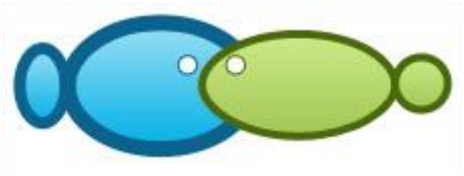

Relationship of the reproductive cycle with the migration of longtail shad (*Tenualosa macrura*) in Bengkalis Riau, Indonesia

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Abstract. Longtail shad (*Tenualosa macrura*) is a species of migratory hermaphrodite fish. Its most significant potentialssible migration occurs between the Malacca Strait to the Dompas waters, at the mouth of the Siak and Siak Kecil rivers. This study aimed to found the best fish spawning sites. When in the juvenile period fish are female, they turn to males when they become adults. The sampling was carried out in the Buruk Bakul Waters, the Dompas Waters and the Bunsur Sea, from July 24 to September 8, 2021. The data processing uses graphs and descriptive analysis. The study found that the spawning ground for this species is at the confluence of the Siak and Siak Kecil rivers with Dompas waters, precisely in the sea waters bordered by the waterfront, but side by side with the join point of the three waters. The flow of water in the two rivers was insignificantly affected, and the *T. macrura* still spawn every month, between the 13th and the 15th of the month, at full moon or at dark moon, the 29th and 30th. The playground for these fish is different, according to their age.

Key Words: longtail shad, migration, spawning.

Introduction. Fish groups have various patterns in the sexual process. Less than 1% of vertebrate species are hermaphrodites, and essentially these are fishes (Kuwamura et al 2020). Hermaphroditism, the expression of a single individual's male and female reproductive functions, arouses the most significant curiosity and controversy. However, diagnosing the sex forms of these fish continues to challenge researchers, particularly the differences between hermaphrodites and non-hermaphrodites. These differences reflected in the relationship between gonad shape and function are essential to improve understanding of the origin of hermaphrodites in fish and their high expression today (Sadovy & Liu 2008). There were over 35,000 species of fish vertebrates among the over 69,000 species of vertebrates living in the world in 2021 (Fricke et al 2022; Maclean 2023). About 1-2% of vertebrate species of fish are hermaphrodites, and almost all come from fish groups (Ashman et al 2014). Hermaphrodite fish are grouped into four categories (Sadovy & Liu 2008; Munday et al 2010; Kuwamura et al 2007).

Tenualosa macrura is one of the protected marine fish species in Bengkalis waters, Riau, Indonesia (Suwarso et al 2017). Although in Bengkalis Regency, Riau, it has been designated as a protected fish, the regulations implementation still meets many obstacles. Fishermen continue to catch the fish for its taste and eggs.

Indonesia has abundant natural resources, with a wide variety of marine resources, comparable only to the Amazonian rainforest. The results of research on bioecology and reproduction of both freshwater and seawater fish are still minimal. Likewise, research on bioecology and fish reproductive cycles in Indonesia is still behind the research on the same topic in other countries, considering the proportion of marine waters and the

number of inhabitants in Indonesia. Besides, *T. macrura* has migratory abilities, especially related to the spawning process (Thamrin 2019; Thamrin et al 2021) although only on a relatively short distance. It is estimated that *T. macrura* only migrate from the Melaka Strait towards the outskirts of Sumatra Island, to find food, and this research was conducted to confirm this supposition. Reproductive studies on this fish species have been carried out by Thamrin et al (2019), showing that *T. macrura* spawn throughout the year. On the other side, the reproductive of fish around the 13th, 14th, and 15th or on the 29th, 30th, and 1st of each month.

T. macrura is an economically essential fish with a high selling value and a high price of eggs. This condition causes a decrease in the *T. macrura* resources in Bengkalis waters. The study conducted by Blaber et al (1999) found that the flow of two major rivers in Bengkalis had no significant effect on spawning activity. Additionally, it was observed that *T. macrura* continued to spawn during the periods of the 13th to 15th day of each month, coinciding with either a full or dark moon, as well as the 29th and 30th day of each month. Due to its migratory nature, various aspects of this fish need to be studied, including spawning sites, juvenile life, transitional sex and population distribution patterns. The main objective of the study was to identify the most suitable spawning sites for the endemic fish *T. macrura*. This investigation is seen as a key step towards improving the species' abundance and long-term viability in aquatic environments.

