Revisiting the Spawning Pattern of Nyale Worms (Eunicidae) Using the Metonic Cycle

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Abstract

Mass spawning dates of nyale worms (Eunicidae) have been scientifically predictable since 2019. However, the prediction of split spawning, i.e. the phenomenon when nyale worms spawn in both February and March, was made based on limited data. The present study aimed to revisit the dates of the split spawning prediction using the Metonic Cycle, i.e. 19-year lunisolar cycle. Using the existing prediction method 114 years of prediction dates were generated and then matched the dates with the Metonic Cycle. The results show that the spawning prediction dates generally follow the Metonic Cycle. There are only a few dates that need to be revised, i.e. when the full moon rises on the 14th of February. It is suggested that split spawning of worms is likely to occur when the full moon rises between the 7th to 13th of February. When the full moon appears before the 7th of February, single spawning will take place on the fifth day after March's full moon. When the full moon occurs after the 13th of February, single spawning will occur on the fifth day after February's full moon. The present work is the first study that demonstrates the relationship between nyale worms' spawning patterns and the Metonic Cycle.

Keywords: *bau nyale, Lombok, Polychaete, swarming, cultural tourism, prediction, hypothesis*

Introduction

Mass spawning of *nyale* worms (Eunicidae, Polychaeta) is a very important annual event for Lombok people. *Nyale* worms are multiple species that are mainly composed of *Palola (Eunice)* sp. and *Lycidice* sp. (Jekti *et al*., 1993). Although the Nereididae worms also swarm at the same time as the Eunicidae, they are not considered as the *nyale* worms. Lombok people neither collect nor consume the nereidid worms. The *nyale* worms release their generative body parts or epitokes simultaneously that the water contains plenty of epitokes. The swarming epitokes or *nyale* (in *Sasak*, Lomboker tribe language) have been foraged for centuries by coastal communities for their free delicacies. The tradition of *bau nyale* (foraging epitokes) has been promoted as one of the biggest cultural festivals of Indonesia (Triyanti *et al*., 2020; Taqwiem *et al.,* 2020) and attracting tens of thousands of visitors. As the peak of spawning occurs in one night, the prediction of the mass spawning is crucial to satisfy the visitors of the annual cultural festival. Traditionally, the prediction was only made by cultural leaders in a sacred ritual meeting (Odani *et al*., 2016). A similar traditional prediction also applies to *nyale* worms on Sumba Island (Furusawa and Siburian, 2019), *laor* worms on Ambon Island (Mahulette, 2020), and *palolo* worms on Samoa (Lefale, 2010). All these worms are referred to Eunicidae worms releasing epitokes, particularly *Palola* spp. and *Lysidice* spp.

In 2019, the first scientific prediction was introduced for *nyale* worms (Bachtiar and Bachtiar, 2019). The prediction enables all people to make predictions provided that they have access to the date of February's full moon of a particular year. In many marine invertebrates, the moon cycle is strongly linked with the date of spawning (Willis *et al*., 1985; Wolstenholme *et al*., 2018; Vélez-Arellano *et al*., 2020), while the annual sea temperature cycle coincides with the month of spawning (Babcock *et al*., 1985; Nozawa, 2012; Caballes and Pratchett, 2017), and the tidal cycle is related to the time of spawning (Willis *et al*., 1985; Darnell *et al*., 2012; Collin *et al*., 2017). A one hundred years spawning prediction of *nyale* worms generated in Bachtiar and Bachtiar (2019) showed a higher accuracy than the traditional one. In the last 14 years, its accuracy was 100%, while traditional prediction was missed three times in the last six years. The scientific prediction is based on both lunar and solar cycles. Bachtiar and Bachtiar (2019) suggested three hypotheses: First, when the full moon occurs before the 7th of February, the

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spawning of worms will take place on the fifth day after the full moon of March (20th lunar calendar). Second, when the full moon rises between the 7th and 14th February, the spawning will take place twice, i.e. on the fifth day after the full moon of February (20th lunar calendar) and the fifth day after the full moon of March. Third, when the full moon occurs after the 14th of February, the spawning will occur on the fifth day after the full moon of February.

