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Periodicity and Exogenous Factors in Coincidence with "Nyalé" (*Palola viridis*) Swarming in Lombok

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Reproduction mechanism of most polychaetes or sea worms is attributable to various endogenous and exogenous factors. Exogenous factors associated with the reproduction time of sea worms include seasons, tidal phase, seawater temperature, lunar phase and solar day cycle. A descriptive research was conducted to identify the periodic pattern and exogenous factors associated with the swarming time of the sea worms, locally known as *nyalé* (*Palola viridis*), in Lombok. The position of the sun relative to the Java trench in southern Indian Ocean at 10°S to 11°S, and that of the moon relative to the southern beach of Kuta, Lombok (8.9°S, 116.28°E) at the dates of *nyalé* swarming were determined. The results showed that (i) annual swarming and spawning of *nyalé* in Lombok occurred during the last quarter of lunar phase, i.e. on the lunar date of 19th or 20th, of the tenth month in local Sasak calendar which corresponds to either February or March, (ii) there were three possible positions of the sun at the date of *nyalé* swarming, namely at south, above, or north of the Java trench. *Nyalé* swarming would occur along with heavy rain when the sun was at the north of the trench on 20th of lunar date in a particular year, and (iii) the moon was precisely at the south of Lombok on the date of *nyalé* swarming in February, and the event was postponed to March on the similar lunar date if the moon was not at that particular site. In conclusion, *nyalé* swarming in Lombok occurred on the lunar date of 19th or 20th in February or March annually. It coincided with culmination of the last quarter moon at the southern beach of Kuta, Lombok, with the sun at around the Java trench. The sudden increase in the abundance of *nyalé* population appeared to be related to exogenous factors driven by solar radiation such as seawater temperature, as well as by the moon phase which may indirectly induce swarming through hydrodynamic mechanisms.

Keywords: exogenous; *nyalé*; *Palola*; lunar date

I. INTRODUCTION

The swarming of sea worms, known as *nyalé*, in Lombok is a regular event occurring once every year on the 19th or 20th of the tenth month in the lunar Sasak calendar (Mahrup *et al.*, 2012), of which the tenth month usually corresponds to February in the Gregorian calendar (Bachtiar & Bachtiar, 2019). The sea worms are not just a cultural delicacy, but a classic example of marine life cycle based on lunar periodicity (Caspers, 1984). Computer simulations within a 21-year period have brought a clear understanding of its periodicity in southern Lombok (Mahrup *et al.*, 2018). Similar sea worms with different times of appearance and local names are also found in other areas, including *laor* in the Moluccan islands, eastern Indonesia in March or April (Hadiyanto, 2013), and *palolo* in the Samoan islands of the Pacific Ocean in November or October (Caspers, 1984).

The sea worms spend most of their time in burrows at the base of the reefs (Caspers, 1984; Zanol *et al.*, 2007) of

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flat shallow beaches in Pacific, Atlantic and Indian Ocean (Miller & Pen, 1959), including the Ambonese water in Maluku, Indonesia (Pamungkas, 2015). The body of sea worms is constituted of two main parts, namely the anterior head part (known as atoke) and the posterior part (known as epitoke) packed with reproductive organ (Caspers, 1984). Their reproductive timing is uniquely synchronised to moon phases (Zantke *et al.*, 2014). Reproduction of sea worms is indicated by mass swarming, where the terminal segment of the body bearing reproductive organ which contains eggs and sperms was shed to the water column and rose to the water surface (Caspers, 1984; Woodworth, 1903) at night in the spring or early summer in the southern hemisphere (Franke, 1986). This process takes place in a very short time after midnight (Coutures, 2003), where about 30 min after the first appearance, the population increased sharply and the process lasted about 2 h (Caspers, 1984).