Material and Method

Description of the study sites. The research was carried out for three months, from July to September 2021, in the Buruk Bakul Waters (the strait between Buruk Bakul and Bengkalis), Dompas Waters (the strait between Sumatra Island and Padang Island Selat Panjang), and Bunsur Waters (adjacent to the Lalang Strait) (Figure 1). Samples are taken from the fishermen's gillnet catch, at least three times, from three vessels.

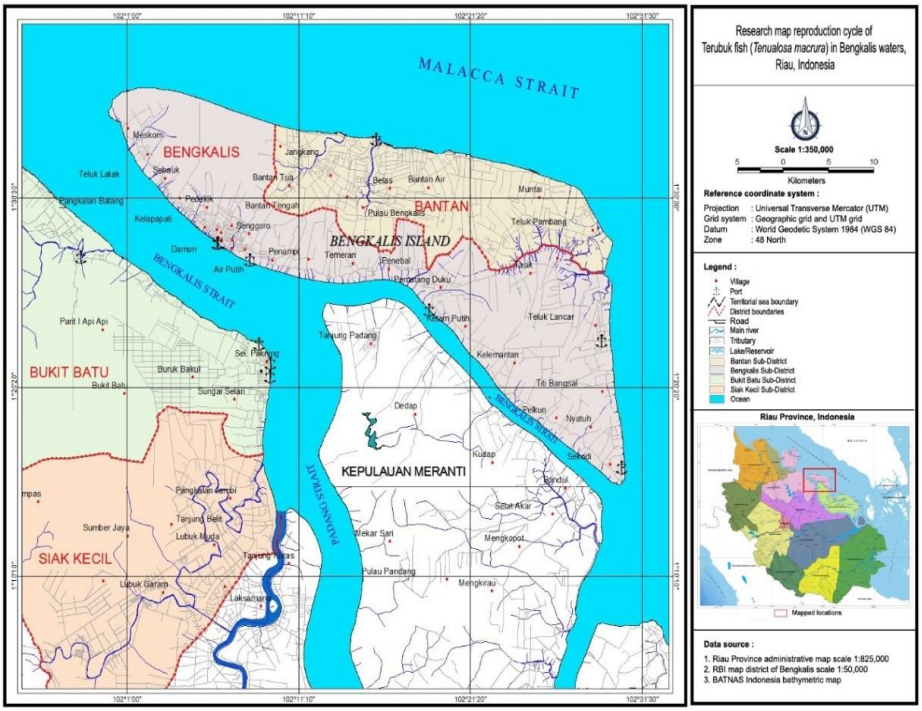

Figure 1. Research location.

Determination of sample size. This study used a survey method, and the sample points were determined using a purposive fishing ground to find different results from the three stations, so the *T. macrura* sought did describe a real difference, based on previous research (Thamrin et al 2021) as a migratory fish in the spawning process. The experimental specimens of the *T. macrura* fish used in the study depended on the gillnet

catch obtained by fishermen from the three locations (Buruk Bakul Waters, Dompas Waters, and Bunsur Waters). *T. macrura* obtained were grouped according to the location. The cycles found were used in determining the best period for an extensive fishing.

Data collection. Since these fish belong to a protected group, the capture and the sampling period are limited to July, August, and September (2021), the peak of spawning of the *T. macrura*. Since this *T. macrura* are hermaphrodites, all sizes of fish caught are sampled. Generally, female *T. macrura* specimens exhibit a larger size, while their male counterparts tend to be relatively smaller (Blaber et al 1999). The data collected in this study consisted of fish specimens' total length (TL), standard length (SL), and the weight. The data was taken from the samples obtained included fish length, fish weight, gamete weight, egg fecundity, and egg diameter. The fish samples collected were preserved using ice crystals to keep the samples fresh, and data on the length and weight of the fish and the weight of gametes (eggs) were measured directly in the Bioper laboratory, Faculty of Fisheries, Riau University. Likewise, egg diameter and fecundity were observed in the Faculty of Fisheries and Marine Sciences laboratory, University of Riau. The samples of fish and gametes were selected and handled using ice crystals, besides the best fish samples. The equipment used included a plastic gamete sample holder, a scale to measure the weight of fish samples and a scale to measure the weight of gametes, a set of microscopes to observe gametes in the laboratory, a refractometer to measure water salinity, tweezers and scissors to dissect the fish, along with a camera.

