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MODELLING THE ENVIRONMENTAL AND BIOLOGICAL CUES FOR THE BLOOM OF SERGESTID SHRIMP *Acetes* (DECAPODA: SERGESTIDAE) IN COASTAL WATER OF MIRI, SARAWAK, MALAYSIAN BORNEO

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ABSTRACT

The sergestid shrimp (*Acetes* spp.) shows the annual peak season from February to April. This krill-like shrimp, locally known as 'bubok', is one of the commercially important fisheries in Miri, Sarawak, Malaysian Borneo. Previous researchers had reported patchy data on the environmental factors and Acetes distribution in Miri-Bintulu adjacent areas. Moreover, insufficient analysis has led to the inability to conduct sustainable management strategies for *Acetes* fisheries. Therefore, this study is designed to explore the mathematical model usage to understand the interaction between selected water quality parameters and zooplankton assemblages with the *Acetes* population in the coastal water of Miri. Selected temporal biotic and abiotic data were collected using standard methods and later subjected to mathematical time series analysis called the Granger causality test. The results show bi-directional Granger causality between the abundance of *Acetes* and dissolved oxygen (DO). Interaction between other water quality parameters (temperature, salinity, turbidity, pH, TSS and *Chlorophyll a*) with the abundance of *Acetes* has also emerged. The number of zooplankton in the water column, namely *Centropages*, *Euterpina*, *Oithona rigida*, and *Oncaea* shows a significant causality towards the abundance of *Acetes*. The findings imply that complex interaction between biotic and abiotic factors exists during the bloom of *Acetes* in Miri; thus, relevant agencies should step up measures to ensure sustainable management of the coastal areas where *Acetes* bloom occurs.

Key words: Granger causality, sergestid shrimp, water quality, zooplankton

INTRODUCTION

Coastal water is defined as a zone where land and water interact with each other (Moksness *et al*., 2013), serves as an important settlement area for human and home for various species of fishes, molluscs, prawns and crabs, providing natural foods for human as well as daily income for the locals (Srinivasan *et al*., 2013; Obatitor, 2014). Miri is a coastal city, located in the northwest part of Sarawak, Malaysia, which has an open coastline type facing the South China Sea, ranging from the mouth of Baram River until Tanjong Lobang beach (Ee & Zae, 2010). Miri coastal water is made up of coral reef, seagrass, beach forest and mangrove, provides important fisheries such as skipjack tuna, Spanish mackerel, grouper and sergestid shrimp known as *Acetes* (Amin *et al*., 2010). *Acetes* spp. (local name: 'bubok') show peak season from February to April and this krill-like shrimp is commercially important in Miri (Anandkumar *et al*., 2017). Shrimp and its product could be sold as high as 12 USD per kilogram (Hassan & Othman, 2021). The by-products of *Acetes* include 'belacan', a fermented shrimp paste and a pickle 'cincalok', are Malaysian local cooking ingredients. The fresh *Acetes* shrimps could be sold at approximately 0.8

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to 1 USD per kilogram especially during the peak season in February and March (Abdullah, 2018; Ringgit, 2019). Meanwhile, the fermented shrimp paste is sold at a range price of 12 to 17 USD per kilogram (Abdullah, 2019) Therefore, the presence of *Acetes* in Miri is generating income to both artisanal and commercial fishermen as well as the local people.

Acetes is commonly found in tropical and subtropical areas (Amin *et al*., 2012). Studies claimed that the distribution and abundance of *Acetes* are influenced by environmental factors, such as water temperature, salinity and type of sediment (Chiou *et al*., 2000; Calazans, 2002; Chen & Chen, 2002; Simoes *et al*., 2013). According to Chiou *et al*. (2000), rainfall could trigger the swarming of *A. intermedius* at the surface water in southwest Taiwan where low salinity provides an optimum condition for its pre-spawning aggregation. An experiment done by Chen and Chen (2002) showed that *A. intermedius* in Kaohsiung harbour, Taiwan preferred estuary habitat with salinity between 25 to 30 PSU as its spawning ground. Chen and Chen (2002) also reported that the salinity of estuary between 20 PSU to 30 PSU showed a higher metamorphosis rate of nauplii into protozoea I of *A. intermedius*. Therefore, *Acetes* has different tolerance against salinity change in different regions and evidence shows salinity is closely related to the spawning period and growth rate of this shrimp (Calazans, 2002; Simoes *et al*., 2013).