The sea worms in Indonesia, known as *nyalé* in Lombok (Jekti *et al.*, 1993) and *laor* in Ambon (Liline *et al.*, 2015), belong to several species, including *Lycidice collaris* and *Eunice siciliencis* (synonymous with *Palola viridis*) of the family Eunicidae, and *Dendronereides heteropoda* of the family Nereididae. The dominant species of *nyalé* is *Palola viridis*, with the species name *viridis* referring to the green colour of the worm. They favourably live in calcareous coral reefs. Apparently, sea worms mainly feed on the symbiotic algae of the coral reefs (Caspers, 1984), and they live in sediments rich in organic matter (Habonaran *et al.*, 2015). Seawater temperature higher than 0.5°C above the annual average limits the population abundance of *Palola viridis* at Samoan islands in the Pacific Ocean (Anonymous, 2017). This indicates the sensitivity of sea worms to exogenous factors or environmental changes (Franke, 1986).

Variation in the position of the sun and the moon may result in different exogenous factors, such as seawater temperature and tidal cycle that influence the swarming and spawning process (Franke, 1986) of *nyalé* in Lombok (Mahrup *et al.*, 2012). For example, different positions of the sun relative to Java trench, the nearest place to southern Lombok with geophysical data available, were documented on the 20^{th} of lunar date in February of 2008 and 2009 when *nyalé* swarming occurred. The sun was far south at 13°S on 14 February 2009, while on the same lunar date the year before, 26 February 2008, the sun was at 8.9°S, close to Kuta Beach in Lombok, Eastern Indonesia (Figure 1). Differing positions of the sun would affect the atmospheric features in the southern Indian Ocean differently during *nyalé* swarming. This study aims to identify the periodic pattern and exogenous factors associated with the swarming time of the sea worms, locally known as *nyalé* (*Palola viridis*), in Lombok based on the analysis of ephemeris and environmental data collected for nearly a decade.

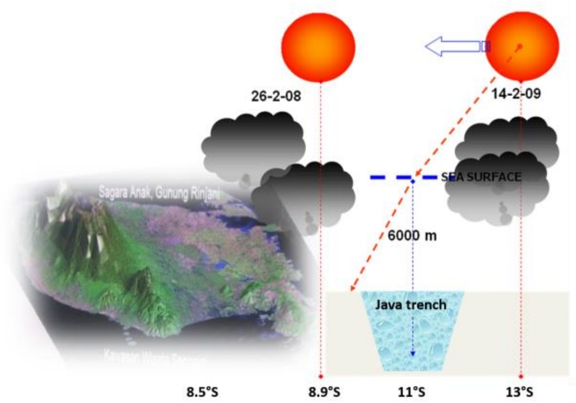

Figure 1. Positions of the sun relative to Java trench in the southern Indian Ocean on 26 February 2008 and 14 February 2009 (figure courtesy of Mahrup *et al.*, 2012).

II. MATERIALS AND METHODS

A. Method, Location and Time

The research was carried out using descriptive method with surveys and computer simulations. The study area was determined by purposive sampling based on the prevalence of *nyalé* (*Palola viridis*) swarming. The selected study location was Kuta beach (8.9°S, 116.28°E) on the southern coast of Lombok directly adjacent to the Indian Ocean. Topographically, the land area is at an altitude of 0 to <200 m above sea level; the coast is sloping, with the continental shelf and slope extending to the south and reaches a maximum depth of ± 6000 m in the Java trench, which is about 230 km to the south of the coast, spanning 10°S to 11°S. The Java trench is a southern border of the convergence zone in the southern hemisphere. Data were collected in the first three months of 2018.

B. Data Collection and Analyses

Data and information were collected through interviews with local resources. Secondary data were obtained online or generated from computer simulations. Data of the sea surface temperatures (SST) for latitudes 9.5°S, 10°S and 11.5°S around the Java trench within the period 1982–2017 were downloaded from Rainman International (2017), while those of the temperature of seawater surrounding Lombok within 2010–2018 were downloaded from https://www.seatemperature.org/asia/ indonesia/mataram.htm. The tidal cycle and solunar data in Lombok within the period 2010–2018 were downloaded from APNIC (2018) and https://www.tide-forecast.com by inputting the location as Mataram. Ephemeris data on the position of the sun and the moon within the period 2010–2030 were acquired or generated from computer simulations using Planet Watch version 1.1 and Home Planet version 2.0, respectively.