Data analysis. The maturity level of the *T. macrura* gametes is determined based on the level of gonad maturity (TKG), based on the general shape and size of the gonads (modification of the Cassie method as described by Effendie (1979). The comparison of the three data from the Bad Waters of Bakul, Dompas waters, and Bunsur waters was analyzed descriptively. Primary data determined the best fishing time. Data were analyzed at the peak of the *T. macrura* spawning, the purpose of this analysis was to limit catches, maintaining the *T. macrura* prices, in order to protect aquatic fish populations.

Results. A capture session was carried out in Buruk Bakul and Dompas waters on July 24 th, 2021. The *T. macrura* caught in Dompas waters amounted to 15 females and 14 males. Meanwhile, in Buruk Bakul catch there were counted 21 individuals, only females. Figure 2 illustrates the presence of species at different stages of gonad maturity for both males and females.

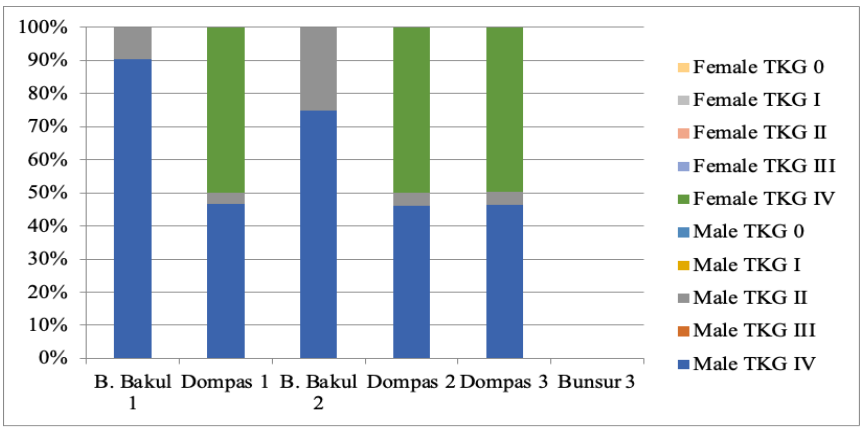

Figure 2. Development of male and female gametes (%) from the three waters where the *Tenualosa macrura* sampling was carried out (1 = July 24 2021, 2 = August 8, 2021, and 3 = September 8, 2021).

A second sampling was carried out on September 8, 2021, in Buruk Bakul waters, Dompas waters and in Bunsur waters. In two sampling times, only females were found

without any males in Buruk Bakul waters, with gonad maturity levels I and IV. While in the waters of Dompas, both male and female gonad maturity Levels were found in scale IV. A limited number of females with Gonat maturity level I were also found in Dompas waters. However, fishing in Bunsur waters uses nets and traps, catching most types of fish at the bottom of the current. The *T. macrura* obtained were generally small or did not have 21 gametes. Among the samples obtained from the Dompas waters, 15 females and eight males were found (Figure 2).

The development pattern of the maturity level gonad. The pattern of egg development of the *T. macrura* obtained in Buruk Bakul Waters can be seen in Figures 3a and 3c.