Previous research on *Acetes* in Malaysian Borneo focused on the status of *Acetes* landing (Stephenie *et al*., 2021), checklist of Acetes (Othman *et al*., 2020), population structure and feeding habits (Saini, 2013), morphometric study (Musel *et al*., 2019) and molecular phylogeny (Hassan & Othman, 2021). Lack of information documented on the environmental factors which could influence *Acetes* distribution had been highlighted by Saini *et al*. (2011) and Saini (2013). Interaction between biotic and abiotic factors is important to support the survival of a species and the overall health of an ecosystem (Molles & Simon, 2019). The environmental complexity and the dynamics of coastal areas have become the challenges in modeling the yearly bloom of *Acetes* in Miri coastal water. Besides that, lack of scientific data and low phenomenon forecasting ability had hindered sustainable management of the resource. Other studies elsewhere for example by Childress (2015) had successfully forecasted other aquatic life which is crab fishery using real-time freshwater flow data that led to better management of freshwater discharge since overall landings will decline if discharge also continues to decrease over time. Therefore, this study was conducted to investigate the possible interaction between selected water quality parameters and the abundance of zooplankton towards the abundance of *Acetes* population in coastal water of Miri, Sarawak, using Mathematical time series analysis called Granger causality test.

MATERIALS AND METHODS

Study area

Monthly field samplings were conducted in the coastal water of Kuala Baram and Batu 1, Miri, Sarawak from May 2017 until April 2018. Four stations were chosen and their coordinates were recorded using Global Positioning System (GPSmap 62S, GARMIN). Table 1 shows the coordinates and brief descriptions of each station. Table 2 shows the weather and condition of water during the field samplings. Figure 1 shows the location of the stations involved in this study.

Physico-chemical parameters of water

Selected water quality parameters were measured at approximately 0.5 meters below the surface water during flooding tide at every station and triplicate

Table 1. Coordinate and brief descriptions of each station

Station	Coordinate	Brief descriptions
1	N 04° 33'50.4" E 113° 58'15.6"	● Near the mouth of Baram River ● Sandy beach ● Presence of black, small fragment of woods and branches on the seabed ● Sea wall could be seen along the coastline
2	N 04° 33'11.8" E 113° 58'28.6"	● Sandy beach
3	N 04° 31'27.4" E 113° 59'05.3"	● Located near a small river ● Tyre factory could be seen at the coast ● No beach, sea wall could be seen
4	N 04° 29.796" E 113° 59.469"	● Located near Batu 1 jetty and fish market ● Beach absent, seawall could be seen along the coastline

Table 2. Weather and condition of water from May 2017 until April 2018

Month	Monsoon	Weather
May 17	SWM	Sunny
June 17	SWM	Cloudy
July 17	SWM	Cloudy
Aug 17	SWM	Sunny, windy
Sept 17	SWM	Cloudy
Oct 17	IM	Windy, rainy (inter-monsoon)
Nov 17	NEM	Sunny
Dec 17	NEM	Cloudy, strong wind (Tropical storm Kai Tak)
Jan 18	NEM	Cloudy
Feb 18	NEM	Cloudy
Mar 18	NEM	Sunny
Apr 18	IM	Sunny

*NEM: northeast monsoon, SWM: southwest monsoon, IM: inter monsoon.