III. RESULTS AND DISCUSSION

A. Sea Surface Temperatures in Southern Indian Ocean

The average monthly sea surface temperatures (SST) north of Java trench (9.5°S), above the Java trench (10°S), and south of Java trench (11.5°S) recorded from 1982–2017 were presented in Figure 2. It was clearly shown in Figure 2 that SST was lowest in August and increased successively from September towards the end of the year. The SST at all three latitudes were relatively stable from January to April, and dropped sharply from May to August, reaching the lowest at 26.17°C. Note that the average SST in February, the month *nyalé* swarming occurred, was 29.03°C, which was about the average SST during the peak of the rainy season (January to March) in Lombok. Obvious spatial variation of SST was observed from July to December. During this period, SST at 9.5°S was relatively higher than those at 10°S (above Java trench) and at 11.5°C (south of Java trench).

In Lombok, the average maximum seawater temperature or day time temperature was relatively stable from January to December, while the average minimum temperature at midnight appeared to fluctuate throughout the years (Figure 3). The maximum seawater temperature reached the lowest level in August, but the lowest minimum temperature was recorded in September. The largest temperature difference between maximum and minimum was observed in February at 3.6°C, which was above the average temperature difference of 2.52°C, with the average seawater temperature declined from 30.4°C at midday to 26.8°C at midnight. It indicated a sharp decline in the seawater temperature at night in February.

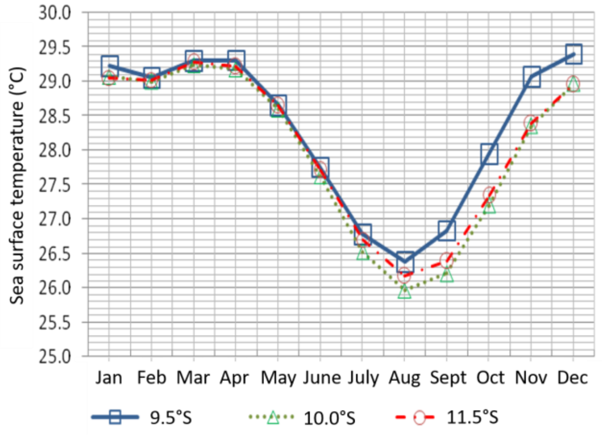

Figure 2. Average monthly sea surface temperature in the southern Indian Ocean at different latitudes around the Java trench (9.5°S, 10°S and 11.5°S) from 1982 to 2017 (Source: Rainman International, 2017).

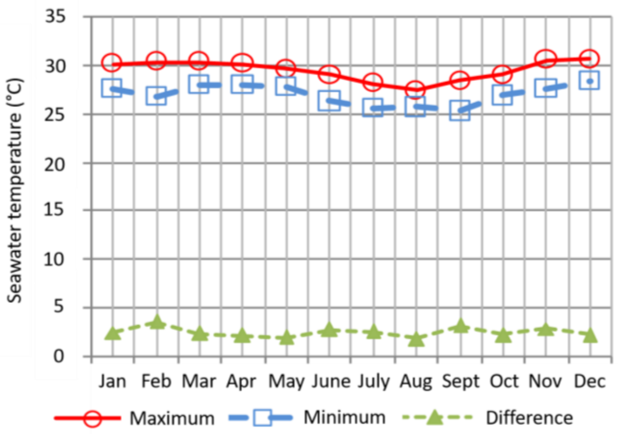

Figure 3. Average monthly maximum and minimum seawater temperature and their difference in Lombok from 2010–2018 (Source: https://www.seatemperature .org/asia/indonesia/mataram.htm).

B. Position of the Sun and Moon During Nyalé *Swarming in Lombok*

Ephemeris data on the position of the sun and the moon at the date of *nyalé* swarming in Lombok generated with computer simulations were presented in Figure 4.