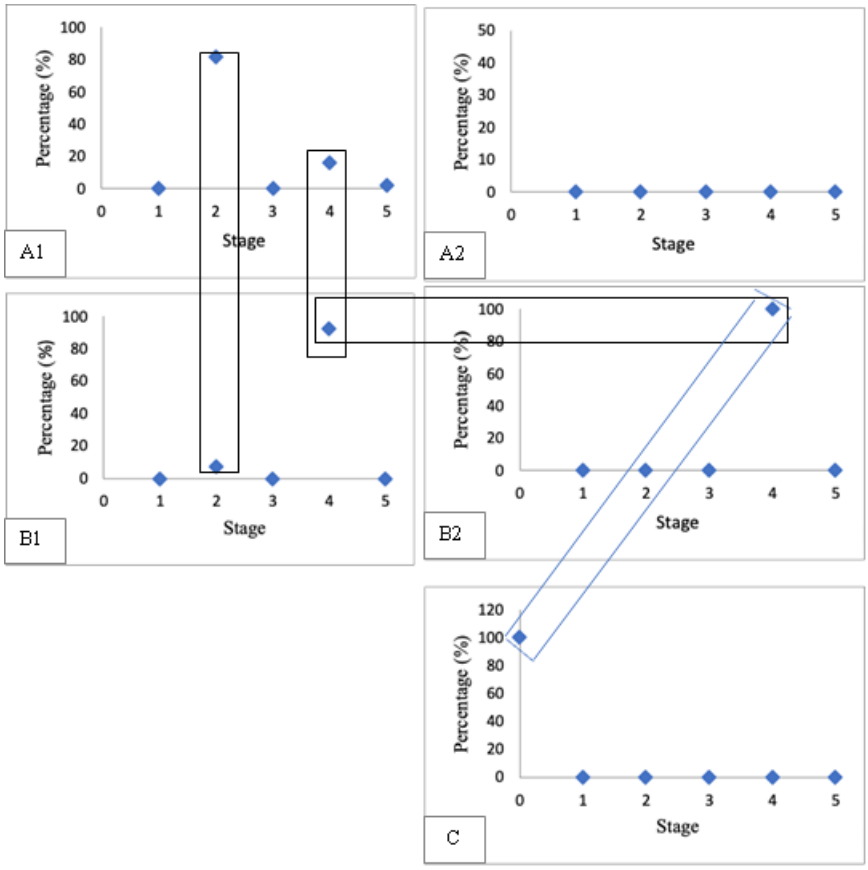

Figure 3. The average presence of each gonad maturity level of male and female *Tenualosa macrura* gametes from July to September 2021. Female (A1) and male (A2) in Buruk Bakul waters. Dompas waters female (B1) and male (B2), in Bunsur waters (C).

Only females were caught in the waters of the Buruk Bakul, but all of them were still juveniles. However, in Dompas waters, developing gametes of *T. macrura* were generally only at gonad maturity level IV. Less than 10% were found to have gonad maturity level II. In Dompas waters, there were found both male and female types. The female *T. macrura* is likely foraging for food in the Malacca Strait. However, when the eggs develop into maturity level II gonads, they migrate to the waters of Buruk Bakul. The female *T. macrura* at the maturity level II are generally found only in the Buruk Bakul waters. A small number of female *T. macrura* (<10) were found in these waters, but those at the gonads' maturity level IV at the time of catching were actually caught in the transitional waters, as gill nets are used to follow the flow of tidal currents. When the net was lowered in the Buruk Bakul Waters, it followed the tidal current to the South from the point 1º25'27.65" N 102º06'45.36" E towards the North to 1º28'18.41 U 102º 2'13.61" E, and vice versa at low tide. The average distance between the two points lowers the net and raises it about 9.9 Km (6.1 mi) (Figure 4). The same pattern applies to Dompas waters: the gill nets are installed at points 1º19'18.2" N and 102º11'47,8" E to

1º19'18.2" N and 102º11'47.8" E to 1º20'21.3" N and 102º12'20.1" E, approx. 9.98 Km (6.20 mi), and vice versa at the time of installation. The distance covered is about 9.0 Km (6.0 miles).

