 1. Goodness-of-fit tests for the fitted distributions to the transformed SF data.

Fitted distribution	AIC	Goodness-of-fit test (p-value)	
		Chi-square	Kolmogorov-Smirnov
<i>Normal</i> (5.367, 12.797)	391.870	0.00000635	0.02975
<i>Gamma</i> (2.408, 2.229)	364.946	0.064	0.3172
<i>Log-normal</i> (1.458, 0.469)	363.894	0.257	0.6641

Fig. 2. Q-Q plots of the Fitted distributions to the transformed SF data.

suggesting a better fit than the *Normal* and *Gamma* distribution to the copepod data.

From the Q-Q plot it is also evident (Fig. 2) that the *Log-normal* is also the better fit in comparison with *Normal* and *Gamma* distributions. Figure 3 shows the histogram of the copepod data which is over-layered by the fitted probability curves. Based on these evidence, it appears that the *Log-normal* is a reasonable fit.

3.2. Seagrass bed/meadow

From Table 2 we can see that the *Normal* and *Gamma* distributions are not suitable to the copepod data. It clearly rejects the null hypothesis at 0.05 level for

Fig. 3. The fitted probability curves to the transformed SF data.

Table 2. Goodness-of-fitted distribution to the transformed SG data.

Fitted distribution	AIC	Goodness-of-fit test (p-value)	
		Chi-square	Kolmogrov-Smirnov
<i>Normal</i> (10.789, 186.068)	584.607	2.838e-44	1.161e-05
<i>Gamma</i> (0.713, 1.402)	484.299	1.226175e-06	8.882e-16
<i>Log-normal</i> (1.533, 1.800)	471.446	0.003	0.227

both Chi-square and Kolmogrov-Smirnov tests. Note that the *AIC* statistics for the *Log-normal* has the lowest value among the three distributions. Moreover, the *p*-value of the Kolmogrov-Smirnov test is greater than 0.05, suggesting that *Log-normal* distribution is the reasonable fit for the copepod data amongst the three distributions. It is also evident from the Q-Q plot (Fig. 4) that the *Log-normal* is the better fit in comparison with both the *Normal* and *Gamma* distributions. Figure 5 shows the histogram of the copepod data which is over-layered by the fitted probability curves.

3.3. Cage mariculture area

In Table 3 the results for the fitted distribution are shown. The null hypothesis for the goodness-of-fit tests are not rejected for all the three distributions. However, among the three distributions considered in this study, the Chi-square and Kolmogrov-Smirnov test shows higher *p*-values for the *Log-normal* distribution which may suggest a better fit. Similarly, the Q-Q plot (Fig. 6) also shows that the *Log-normal* has the better fit. On the other hand, the *AIC* statistics for the

Fig. 4. Q-Q plots of the Fitted distributions to the transformed SG data.

Fig. 5. The fitted probability curves to the transformed SG data.

Table 3. Goodness-of-fitted distribution to the transformed CA data.

Fitted distribution	AIC	Goodness-of-fit test (p-value)	
		Chi-square	Kolmogorov-Smirnov
<i>Normal</i> (1.689, 0.267)	113.319	0.256	0.1482
<i>Gamma</i> (10.519, 0.161)	109.691	0.599	0.5522
<i>Log-normal</i> (0.476, 0.101)	111.517	0.665	0.6046

Fig. 6. Q-Q plots of the Fitted distributions to the transformed CA data.

Gamma distribution has the lowest value among the three distributions. Therefore in this case, it is rather difficult to make a choice between the *Gamma* and *Log-normal* distributions. Figure 7 shows the histogram of the copepod data which is over-layered by the fitted probability curves.

4. Conclusion

The objective of this study was to fit probability distributions to copepods observed in three different ecosystems in coastal waters of the Straits of Malacca. It is quite clear in this study that the *Log-normal* distribution is the better fit (compared with *Gamma* or *Normal* distribution) for the two ecosystems, namely *coastal waters of*

Fig. 7. The fitted probability curves to the transformed CA data.

shrimp aquaculture farm and *seagrass bed/meadow*. However, for the *cage mariculture area* it is quite difficult to make a choice between *Log-normal* and *Gamma* distribution since both were somewhat close to each other. This is an initial study where we have only considered three distributions. The authors plan to investigate a wider range of distributions which will be reported in a future paper.

Acknowledgments

This research is supported with the e-Science fund (Project No. 04-01-04-SF0418) and IOC-TEMA Research Grant No: 4500025145.

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