Simulation of the position of the sun and the moon during the *nyalé* swarming was run for 9 times in the past (2010–2018) and two years ahead (2019 and 2020). The sun and the moon were found at different locations during *nyalé* swarming, with the sun above the Pacific Ocean at the equator, while the moon above the southern Indian Ocean. The sun was at longitude ranging between 114.28°W and 132.01°W, and at latitude between 6.24°S and 17.16°S when *nyalé* swarming occurred. Figure 4 clearly indicated that the moon on 20th of lunar date in February was precisely above Kuta beach at Lombok Island, with the meridian or longitude position of the moon fixed at 116.28°E, and its zonal or latitude position varied between 5.4°S to 19.4°S. It was clear from Figure 4 that the moon was mostly at the south of Lombok on 20th lunar day in February. In the 11-year period from 2010 to 2020, there were three occasions in which the moon was at the north of the beach, namely on the 1 February 2013 (6.18°S), 16 February 2017 (5.7°S), and 6 February 2018 (5.4°S), during which a small population of *nyalé* was harvested (data from interview with the locals). This condition is known as *nyalé poto* in the local language, which means the *nyalé* swarming would be postponed for one month and take place on 20th lunar day in March.

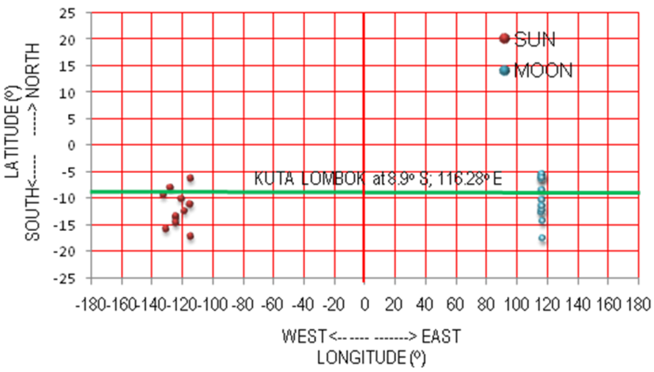

Figure 4. Position of the sun and the moon on the dates of *nyalé* swarming from 2010 to 2020.

C. Neap Tide During Nyalé *Swarming in Lombok*

Nine-year data on neap tide at the time of *nyalé* swarming in Lombok from 2010 to 2018 were shown in Figure 5. It seems that *nyalé* swarming did not occur during the lowest tide at 0.59 m as it was in January (Figure 5A). Instead, it frequently occurred in February or March when the minimum tide was about 0.77 m and 0.78 m, respectively. This implies that the minimum tide was not a critical factor in controlling the swarming time of *nyalé*. Furthermore, it was clearly indicated in Figure 5B that lower water level of low tide was recorded on two occasions, namely in 2013 and 2018. In both years, the last quarter of the lunar phase or the 20th of tenth month in local calendar corresponded to early February, i.e. the 1st and 6th February respectively, during which the position of the moon was far north from Lombok at 6.18°S in 2013 and at 5.44°S in 2018, and *nyalé* swarming was postponed until March.

D. Coincidence of Exogenous Factors and Periodicity of Nyalé *Swarming in Lombok*

Ephemeris data related to *nyalé* swarming from 2010 to 2019 were generated and analysed to look for an association between the exogenous factors and the reproduction timing of *nyalé*. According to Zantke *et al.* (2014), most of the sea worms synchronised their reproductive cycle to lunar phases. Periodic pattern in the dates of *nyalé* swarming corresponding to the synodic months, or the periods of moon phases, was observed. Firstly, swarming would occur on the same date every 19 years, a period which corresponds to a metonic cycle, after which the moon phases repeated on the same days of the solar year. Based on Table 1, a metonic cycle for *nyalé* swarming would be from 5 February 2010 to 4 February 2029, or from 23 February 2011 to 24 February 2030.