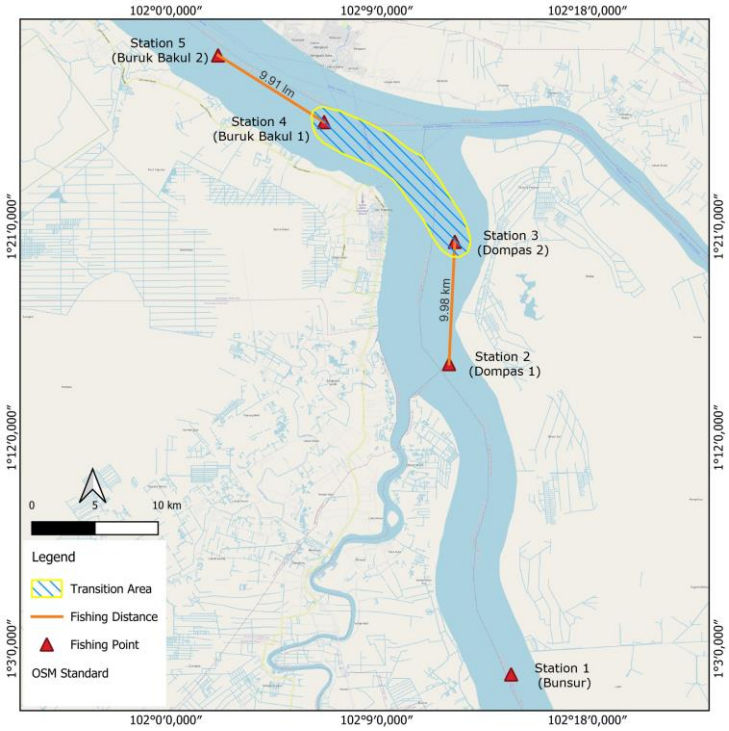

Figure 4. Research location *Tenualosa macrura* in the waters of Bakul Bengkalis, Dompas waters in Pakning River and in Bunsur Waters, between Simatera Island and Padang Selat Panjang Island.

At low tide the estuary of the Siak River'ss position exposes it to the influence of the Siak River, except for the East of the estuary. Thus, when the tide comes from the Malacca Strait, it will split into two: the West towards the Siak river and the East towards the Lalang and Bunsur Straits. At low tide, the western part of the Dompas waters is influenced by the Siak and Siak Kecil rivers, while in the East, the situation is the opposite. The distribution pattern of the *T. macrura* depends on the method of catching, as observed in Figure 3. The nets used for catching the *T. macrura* were deployed at the point 1º25'27.65" N and 102º06'45.36" E, towards the North to 1º28'18.41 N and 102º2'13.61" E. The distance between these two points is about 9.91 Km (6.16 mill), starting from the location where the nets are operated (gillnet), at the capture time, to the point where nets are deployed. Meanwhile, in Dompas waters, fishing in the *T. macrura* used a net similar to that carried out in the waters of Bad Baruk, between the point 1º19'18.2" N and 102º11'47.8" E to the point 1º19'18.2" N and 102º11'47.8" E to 1º20'21.3" N 102 º 12'20.1" E, with a distance of about 9.98 Km (6.20 mi).

Two fishing grounds, namely Buruk Bakul waters and Dompas waters, showed that the migration of the *T. macrura* was determined by the maturity level of the gonads. If the *T. macrura* gametes are in Stage II, the *T. macrura* will migrate to the waters of Buruk Bakul and probably will not reach the waters of Dompas. The last day of migration, they can still be found in Buruk Bakul waters, in Stage II, but the next day, the fish will no longer be found in Buruk Bakul waters and Dompas waters. However, male fish were never found in Buruk Bakul waters, either in gonad maturity level I, II, III or IV and Stage V, in July, August to October. It is considered that *T. macrura* that, after spawning, will live in the Bunsur and Lalang straits until they become male *T. macrura*, then, after, reaching Stage IV, they migrate to Dompas waters, at full moon or dead moon, to spawn. After the last spawning and after becoming a female, the *T. macrura* migrate instead of returning to the Lalang and Bunsur straits. However, they follow their partners to the Malacca Strait, where the smallest fish are found almost every day (Figure 4).