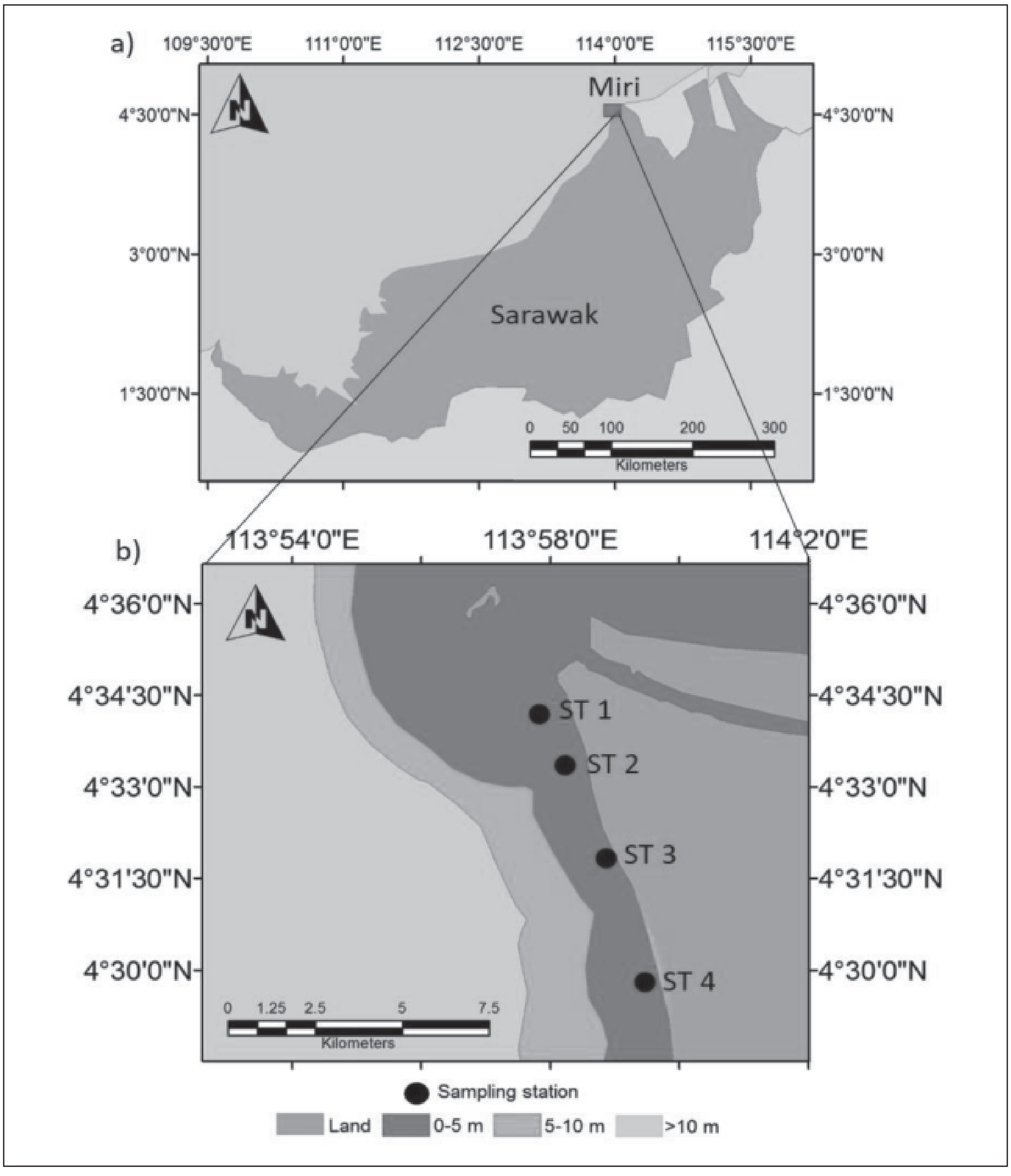

Fig. 1. (a) Map of Sarawak; (b) The black dot indicates the sampling stations in Miri, Sarawak (ST1-ST4).

readings were recorded. The total number of data collected was 96 4 stations × 3 replicates × 8 sampling months. In this study, data could not be collected in July 2017, September 2017, October 2017 and January 2018 due to bad weather and rough sea condition. Dissolved oxygen (DO), temperature, turbidity, pH, and salinity were measured *in situ* using DO meter (HI9146, Hanna Instrument), turbidity meter (TU-2016, Lutron), pH meter (HI 991003, Hanna Instrument), and refractometer (300011, Sper Scientific).

During the same fieldwork, selected ex situ water quality parameters namely chlorophyll *a* (chl *a*) and total suspended solids (TSS) were also obtained. Similar to *in situ* water quality parameters, the total data collected was 96. At each station, 2 litres of water samples were collected using a horizontal Van Dorn water sampler at approximately 0.5 meters depth from the surface of the seawater and stored in polyethylene bottles. All samples were kept in a cooler box with ice and brought back to the laboratory in Universiti Malaysia Sarawak (UNIMAS) for further analysis.

Laboratory work

Chl *a* was analysed using the method proposed by Aminot and Rey (2000). A total of 500 mL of water sample was filtered through clean glass fibre filter paper (Whatmann, GF/C, 1.2 µm pore size, 47 mm diameter) using an electrical filter pump. The wavelength of 630 nm, 647 nm, 664 nm and 750 nm were obtained using a spectrophotometer (DR 2800, Hach).