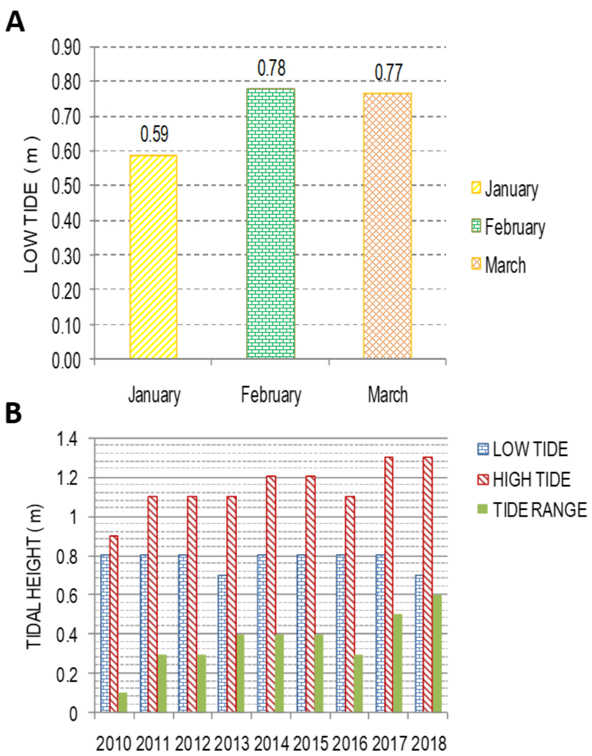

Figure 5. Neap tide data in Lombok for 9 years from 2010–2018: (A) the average low tide level in January, February and March, and (B) the nocturnal low tide, high tide and tidal range on the date of *nyalé* swarming in Lombok (Sources: APNIC, 2018 and https://www.tide-forecast.com).

Secondly, the annual *nyalé* swarming in Lombok takes place on the lunar date of 19th or 20th of the tenth month in the local calendar which usually corresponds to February.

There were two conditions for a significant population of *nyalé* to appear in February, namely when (1) the last quarter moon (20th lunar day) occurred after the first week of February, and (2) the last quarter moon culminated over the south of Lombok on the lunar date of 20th of the tenth month in local calendar. If either of the two conditions is not fulfilled, then the swarming of *nyalé* will be postponed to March on the same lunar date. We postulated that *nyalé* swarming would not happen if the last quarter of the moon (20th lunar day) was observed in the first week of February, when the moon was at far north from the southern coast of Lombok. The period for *Palola viridis* to produce large population varied between 12 to 13 synodic months (Caspers, 1984). Therefore, a one-month delay in *nyalé* swarming as part of the biological mechanism to complete the reproduction was not unexpected. Local time in Table 1 referred to the exact time at which the last quarter moon culminates over the meridian line of Kuta beach in Lombok (116.28°E) in the early morning on the 20th lunar day in February. Culmination time roughly ranged from 03:00 to 05:00 a.m., or before the sun rises. Meanwhile, the minimum tide frequently occurred from 05:00 to 07:43 a.m., and the maximum tide at midnight reached between 0:09 and 1:48 a.m. (APNIC, 2018). Therefore, the possible time for *nyalé* to emerge in Lombok is from 03:00 to 05:00 a.m. before the sun rises.

From the biophysical point of view, we proposed some possible physical mechanisms by which the posterior segments of the sea worms can be cast off and emerge to the water surface. The reduced hydrostatic pressure at the bottom of the sea where sea worms are usually found, as well as the increased buoyancy force in water column

Table 1. Ephemeris data during *nyalé* swarming on 20th lunar day from 2010 to 2030.