Discussion. The reproduction of *T. macrura* has been studied by Bleber et al (1990), Thamrin (2019) and Thamrin et al (2022). This species is one of the migratory fish species, so it cannot be found every time. However, the migration distance is not that far; it is only estimated to be from the Malacca Strait, for foraging, to the Dompas Strait at the mouth of the Siak river for spawning. However, it was discovered that a more precise location would be in the Dompas Strait, slightly to the West of the Lalang Strait. The area is the mouth of the Siak River. The Siak River comes from the South on Sumatra Island to the Dompas Strait junction (the Strait between Sumatra Island and the Tebing Tinggi Island Strait or Tebing Tinggi Island), forming a straight line towards Bengkalis Island. Meanwhile, the North to South axis turns to Southeast at the intersection with the Siak River, at Dompak strait (Figures 1 and 4). The Siak River is located to the West of both rivers. The Dompas Strait is under the influence of the Siak River, but to the East, it is free from the influence of the river (Figures 1 and 4). So, in order to catch the *T. macrura* the fishermen of Dompas Village have to cross far to the east side to approach Tebing Tinggi Island, staying away from the influence of water flow from the Siak and Siak Kecil rivers at low tide. The *T. macrura* avoid the watersheds of the two Siak and Siak Kecil rivers (Amri et al 2023), the limits of the influence of river and sea water, due to the fluctuations in water salinity. According to a research by Baum (2008), the increasing salinity indicates the beginning of the estuary suggested that dilution of the DOM-rich Siak water DOM-ppor ocean water. Part of the Dompas waters receives the influence of the Siak River at low tide. The spawning is possibly carried out around the Dompas waters, but not under the Siak River. In the Dompas waters, the salinitystill the same as in the highest waters (28-30$^{o}/_{oo}$). Meanwhile, where Dompas waters are directly affected by the Siak River, they have a salinity between 15 to 24$^{o}/_{oo}$, and fishermen can never encounter benthic fish. According to fishermen, the new *T. macrura*, down the streams of Siak River and Siak Kecil River, has only been found at north of Pertamina Port, in waters with a high salinity of 27$^{o}/_{oo,}$ salinity still varied between 25-30$^{o}/_{oo,}$ which the lowest value was measured at the closest to Siak River, where water body is influenced by freshwater (Amri et al 2018; Seygita et al 2021).

The three fishing grounds, namely Buruk Bakul waters, Dompas waters, and Bunsur waters, show that the migration of the *T. macrura* is determined by the level of maturity of the gonads. If the eggs of the *T. macrura* develop into gonad maturity level II, these fish are found in Buruk Bakul waters, except for the male *T. macrura*. When the maturity level of the gonads has reached gonad maturity level IV, the *T. macrura* migrate directly to the Dompas waters. However, in the waters of Bunsur, fish (mostly male adults) were still small, immature. Male *T. macrura* are considered mature after their sperm is fertile and they migrate to the Dompas waters, during the full moon or the dark moon. These findings are consistent with the research conducted by Amri et al (2023), which indicates that the initial stage of fish spawning migration takes place in April during the dark moon phase, whereas the final stage of the spawning process occurs in June during the full moon phase.

The migration of *T. macrura* during spawning is influenced by water quality and the lunar phase. Optimal spawning locations for *T. macrura* were characterized by slightly cooler waters with higher salinity and DO levels, as observed in the Dompas waters (Station 2). The Dompas waters have an average temperature of 30.3 °C, transparency of 0.27 m, salinity of 27$^{0}/_{00}$, and DO level of 7.8 mg L^{-1} (Seygita et al 2021). During the peak spawning season, which coincided with the full moon, the spawning habitat of *T. macrura* exhibited higher average salinity and pH values. Specifically, the salinity ranges from 28.5 to 30.5, while the pH ranges from 6.1 to 8.1 (Amri et al 2023). The proximity of the Dompas waters to the mouth of the Siak River facilitates the spawning process and enhances the ability of the larvae to migrate towards freshwater, which serves as the primary source of essential life support. *T. macrura* larvae were found in freshwater of the Siak River after tidal surges (Blaber et al 1999). The Dompas Estuary, located in a sheltered area with muddy substrate, serves as a spawning habitat for *T. macrura* (Ahmad et al 1995). The preference for spawning sites in *T. macrura* is also influenced by food availability. *T. macrura*, belonging to the *Clupeidae* family, primarily feeds on

plankton, especially zooplankton. This dietary preference aligns with findings regarding the diet of fish larvae in the *Clupeidae* family reported by Ara et al (2011). Therefore, the abundance of phytoplankton and zooplankton directly affects the number of *T. macrura* larvae in the water. Seygita et al (2021) discovered a significant presence of *T. macrura* larvae in areas with high concentrations of *Trichodesmium* sp. phytoplankton, *Tintinnopsis* sp., and *Nauplius* sp. zooplankton species. However, further research is necessary to determine the presence of *Chaetoceros* sp. phytoplankton specifically at the spawning sites in the Dompas waters (Station 2), as this particular type of phytoplankton was not detected at other stations.