Inspite of its high accuracy, the second hypothesis has not been tested yet in the field. The period that leads to split spawning is considered as critical dates in Bachtiar and Bachtiar (2019) due to lack of available data and is hardly proven until the time comes. The full moon on the 7th of February will occur in 2031, and the full moon on the 14th of February will rise in 2033 (www.timeanddate.com). Casper (1984) found some periods with uncertain spawning events when he studied spawning periodicities of *palolo* worms in Samoa. He also noticed that there was a 19-year cycle, in 1940 and 1959, in which the date of spawning was the same on the 24th of October. The 19-years cycle (or 18.6 years to be exact) has been long identified in a lunisolar cycle that is well known as the Metonic Cycle. The cycle is strongly related to tidal cycles (Currie and Fairbridge, 1985; Yasuda, 2018) and may provide the best foundation to test and strengthen the second hypothesis of Bachtiar and Bachtiar (2019).

The present study aimed to revisit the spawning pattern of nyale worms using the 19-year Metonic Cycle. As the scientific prediction is not yet available for *laor* worms in Maluku, *palolo* worms in Samoa, the results of the study may also apply or at least adaptable to those worms, since nearly all of them belong to the Family Eunicidae and Nereididae. In the central and western Pacific, the month of spawning is October or November, while in the eastern Indian Ocean the month of spawning is February or March.

Materials and Methods

To match the scientific prediction of *nyale* worms' spawning dates with the patterns of the Metonic Cycle (19-years), an existing 100 years (2000-2100) spawning prediction dates in Bachtiar and Bachtiar (2019) were revisited to find a pattern of the Metonic Cycle. The prediction dates were developed from available spawning date records in four years (2015-2018) and validated using eight years data (2007-2014) from online media and amateur writers on electronic materials (blogs, Youtube). Full moon dates were obtained from www.timeanddate.com. Despite its relatively small number of data used to construct the hypotheses, the prediction has 100% accuracy from 2007 to 2021.

The 19-year cycles were detected in the periods of 2001-2019, 2020-2038, 2039-2057, 2058-2076, and 2077-2095 (Table 1). The prediction dates were then extended to the year 2114 to obtain six full Metonic Cycles. The prediction dates were reviewed for any patterns of coincidence or violations to the six Metonic Cycles. It was expected that the occurrence pattern of the split spawning is consistently match up with the 19-years cycle, and the same spawning dates reoccur every 19 years.

Result and Discussion

The Metonic Cycle shows the orderly occurrence of split- and single- spawnings. In each cycle, 5 (five) split spawning and 14 single spawnings are identified. The pattern of spawnings in a single cycle (19 years) may be described as 1-4-1-2-1-2-1-4-1-2. Numbers 1 represent split spawnings, whereas numbers 2 and 4 represent single spawnings. The spawning type composition of nyale worms based on the Metonic Cycle is 1 split spawning followed by 4 single spawnings, then 1 split spawning tracked by 2 single spawnings, and another 1 (one) split spawning followed by 2 single spawnings, and back to 1 split spawning and 4 single spawnings. The 19-year cycle is finally closed by the occurrence of 1 split spawning followed by 2 single spawnings. This pattern is consistent from 2001 to 2114 (114 years), which consists of six cycles.

The split spawning pattern of *nyale* worms is different from that of corals. A decade observation on the coral spawning in Scott Reefs (Western Australia) showed that split spawnings occurred more frequently every two or three years (Foster *et al*., 2018). The coral split spawning occurred in 2007, 2010, 2013, and 2015. During the same period (2007-2016), *nyale* worms demonstrated split spawning only twice, i.e. in 2009 and 2012. A combination of single and split spawnings may increase the variation of larval supply and enhance inter-reef connectivity (Hock *et al.,* 2019).