Total suspended solids (TSS) was analysed using the method proposed by Scannell and Jacobs (2001). A total of 500 mL of water sample was filtered through clean glass fibre filter paper (Whatmann, GF/C, 1.2 µm pore size, 47 mm diameter) using an electrical filter pump. Before filter, the filter paper was weighed using an analytical balance (Ohaus) to determine the initial weight (FS). The filter paper with samples was dried in the oven for 24 hours at 60°C followed by weighing to determine the final weight (FF). The standard protocol was used to calculate the TSS values.

***Acetes* sampling**

The bottom trawl net was used to catch the *Acetes* at every station with aid from local fishermen. Samples were only available for May 2017, August 2017, November 2017, March 2018 and April 2018. *Acetes* could not be collected during other field trips due to bad weather, rough sea and the presence of wood fragments on the seabed which prohibit trawling activities. The net was towed by a boat with a speed of 2 km/h for 15 minutes and two replicates of the collection were done. The total number of samples collected was 40 (4 stations × 2 replicates × 5 sampling months). Approximately 200 g of samples were collected from every trawl, fixed in 10% formalin and brought back to the laboratory in the Faculty Resource Science and Technology, Universiti Malaysia Sarawak (UNIMAS) for further analysis. Identification of *Acetes* was based on species identification keys provided by Pathansali (1966), Omori (1975), Amin *et al*. (2011) and Vereshchaka *et al.* (2016).

Plankton sampling

Plankton net was used to collect the sample of zooplankton following methods by Al-Kandari *et al.* (2009). The volume of water sampled by the zooplankton net was calculated using the formula derived from Perry (2003) given as:

$$\text{Volume} = \pi r^2 L \qquad (1)$$

where

r = radius of net opening (m^2)

L = length of tow (boat speed × time)

Two replicate samples of zooplankton were collected at every station using a zooplankton net with a mesh size of 100 µm. The net was towed horizontally, at depth of 0.5 m from the water surface, at the speed of 2.0 to 2.5 km/h for 5 minutes. Therefore, the estimated volume of water filtered was 29 – 37 L. All samples were transferred into 50 mL bottles, preserved with 5% formalin and transported back to the laboratory. Laboratory work involved the used Sedgewick-Rafter counting chamber, following the standard protocol as suggested by Marsden (1992). Water sample (1 mL) was transferred onto the chamber and observed using a compound microscope (Olympus SZ51) with either 10 or 40 magnification. Zooplankton groups were identified to the lowest possible taxon using standard zooplankton identification keys of Hasle *et al*. (1996), Johnson and Allen (2005) and Al-Kandari *et al*. (2009). Cell enumeration for each taxon was carried out simultaneously, following methods by Goswami (2004).

Time series analysis

This study used monthly data from May 2017 to April 2018. Since the data are indexed in time order, the time series analyses such as the Granger causality test can be applied to these data.

Unit root test

Before testing for the causality, a stationary test is necessary. Thus, the unit root test to examine the stationarity of the variables is conducted (Glynn *et al*., 2007). The Augmented Dickey-Fuller (ADF) test was used to measure the robustness. The ADF test should suggest that all variables are integrated at level denoted as I (0) or order one denoted as I (1) to validate the use of the Granger causality test.

Granger causality test

The study followed Toda and Yamamoto (1995) procedure to test for Granger causality. In explaining the core dynamics of ecological systems, Granger causality can be used to untangle direct and feedback relationship between the different components of the system (Detto *et al*., 2012). The bivariate relationship between the total number of *Acetes* with the total number of zooplankton and selected water quality parameters such as surface water temperature, salinity, turbidity, dissolved oxygen (DO), pH, depth, TSS and chlorophyll *a* are examined. The Granger causality test examines whether a variable X is the cause of another variable Y (the aggregation of sergestid shrimp *Acetes*). The Vector Autoregressive (VAR) model of the two time series are given as

$$y_t = a_0 + a_1 y_{t-1} + \cdots + a_p y_{t-p} + b_1 x_{t-1} + \cdots + b_p x_{t-p} + u_t \quad (2)$$

$$x_t = a_0 + c_1 x_{t-1} + \cdots + c_p x_{t-p} + d_1 y_{t-1} + \cdots + d_p y_{t-p} + v_t \quad (3)$$

where x represents the water quality parameters or the total number of zooplankton and y represents the total number of *Acetes*. Using the null hypothesis, H_0: $b_1 = b_2 = \cdots = b_p = 0$ or H_0: $d_1 = d_2 = \cdots = d_p = 0$, a rejection of the null implies there is Granger causality.