Date	Year	Local time	Position of the sun		Position of the moon		Remarks	
			Latitude	Longitude	Latitude	Longitude	*Nyalé* swarming	Weather
5-Feb	2010	5:07:50	16.06°S	133.47°W	17.12°S	116.44°E	Postponed	Clear
23-Feb	2011	4:15:32	10.09°S	120.51°W	17.55°S	116.44°E	Regular presence	Shower
13-Feb	2012	4:29:37	13.67°S	123.85°W	14.32°S	116.08°E	Regular presence	Clear
1-Feb	2013	3:51:22	17.16°S	114.46°W	6.18°S	116.30°E	Postponed	Clear
20-Feb	2014	3:51:47	11.08°S	114.66°W	10.34°S	116.24°E	Regular presence	Shower
10-Feb	2015	4:30:17	14.57°S	124.02°W	8.42°S	116.11°E	Regular presence	Clear
29 Feb	2016	4:43:17	7.93°S	127.68°W	12.60°S	116.28°E	Regular presence	Rain
16-Feb	2017	4:08:17	12.39°S	118.55°W	5.70°S	116.26°E	Postponed	Clear
6-Feb	2018	4:55:54	15.74°S	130.48°W	5.44°S	116.22°E	Postponed	Clear
26-Feb	2019	4:59:11	9.33°S	132.01°W	12.14°S	116.32°E	Regular presence	Rain
24-Feb	2020	4:29:11	13.32°S	124.09°W	6.09°S	116.31°E	Postponed	Clear
2-Feb	2021	3:51:20	16.68°S	114.43°W	2.5°N	116.42°E	Postponed	Clear
22-Feb	2022	4:25:19	10.34°S	122.95°W	12.00°S	116.51°E	Regular presence	Shower
12-Feb	2023	4:44:19	13.90°S	127.78°W	11.40°S	116.24°E	Regular presence	Clear
31-Jan	2024	3:56:55	17.63°S	115.92°W	1.34°S	116.99°E	Postponed	Clear
18-Feb	2025	3:00:54	11.68°S	116.74°W	13.19°S	116.64°E	Regular presence	Clear
8-Feb	2026	3:51:49	15.10°S	129.42°W	15.62°S	116.26°E	Regular presence	Clear
27-Feb	2027	5:04:35	8.56°S	132.94°W	23.57°S	116.36°E	Regular presence	Rain
16-Feb	2028	4:50:16	12.61°S	129.04°W	19.27°S	116.40°E	Regular presence	Clear
4-Feb	2029	4:16:16	16.25°S	120.60°W	11.86°S	116.23°E	Postponed	Clear
24-Feb	2030	5:04:23	9.57°S	132.78°W	20.25°S	116.34°E	Regular presence	Rain

due to the increased water density of cold water (Schmidt *et al.*, 2018) are considered to have aided in the movement of epitoke bearing reproductive organs to the water surface. Hydrostatic pressure (p_h) is the downward force exerted per unit area of any bodies in water, which can be calculated as $\rho \times g \times h$, where ρ is the water density, g is the gravity, and h is the water level (Serway, 1990). The change in hydrostatic pressure on sea worms is likely with a change in the seawater temperature or seawater level. Figure 6 is a schematic diagram showing the change in hydrostatic pressure at the bottom of the shore associated with the lowering of seawater level during neap tide. *Nyalé* swarming in Lombok is likely to be influenced by gravity of the moon. As the gravitational force of the moon diminishes when the sun and the moon is at the right angle relative to the Earth during the last quarter lunar phase, neap tide occurs with a reduced depth of the water on shores. The time of *nyalé* swarming appeared to coincide with the time before the seawater level was lowest and the sun rose. This observation lent support to the hypothesis that reduced hydrostatic pressure at the bottom of the sea where sea worms are usually found might have assisted in the swarming process, as the hydrostatic pressure at the bottom of the shore decreases when the sea level slowly drops from its peak (h_i) at midnight to its lowest level (h_f) before the sun rises (Figure 6).