The Metonic Cycle also shows a repeated pattern of months of single spawnings. In the case of two consecutive single spawnings, the order month of spawning is consistently in March and then February. In the case of four consecutive single spawnings, the general order is also March – February – March - February. There are two cycles, however, in which the first period of four consecutive single spawnings does not seem to follow this general rule. In the cycles of 2001-2019 and 2039-2057, the month order of the first four consecutive single spawnings is March-February-March-March. The difference occurs in the 5th year of the cycles. In fact, in all the 5th years of the cycles, all *nyale* worms spawn after the full moon of February. Since the full moon occurs in late February

Table 1. Observed and predicted spawning patterns of nyale worms at the southern coast of Lombok Island. Grey cells show split spawning.

No	Year	*Fm Feb	Fm Mar	Spawning Date	Year	Fm Feb	Fm Mar	Spawning Date	Year	Fm Feb	Fm Mar	Spawning Date
1	2001	8	10	13 Feb and 15 Mar*	2020	9	10	14 Feb and 15 Mar*	2039	9	11	14 Feb and 16 Mar*
2	2002	27	29	04-Mar	2021	27	29	04-Mar	2040	28	28	05-Mar
3	2003	17	18	22-Feb	2022	17	18	22-Feb	2041	16	18	21-Feb
4	2004	6	7	12-Mar	2023	6	7	12-Mar	2042	5	7	12-Mar
5	2005	24	26	01-Mar	2024	24	25	29-Feb	2043	24	25	01-Mar
6	2006	13	15	18 Feb and 20 Mar	2025	12	14	17 Feb and 19 Mar	2044	13	14	18 Feb dan 19 Mar
7	2007	2	4	09-Mar	2026	2	3	08-Mar	2045	2	3	08-Mar
8	2008	21	22	26-Feb	2027	21	22	26-Feb	2046	21	22	26-Feb
9	2009	9	11	14 Feb and 16 Mar	2028	10	11	15 Feb and 16 Mar	2047	10	12	15 Feb and 17 Mar
10	2010	--	1 and 30	06-Mar	2029	--	1 and 30	06-Mar	2048	29	30	05-Mar
11	2011	18	20	23-Feb	2030	18	20	23-Feb	2049	18	19	23-Feb
12	2012	8	8	13 Feb and 13 Mar	2031	7	9	12 Feb and 14 Mar	2050	7	8	12 Feb and 15 Mar
13	2013	26	27	03-Mar	2032	26	27	03-Mar	2051	25	27	02-Mar
14	2014	15	17	20-Feb	2033	14	16	19 Feb**	2052	15	15	20-Feb
15	2015	4	6	11-Mar	2034	3	5	10-Mar	2053	3	5	10-Mar
16	2016	23	23	28-Feb	2035	22	24	27-Feb	2054	22	24	27-Feb
17	2017	11	12	16 Feb and 17 Mar	2036	12	12	17 Feb and 17 Mar	2055	12	13	17 Feb and 18 Mar
18	2018	--	2 and 31	07-Mar	2037	--	2 and 31	07-Mar	2056	1	2	07-Mar
19	2019	19	21	24-Feb	2038	20	21	25-Feb	2057	19	21	24-Feb

Notes: *Start of the Metonic Cycle. **It was previously predicted to be split spawning. ***It was previously predicted to be single spawning (Bachtiar and Bachtiar, 2019).

Table 1. Observed and predicted spawning patterns of nyale worms at the southern coast of Lombok Island. Grey cells show split spawning (Continued)