Optimal lag selection

The estimation of the VAR model requires appropriate lag length (Glynn *et al*., 2007). For this case, the choice of lag length was based on Akaike Information Criterion (AIC). The appropriate lag length for the VAR models is estimated at the level. The appropriate lag is selected according to AIC for every model. Each model has to undergo a serial correlation test in its residual. The Portmanteau test for serial correlation is used with the null hypothesis of no autocorrelation in the residuals. The next VAR model with $p+m$ lags is modelled where p is the number of lags found in the previous analysis and m represents the maximum order of integration that occurred in the process.

Granger causality F-statistics

After the new VAR models are constructed, Granger causality using Wald test (F-test) for linear restriction is tested. The Wald statistics is asymptotically chi-square distributed under the null hypothesis. Rejection of this hypothesis supports the presence of Granger causality.

RESULTS AND DISCUSSION

Three species namely *Acetes erythraeus*, *A. serrulatus* and *A. japonicus* were identified in Miri coastal water and their descriptions agreed well with diagnosis and illustrations provided by Pathansali (1966), Omori (1975), Amin *et al*. (2011) and Vereshchaka *et al.* (2016). The morphological descriptions of these species have been described by Othman *et al*. (2020). Male *A. erythraeus* had 15 to 16 segments of the antennular flagellum, a single clasping spine with tubercles and petasma with one large hook followed by three to four small hooks. Female *A. erythraeus* had 12 to 16 segments of lower antennular flagellum while the third thoracic sternite has a trapezoid shape as shown in Figure 2.

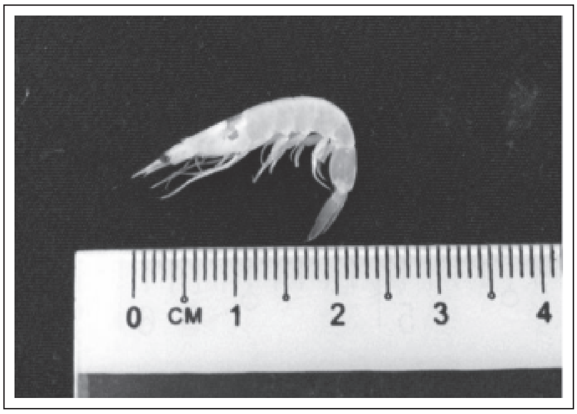

Fig. 2. Whole body of *Acetes erythraeus.*

Male *A. serrulatus* was identified with 11 segments of the antennular flagellum and two clasping spines with different lengths while female *A. serrulatus* was identified based on the third thoracic sternite with a curve at the middle as shown in Figure 3.

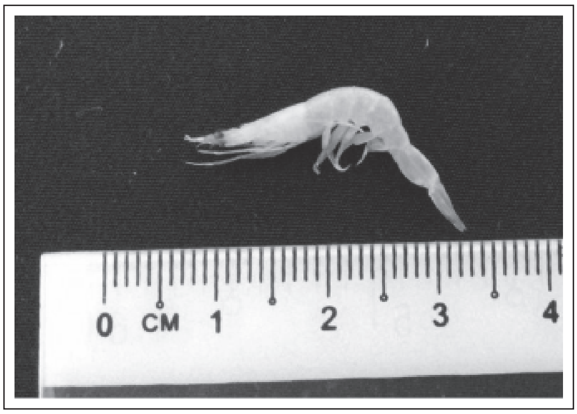

Fig. 3. Whole body of *A. serrulatus.*

Only male *A. japonicus* was found in Miri coastal water with 11 segments of the lower antennular flagellum, two different lengths of clasping spines with tubercles on the surface and petasma shaped like a bulb with numbers of small hooks.