Migration is finalized when the *T. macrura* will spawn; this event will occur for three days, on the 14th, 15th and 16th of each month. However, sometimes the spawning time moves at dead moon, on the 29th, 30th, and 1st of the month (Arabic month). The implications of the lunar cycle for designing a sampling program are discussed by (Gaudreau & Boisclair 2000). However, in *T. macrura* spawning does not always occur at full moon and sometimes occurs at dead moon. If migration and spawning occur at dead moon, the full moon spawning will not occur again, but this event cannot be determined. The success of fish spawning is also unknown. Salmon (*Oncorhynchus nerka*) have a 3.7 times greater chance of dying without spawning, in the Fraser River sockeye (Miller et al 2011). In migration, the *T. macrura,* which are thought to have come from the Malacca Strait, will continue to migrate for spawning in the Dompas waters, but some of the female *T. macrura* will reach the Buruk Bakul waters. Especially when the new *T. macrura* have a Stage IV gonad maturity level, female fish migrate to Dompas Waters. Ripe *T. macrura* that has eggs become mature after three days and migrate to the Dompas waters, where male *T. macrura,* also at Stage IV, has been waiting. *T. macrura* migrates for only three days a month. Meanwhile, the worst catch in the waters of Buruk Bakul concerns fish in stage II, on the third day of spawning (at full moon or at dead moon). When catching the *T. macrura* in the Buruk Bakul Waters, the fishermen never found fish to have Stage IV eggs, and the *T. macrura* caught had only Stage I, II, or III in those waters. At the same time, some fish (<10% in July and 25% in August) were found to have Stage IV in Buruk Bakul Waters. *T. macrura* is thought to have occurred in the transitional waters to the South, where the nets were lowered (Figure 4). While catching fish, fishermen follow the current, whether at trade or low tide (Figures 3 and 4). The same situation also occurred in Dompas waters; the female over 90% of *T. macrura* found had Stage IV and only 6.67% had Stage II on July 24th, 8% on August 8th, and 6.67% on September 8th 2021. *T. macrura* in stage II was caught in Dompas waters. They are estimated to be in a transitional area and migrated to the middle zone, at North of the fishing ground (Figures 3 and 4). Meanwhile, male fish were only caught in Dompas waters, with a total score of Stage IV. The distance between the fishing grounds in the waters of Buruk Bakul is about 9.98 km (5.12 miles). It is assumed that the possible transitional area is located about 2 km at South. therefore, only a few *T. macrura* have Stage IV eggs; on the contrary, Stage II oocytes are found in the transitional area at North of the fishing area, in Dompas waters. A similar trend was reported by Machrizar et al (2017).

Factors influencing spawning migration patterns such as migration distance, migration frequency, and spawning site fidelity are not well understood (Claydon et al 2012). It is estimated that only female fish migrate from the Malacca Strait. Males are believed to migrate only from the Bunsur Strait to the Dompas Strait. Male fish, particularly those in the TKG IV stage, wait for female Terubuk in the Dompas Strait. Since migration requires more energy, larger fry (males) from the Bunsur Waters are the ones that undertake the migration. Additionally, it has been observed that migration incurs costs that increase with the distance traveled: (1) higher energy expenditure, (2) reduced feeding time in preferred areas, (3) increased vulnerability to predators due to conspicuous movements and decreased familiarity with shelters beyond their home range (Chapman & Kramer 2000), and (4) fewer resources allocated to growth and/or gametogenesis. The size and sex of an individual are expected to influence the magnitude of these costs, as predation risk and proportional costs of movement decrease

with increasing size (Roff 1991; Domeier & Colin 1997). Individuals are likely to minimize costs by migrating to nearby spawning sites and exhibiting strong fidelity to these sites.

Conclusions. Based on the results of this study, it was found that the possible spawning locations were in the waters of Dompas, the spawning period occurred every month around the 13th, 14th and 15th day of the month or at dark moon. After spawning, the terubuk fish are enlarged in the Ransang and Bunsur areas and then, after becoming males, they meet the female terubuk in the Dompas waters. After becoming large, they turn into a female and they go to the Malacca Strait.

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Conflict of interest. The authors declare no conflict of interest.

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