No	Year	*Fm Feb	Fm Mar	Spawning Date	Year	Fm Feb	Fm Mar	Spawning Date	Year	Fm Feb	Fm Mar	Spawning Date
1	2058	8	10	13-Feb and 15-Mar*	2077	8	10	13-Feb and 15-Mar*	2096	8	9	13-Feb and 14-Mar*
2	2059	27	29	04-Mar	2078	27	28	04-Mar	2097	26	28	03-Mar
3	2060	16	17	21-Feb	2079	16	17	21 Feb	2098	16	17	21-Feb
4	2061	4	5	10-Mar	2080	5	6	11-Mar	2099	5	7	12-Mar
5	2062	23	25	28-Feb	2081	23	25	28-Feb	2100	24	26	29-Feb
6	2063	13	15	20-Feb and 20-Mar	2082	13	15	18-Feb and 20-Mar	2101	14	15	19-Feb
7	2064	3	3	08-Mar	2083	3	4	09-Mar	2102	3	5	10-Mar
8	2065	21	22	26-Feb	2084	22	22	27-Feb	2103	22	24	27-Feb
9	2066	10	12	15-Feb and 17-Mar	2085	10	11	15 Feb and 16 Mar	2104	11	12	16-Feb and 17-Mar
10	2067	---	1 and 31	06-Mar	2086	28	30	05-Mar	2105	---	1	06-Mar
11	2068	18	19	23-Feb	2087	17	19	22-Feb	2106	18	20	23-Feb
12	2069	6	8	11-Feb and 13-Mar***	2088	7	7	12-Feb and 12-Mar	2107	8	9	13-Feb and 14-Mar
13	2070	25	27	02-Mar	2089	25	26	02-Mar	2108	27	27	03-Mar
14	2071	14	16	19 Feb***	2090	14	16	19 Feb**	2109	15	17	20-Feb
15	2072	4	4	09-Mar	2091	4	5	10-Mar	2110	5	6	11-Mar
16	2073	22	24	27-Feb	2092	23	24	28-Feb	2111	24	25	01-Mar
17	2074	12	13	17-Feb and 18-Mar	2093	11	13	16-Feb and 18-Mar	2112	13	13	18-Feb and 18-Mar
18	2075	1	3	08-Mar	2094	--	2	07-Mar	2113	1	2	07-Mar
19	2076	20	21	25-Feb	2095	19	21	24-Feb	2114	20	21	25-Feb

Notes: *Start of the Metonic Cycle. **It was previously predicted to be split spawning. ***It was previously predicted to be single spawning (Bachtiar and Bachtiar, 2019).

(2005 and 2043), the 20th lunar calendar of February of both years takes place on the 1st March.

In some cases, the Metonic Cycle indicates repeated spawning dates, as suggested by Casper (1984). Prediction data on single- and split-spawnings over the six cycles revealed that no spawning date prediction has the same date across all the six cycles. All the spawning dates, however, are closely related, with a slight difference of only one or two days (Table 1). For example, in the second year of the cycles, the predicted spawning dates are the 4th of March (2002, 2021, 2059, 2078), 3rd of March (2097), and 5th of March (2040). In this case, it is recorded four spawning dates that are in agreement and two spawning dates that are not in agreement with the Metonic Cycle. Of 84 single spawning dates in the six cycles, 52 spawning dates (63%) are in agreement with the same order of years in other cycles, whereas the other 31 dates (37%) are not.

The Metonic Cycle of the *nyale* worm spawning pattern suggests revising the second of the prediction hypothesis in Bachtiar and Bachtiar (2019). The hypothesis suggests that split spawnings typically occur when the full moon rises between the 7th and 14th of February. This hypothesis, in some cases, is not compatible with the Metonic Cycle. There are four years in which the spawning prediction dates do not match with the Metonic Cycle. In 2069, for instance, the full moon occurs on the 6th of February, but the Metonic Cycle indicates split spawning (Table 1). In 2071, 2090, and 2090, the full moons are on the 14th of February, but the Metonic Cycle suggests single spawning. The hypothesis, therefore, needs to be revised; the predicted spawning dates should be moved one day in advance to fit with the Metonic Cycle. Thus the revised second hypothesis is that the split spawning of *nyale* worms will occur when the full moon rises between the 7th and 13th of February (Figure 1). This revision does not change the practical use of the existing scientific method.