Table 3. Range of selected water quality parameters for every station in Miri coastal water, Sarawak

	Station 1	Station 2	Station 3	Station 4
Temperature (°C)	29.0 – 31.5	27.0 – 32.0	26.9 – 32.0	27.3 – 33.2
Salinity (PSU)	5 – 35	5 – 35	5 – 35	17 – 35
Turbidity (mg/L)	22.22 – 530.67	9.23 – 502.50	10.99 – 392.67	10.67 – 492.33
Dissolved Oxygen (mg/L)	4.48 – 7.22	5.31 – 7.05	4.92 – 7.02	5.09 – 7.31
pH	7.03 – 8.32	7.07 – 8.23	7.12 – 8.19	6.98 – 8.18
TSS (mg/L)	52 – 537	37 – 343	36 – 561	26 – 335
chlorophyll *a* (mg/m^3)	0.6632 – 2.7219	0.4262 – 2.2231	0.6119 – 2.3116	0.6597 – 2.4528

Table 4. Unit root test for all variables using ADF test

	t-Statistics in levels	t-Statistics in first difference
Temperature (°C)	-2.336	-4.984*
Salinity (PSU)	-2.831	-8.411*
Turbidity (mg/L)	-1.819	-6.975*
Dissolved Oxygen (mg/L)	-1.198	-4.072*
pH	-3.277	-7.117*
TSS (mg/L)	-3.267	-8.029*
chlorophyll *a* (mg/m^3)	-1.942	-5.216*
Number of *Acetes*	-3.422	-3.471*
Number of zooplankton	-1.714	-3.204*

* Significant at 5% level.

Water quality parameters

The values of selected water quality parameters for every station measured throughout the year from May 2017 until April 2018 are shown in Table 3.

Unit root test

All variables undergo stationary testing at levels and their first difference. Table 4 shows the ADF test result for all variables.

The ADF test from Table 4 shows that all variables are non-stationary and are stationary at the first difference in significance level 5%. Therefore the data series can be characterized as I(1).

Optimal lag selection

The lag length for each variable in the VAR model was estimated using AIC. Table 5 show the result of this test.

Table 5. Lag length for all variables in the VAR model

	Lag, *p*
Temperature (°C)	4
Salinity (PSU)	1
Turbidity (mg/L)	3
Dissolved Oxygen (mg/L)	4
pH	2
TSS (mg/L)	1
chlorophyll *a* (mg/m^3)	0
Number of *Acetes*	1
Number of zooplankton	2

Granger causality VAR model and F-statistics

The last step in the analysis is to create VAR models with $p+m$ lags and test Granger causality using the Wald test for linear restrictions. The number of lags p were taken from the values in Table 5 and are increased by 1 because all variables are I(1). The presence of Granger causality between the water quality parameter and number of zooplankton towards the number of *Acetes* are tested at each station. There are 22 equations involved in the test as indicated in Table 6.

There was evidence of a causal relationship of salinity to the number of *Acetes* at Station 2 as indicated in Table 7. There was also a causal relationship of DO to the number of *Acetes* in Station 1. These findings show that the current number of *Acetes* in Station 2 and Station 1 can be explained by the past values of the A*cetes*, salinity and DO at the area. This was in line with the concept of interaction between biotic and abiotic factors which is important for the survival of a species and the overall health of an ecosystem (Molles & Simon, 2019).

There was evidence of a causal relationship of the number of *Acetes* to pH as indicated in Table 8. pH is one of the parameters that inter-dependent and among the important water parameters to shrimp complex life cycle. Bechmann *et al*. (2011) had reported that variations of pH did not affect the survival of shrimps but lower pH caused significant delays in zoeal progression (development time).