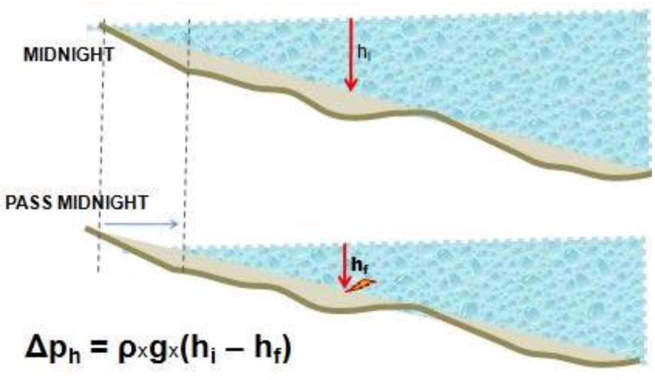

Figure 6. Change in hydrostatic pressure as seawater level drops during neap tide.

In addition, a decrease in water temperature affects the physical properties of water. For example, a decline in temperature is accompanied by an increase in seawater specific density, from 1.024 $gram.cm^{-3}$ at 20°C to 1.028 $gram.cm^{-3}$ at 0°C or from 1.022 $gram.cm^{-3}$ at 30°C to 1.023 $gram.cm^{-3}$ at 27°C (Schmidt *et al.*, 2018). In other words, seawater becomes denser as temperature lowers. The largest difference in seawater temperature accompanied by a sharp decline in midnight temperature observed in February (Figure 3) was thought to have an impact on the buoyancy of epitoke, as the increased specific density of seawater during that time might exert an increased buoyancy force that helps the terminal segments of sea worms to be cast off the body and emerge on the water surface in the swarming process. The combined low hydrostatic pressure during neap tide and the sharp decline in seawater temperature during February are considered as exogenous factors associated with *nyalé* swarming.

The weather condition during *nyalé* swarming was predicted from the position of the sun relative to the Java trench (Table 1). On the date of *nyalé* swarming, the local weather was expected to be bright or clear if the sun was far away to the south, and have heavy rain if the sun was close to Lombok. It will be cloudy or have shower if the sun was above the Java trench. The local community believes that the appearance of *nyalé* in huge population will cause heavy rain. A significant finding from this study was that such relationship between *nyalé* swarming and rain is a misperception stemmed from the coincidence between the time of *nyalé* appearance and the position of the sun relative to the convergence zone in the southern Indian Ocean, within 0° to 10°S (Partridge & Ma'shum, 2002). In this study, Java trench located between 10°S and 11°S was used as the physical datum or reference of the convergence zone. If the sun culminates over north of the Java trench at the time of *nyalé* swarming, it will cause SST in the convergence zone to increase. As a result, evaporation would increase and a low atmospheric pressure region will be formed in the convergence zone, creating a northward wind movement that would bring abundant water vapour to Lombok (Partridge & Ma'shum, 2002). As such, it is possible to have heavy rain in Lombok during *nyalé* swarming. On the other hand, if the sun is far south from the convergence zone, then the evaporation rate and convective activity in the convergence zone will be low, and there will be no northward strong wind (Linacre & Hobbs, 1982). It follows that there will be no rain and the weather would be clear during *nyalé* swarming. In the case when the sun culminates above the Java trench, it will be more likely for Lombok to have a calm weather or shower during *nyalé* swarming.

IV. CONCLUSION

Annual periodicity of *nyalé* swarming is part of the reproduction cycle synchronised to the synodic months. The swarming time could be predicted by determining the time for the last quarter moon to culminate over the southern coast of Lombok (8.9°S, 116.28°E). *Nyalé* swarming occurs once every year on the 20th lunar day of the tenth month in the local calendar, which usually corresponds to after the first week in February. The coincidental presence of *nyalé* in the first week of February is always followed by postponement of swarming for one synodic month until the same lunar day in March. In addition, we considered the following exogenous factors to be associated with swarming time of *nyalé* in Lombok: (i) the moon culmination position at the southern coast of Lombok in February that may initiate swarming of *nyalé*, (ii) the significant difference between the maximum and minimum seawater temperature that might act as a zeitgeber or biological indicator for *nyalé* to emerge, and (iii) a neap tide of about 0.78 m high before sun rise was common during *nyalé* swarming in Lombok.

V. ACKNOWLEDGEMENTS

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