The revised hypothesis makes the spawning prediction almost entirely fit with the 19-year Metonic Cycle, despite a number of inconsistencies found in 2069 and 2101. Table 2 shows the inconsistencies in the predicted spawning dates when the full moon occurs on the 6th and 14th of February. In the 14th February's full moon cases, the inconsistency may be explained by looking at the full moon rising time. When the full moon rises before 12:00 (noon), the 14th of February 2101 is still considered as the 13th February, that *nyale* worms will perform split spawning. This speculation, however, does not apply to the inconsistency that occurred on the 6th of February 2069. The anomalies generally indicate that predicting the spawning dates of *nyale* worms is not very simple; this may also be a correction of the 19-year cycle from 18.6 years tidal cycle.

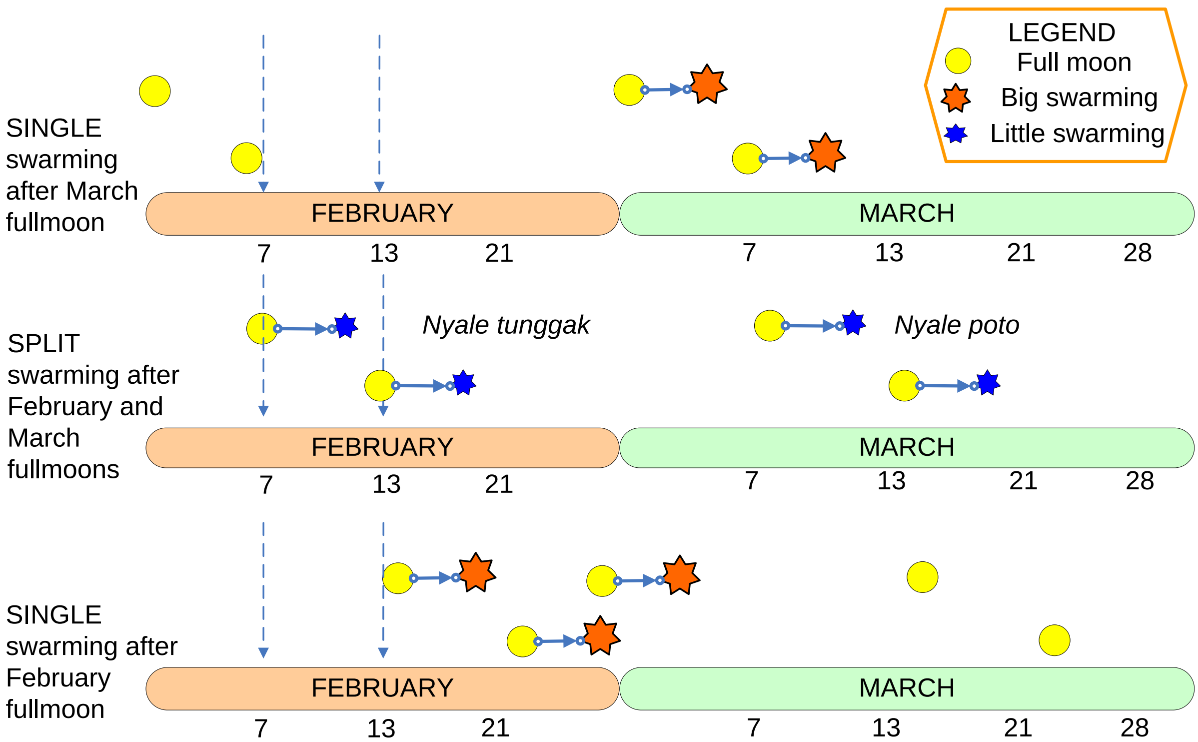

Figure 1. Illustration of three hypotheses to predict the spawning date of nyale worms in Lombok Island. A revision was made on the 13th of February's full moon.