Table 6. The VAR models for the Granger causality test

Dependent Variables, *y*	Independent Variables, *x*	Equations
Number of *Acetes*	Temperature	$y_t = 0.05y_{t-1} + 36.34x_t - 135.43x_{t-1} + 54.93x_{t-2} - 21.96x_{t-3} - 36.63x_{t-4} + \mu_t$
Number of *Acetes*	Salinity	$y_t = -0.47y_{t-1} + 12.2x_t - 15.89x_{t-1} + \mu_t$
Number of *Acetes*	Turbidity	$y_t = -0.89y_{t-1} - 1.66x_t - 1.22x_{t-1} - 0.69x_{t-2} - 0.60x_{t-3} + \mu_t$
Number of *Acetes*	Dissolved Oxygen	$y_t = -0.06y_{t-1} + 211.8x_t + 26.92x_{t-1} + 75.59x_{t-2} - 91.22x_{t-3} + 386.92x_{t-4} + \mu_t$
Number of *Acetes*	pH	$y_t = -0.42y_{t-1} + 572.3x_t - 336.5x_{t-1} - 46.3x_{t-2} + \mu_t$
Number of *Acetes*	TSS	$y_t = -0.26y_{t-1} - 0.95x_t + 0.34x_{t-1} + \mu_t$
Number of *Acetes*	chlorophyll *a*	$y_t = -0.39y_{t-1} + 125.55x_t + \mu_t$
Temperature	Number of *Acetes*	$y_t = 0.09y_{t-1} + 0.63y_{t-2} - 0.14y_{t-3} + 0.17y_{t-4} + 0.001x + 0.005x_{t-1} + \mu_t$
Salinity	Number of *Acetes*	$y_t = 0.15y_{t-1} + 0.02x + 0.02x_{t-1} + \mu_t$
Turbidity	Number of *Acetes*	$y_t = -0.84y_{t-1} - 0.53y_{t-2} - 0.36y_{t-3} - 0.37x - 0.44x_{t-1} + \mu_t$
Dissolved Oxygen	Number of *Acetes*	$y_t = -0.16y_{t-1} - 0.4y_{t-2} + 0.24y_{t-3} - 1.67y_{t-4} + 0.004x + 0.00002x_{t-1} + \mu_t$
pH	Number of *Acetes*	$y_t = 0.49y_{t-1} - 0.01y_{t-2} + 0.0007x + 0.0003x_{t-1} + \mu_t$
TSS	Number of *Acetes*	$y_t = 0.03y_{t-1} - 0.38x - 0.16x_{t-1} + \mu_t$
chlorophyll *a*	Number of *Acetes*	$y_t = 0.0009x + 0.0008x_{t-1} + \mu_t$
Number of *Acetes*	Number of *Centropages*	$y_t = -0.3y_{t-1} + 4.17x_t + 8.81x_{t-1} - 13.53x_{t-2} + \mu_t$
Number of *Acetes*	Number of *Euterpina*	$y_t = -0.39y_{t-1} + 19.14x_t + 34.9x_{t-1} - 13.63x_{t-2} + \mu_t$
Number of *Acetes*	Number of *Oithona rigida*	$y_t = -0.67y_{t-1} - 8.41x_t + 25.37x_{t-1} - 15.33x_{t-2} + \mu_t$
Number of *Acetes*	Number of *Oncaea*	$y_t = -0.38y_{t-1} + 12.52x_t + 11.57x_{t-1} - 16.86x_{t-2} + \mu_t$
Number of *Centropages*	Number of *Acetes*	$y_t = 0.53y_{t-1} - 0.27y_{t-2} + 0.001x_t - 0.006x_{t-1} + \mu_t$
Number of *Euterpina*	Number of *Acetes*	$y_t = 0.37y_{t-1} - 0.11y_{t-2} + 0.0005x_t - 0.001x_{t-1} + \mu_t$
Number of *Oithona rigida*	Number of *Acetes*	$y_t = 0.77y_{t-1} - 0.41y_{t-2} - 0.003x_t - 0.02x_{t-1} + \mu_t$
Number of *Oncaea*	Number of *Acetes*	$y_t = 0.4y_{t-1} - 0.18y_{t-2} + 0.005x_t - 0.003x_{t-1} + \mu_t$

Table 7. The F-value of the Granger causality test using water quality parameter as independent variable and number of *Acetes* as the dependent variable

Parameter	Water quality Parameter → Number of *Acetes*			
	Station 1	Station 2	Station 3	Station 4
Temperature	1.951639	4.200204	1.353954	3.149002
Salinity	0.434895	16.25672*	3.119200	4.147075
Turbidity	0.732178	1.642284	0.831831	3.293736
Dissolved Oxygen	13.13727*	2.590945	1.332515	4.254184
pH	0.632646	3.880500	7.647426	2.300763
TSS	1.427839	6.482468	2.179579	1.186765
chlorophyll *a*	0.171115	2.548306	3.487730	0.827514

* Significant at 5% level.

Granger causality emerged between the abundance of *Acetes* and DO at Station 1 and 3. Station 1 and 3 are located near the rivers, lined with mangrove vegetation and they share the same pattern of interaction between *Acetes* shrimp abundance with turbidity, DO and TSS. Using the Granger causality test, results showed that when *Acetes* blooms happened, the three parameters were affected. Turbidity could be caused by the wastes (i) from animals, (ii) those originated from the marine vessels or (iii) transported from the land, or organic matters in the water column, microscopic microorganisms, planktons, inorganic matters or sediment (Yap *et al*., 2011; Boyd, 2015). Bloom of Sergestid shrimps alone could not cause the turbidity and high concentration of TSS, because it had been reported that freshwater

Table 8. The F-value of the Granger causality test using the number of *Acetes* as the independent variable and water quality parameter as the dependent variable

Parameter	Number of *Acetes* → Water quality Parameter			
	Station 1	Station 2	Station 3	Station 4
Temperature	1.06421	0.19507	3.42072	1.24362
Salinity	0.764683	0.166089	0.231142	3.058537
Turbidity	20.84289*	5.527854	11.33283*	5.541686
Dissolved Oxygen	8.210271*	2.057743	284.6227*	7.497724
pH	8.601894*	1.122728	0.561111	2.521063
TSS	95.19428*	3.620863	2559.298*	2.474972
chlorophyll a	1.632042	1.563292	28.46673*	0.414039

* Significant at 5% level.

Table 9. The F-value of the Granger causality test using the number of zooplankton as independent variable and number of *Acetes* as the dependent variable

Zooplankton	Number of zooplankton → Number of *Acetes*			
	Station 1	Station 2	Station 3	Station 4
Centropages	0.087066	0.029789	0.541095	1.133856
Euterpina	0.950325	37.17876*	1.114025	0.432902
Oithona rigida	0.628400	1.250231	8.583078*	1.226086
Oncaea	0.028176	3.972603	6.576559*	6.358389*

* Significant at 5% level.

Table 10. The F-value of the Granger causality test using the number of *Acetes* as independent variable and number of zooplankton as the dependent variable

Zooplankton	Number of *Acetes* → Number of zooplankton			
	Station 1	Station 2	Station 3	Station 4
Centropages	1.109250	0.263693	0.371455	7.248615*
Euterpina	0.106718	2.345940	2.764512	2.445608
Oithona rigida	6.468700*	0.328327	0.141914	7.929168*
Oncaea	0.025090	3.567029	0.591486	2.224693

* Significant at 5% level.

input may also lead to enhanced transportation of organic matters as well as suspended solids from mangrove litter and dissolution of mangrove soil organic matter (Kida *et al.*, 2019).

Plankton are small organisms that dwell in oceans, seas and bodies of freshwater (McManus & Woodson, 2012). Plankton is composed of viruses, bacteria, phytoplankton, zooplankton and the pelagic larvae of many marine invertebrates and fishes. This group displays a wide range of behavioural capabilities that bridge the transition from being a passive particle to being able to determine the vertical and horizontal position in the ocean (McManus & Woodson, 2012). The concentration of chlorophyll *a* is an important indicator to determine the biomass and growth of phytoplankton (Idrus *et al.*, 2017). In this study, there is evidence of a causal relationship of the number of *Acetes* to chlorophyll *a* as indicated in Table 8. Aggregation of *Acetes* may associate with the presence of phytoplankton, as plankton play a key role in the marine food web by transferring the organic energy produced by the unicellular algae to higher trophic levels such as zooplankton and the pelagic stocks (Varghese *et al.*, 2015).

From Table 9, a causal relationship exists based on the number of zooplankton (*Euterpina*, *Oithona rigida* and *Oncaea*) to the number of *Acetes* at Stations 2, 3 and 4.

There was also a causal relationship from number of *Acetes* to the number of zooplankton (*Centropages* and *Oithona rigida*) at Stations 1 and 4 as indicated in Table 10. Zooplankton *Oithona rigida* and *Acetes* experience bi-directional relationship in terms of abundance with each other. Previous researchers, for example, Omori (1975), Saini *et al.* (2011) and Saini (2013) claimed that diets of Sergestid shrimps are plankton therefore the abundant of the zooplankton has an influence on the aggregation of shrimps in the area.

CONCLUSION

A total of three species of *Acetes* were identified in the coastal water of Miri, Sarawak namely *A. erythraeus*, *A. serrulatus* and *A. japonicas.* This study also highlighted the ability of the econometrics model (Granger causality test) in describing the interaction between environmental and biological factors towards the abundance of *Acetes*. From the causality test against 22 different equations, salinity and DO play a significant impact on the number of *Acetes* in the area whereas *Acetes* assemblages have shown a significant impact on the water quality parameters (temperature, salinity, turbidity, pH,

TSS and chlorophyll *a*). There was also evidence of interaction between zooplankton with the aggregation of *Acetes.* The study and constant monitoring of *Acetes* assemblages are very important in assessing the risk of over-capitalization (over-exploitation) of *Acetes* fishery in Sarawak as it is an open-access fishery.

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