Table 2. Inconsistencies of predicted spawning dates using the Metonic Cycle

Year	February's full moon	March's full moon	Spawning Date	Full Moon Time
2004	6	7	12-Mar	16:46
2023	6	7	12-Mar	02:28
2069	6	8	*SS 11 Feb and 13 Mar	13:29 and 06:35
2033	14	16	19-Feb	15:04
2071	14	16	19-Feb	21:33
2090	14	16	19-Feb	21:40
2101	14	15	SS 19 Feb and 20 Mar	10:44 and 23:51

*SS: split spawning

It should be noted that there could be more than one date of February's full moon since lunar calendars have different methods of calculation (Tsumura, 2012). In Indonesia, for example, there are Hijri (Islamic), Rowot (Sasak, Lombok tribe), Balinese, Javanese, and Chinese calendars. In the last five years, these lunar calendars have been inaccurate for predicting the spawning peak of *nyale* worms. The lunar calendar that available on the internet (www.timeanddate.com) has been proven to be accurate for the prediction. This may explain how traditional leaders could miss one day or one month in their spawning prediction. Although they already did the prediction for decades, they did not have access to the international lunar calendar. As a result, the predicted spawning dates made by them sometimes do not match with the actual cycle.

Patterns of mass spawning have been recognized in many marine invertebrates. Multispecific coral mass spawning has been reported in the Great Barrier Reefs (Willis *et al*., 1985; Hock *et al*., 2019), Scott Reefs-Australia (Foster *et al.,* 2018), Okinawa Islands (Yamano *et al*., 2020), and Indonesia (Wijayanti *et al*., 2019). Multispecies mass spawning of polychaete worms have been described in Samoa (Casper, 1984), the Great Barrier Reefs (Hutchings and Howitt, 1988), Ambon-Indonesia (Pamungkas, 2015; Pamungkas and Glasby, 2019), and Lombok-Indonesia (Bachtiar and Bachtiar, 2019). Prentiss (2020) reported that polychaete worms in the US Virgin Islands do not have multispecies mass spawning, and none of these worms belonged to the family Eunicidae. The date of annual mass spawning may indicate the optimum condition for reproduction (Foster *et al*., 2018). The mass spawning invertebrates have been evolved for millions of years to get the right time for their reproduction (Willis *et al*., 2006). The spawning dates of *nyale* worms are nevertheless the result of such a long evolutionary process that eventually maximizes reproductive outputs. Different reproduction schedules between *nyale* (Bachtiar and Bachtiar, 2019) and *laor* worms (Pamungkas, 2015) may be assigned to different environmental factors required by the worms to spawn.

It is still uncovered, however, how these oceanic and climate cycles affect the spawning pattern of *nyale* worms. At present, no studies are linking marine invertebrate reproduction to the Metonic Cycle. The Metonic Cycle has been reported to associate with oceanographic- (Currie and Fairbridge, 1985; Baart *et al*., 2012; Peng *et al*., 2019) and climate- cycles (Yasuda, 2018; Osafune *et al*., 2020). Spawning time and season may be related to annual cycles of food abundance for larval growth and development and environmental conditions most suitable for larval survival.

The spawning prediction date in the present work needs to be reviewed at least once in a decade since climate change rapidly increases seawater temperature in geological time. In other marine invertebrates, spawning synchrony and dates could change due to climate change. Coral mass spawning has been reported to be accurately predictable with high synchrony (Willis *et al*., 1985). In recent years, however, several corals showed decreasing spawning synchrony in the Red Sea (Fogarty and Maharver, 2019; Shlesinger and Loya, 2019). Repeated coral bleaching events that resulted in coral mass mortality were suggested to be the main disrupting factor in the spawning synchrony. Unlike corals, climate change does not have direct effects on *nyale* worms' survivorships. The worms' spawning synchrony might therefore be unaltered in the next several decades. Although the synchrony may not change, increasing seawater temperature may accelerate the gamete maturation of *nyale* worms that could change the day or month of spawning. Sakai *et al*. (2020) reported a one-day deviation of coral spawning due to changes in sea surface temperature and wind speed. Such changes may also occur to the spawning cycles of *nyale* worms.

Conclusion

Predicted spawning patterns of *nyale* worms over more than one century are mostly in agreement with the Metonic Cycle. There are only two occasions in 114 years when the dates of spawnings defy the Metonic cycle. This concurrence was used to revise the second hypothesis of Bachtiar and Bachtiar

(2019). Split spawning in two consecutive months, i.e. February and March, occurs when the full moon rises between the 7th and 13th of February.

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