6.1 INTRODUCTION

Biological rhythms are a persistent yet frequently disregarded aspect of life, present throughout various taxonomic groups of species. They frequently exhibit synchronization with the primary geophysical cycles of the Earth (Palmer, 1995; Naylor, 2010). Understanding the rhythmicity and predictability of reproductive behaviour in a species that is subject to exploitation is crucial for effective management and conservation efforts (Sutherland, 1998; Naylor, 2005). The lobster species *Nephrops norvegicus* (Linnaeus, 1758) exhibits variations in activity and catchability that are influenced by the light-dark cycle. In contrast, the annual rhythm controls the specific spawning times of the palolo worm species *Eunice viridis* (Gray, 1847) (Naylor, 2010). The significance of tide-related cycles in fisheries management has been highlighted by Naylor (2005).

The lunar synodic cycle, which spans approximately 29.53 days, refers to the recurring pattern of alignment and deviation between the moon, sun, and earth. This cycle plays a significant role in generating the tidal amplitude cycle. When the earth, moon, and sun are lined up in a straight line, which is called syzygy, the tidal amplitudes are at their largest. This happens during the new and full moon phases. The cycles associated with tides hold significant importance for intertidal animals that are subjected to dynamic environmental conditions. Terrestrial crabs, as seen by Burggren and McMahon (1988), have a daily cycle pattern of behaviour wherein they engage in feeding activities during periods of low tide and retreat to their burrows during high tide, as noted by Crane (1975) and Nordhaus et al. (2009).

The ecological significance of brachyuran crabs within the mangrove habitat has been extensively documented in the scientific literature. Notably, Robertson and Hruger (1994) highlighted the significant influence these crabs have on the overall ecology of the mangrove ecosystem. Additionally, other researchers have acknowledged their importance as significant members of the intertidal macrofauna in this habitat, including Macnae (1968), Sasekumar (1974), Jones (1984), Macintosh (1988), and Smith (1991). Brachyuran crab species, such as the mud crab, are known to play a significant role in sustaining coastal zone fisheries across the Indo-Pacific area (Quinn and Hojis, 1987; Prasad and Neelakantan, 1988; Robertson and Hruger, 1994).

A variety of environmental factors influence the ecological activities of brachyuran crabs. One of the primary elements contributing to variations in these activities is the lunar cycle, which influences fluctuations in the tidal range and variations in nocturnal illumination on the beach. The light intensity exhibited variations across distinct lunar days, hence exerting a significant influence on the ecological behaviours of brachyuran crabs. The full moon is associated with the highest levels of nocturnal luminosity, while the new moon is associated with the lowest levels. According to Oliveira and Saraiva (2014), the first quarter and last quarter moon phases offer intermediate values. Ommatids found in the optical lobe's ocular peduncle facilitate crustaceans' ability to perceive light. According to Welsh's (1939, 1941) research, the ommatids' protective pigments change their activity levels in sync with the circadian rhythm. Specifically, during the dark phase, these pigments facilitate the exposure of light receptors, but during the light phase, their primary function is to provide protection to these receptors.

The Ocypodidae Rafinesque, 1815, and Dotillidae Stimpson, 1858, families are prevalent members of the macro-benthic fauna found on sandy and muddy beaches in tropical and subtropical regions worldwide (Mclachlan and Brown, 2006). These animals mostly inhabit burrows for the purpose of seeking protection from adverse weather conditions and the potential threat of predation. Burrows function as a sanctuary throughout the processes of mating, molting, and egg incubation (Schober and Christy, 1993; Chan et al., 2006). The crab species mentioned in the study conducted by Lucrezi and Schlacher (2014) exhibit a consistent pattern of alternating their activities, such as foraging and maintaining burrows, between the surface of the beach and their underground microhabitat. Burrowing crabs have distinct diurnal activity patterns, with heightened levels of activity observed primarily during daylight hours, when these organisms are most active. The activity pattern of crabs is influenced by various environmental variables, including temperature fluctuations, tides, wind intensity, and wave levels (Pombo et al., 2017). According to Steiner and Leatherman (1981) as well as Blankensteyn (2006), it has been observed that members of the Ocypodidae Rafinesque (1815 family exhibit a high level of nocturnal activity and tend to retreat inside their burrows during daylight hours. However, Valero-Pacheco et al. (2007) have shown that this particular species exhibits the majority of its activity during daylight hours, with the highest levels occurring at sunrise and sunset.

Few studies are available that examine how the semilunar phases affect decapod behaviour; most of them deal with larval recruitments during full and new moons, when the tidal range is larger (Fortaleza et al., 2019). However, there is limited research available on the impact of the moon phase on the burrowing behaviour of this particular crab species. The comprehension of ecological dynamics, such as fluctuations in population size and individual characteristics, maintenance patterns of burrows, periods of heightened activity, and spatial distribution along the beach, is contingent upon a thorough understanding of the information provided (_reference__Rios-Jara, 2005). Therefore, in light of tidal changes and the intensity of light reaching the beach, the current study was undertaken to assess the variability in the frequency of burrowing activity across lunar phases. The present study aimed to evaluate the density and size of the resident burrowing crabs at the study site, which encompassed the mudflats of the Gulf of Khambhat, during the course of the entire lunar cycle.

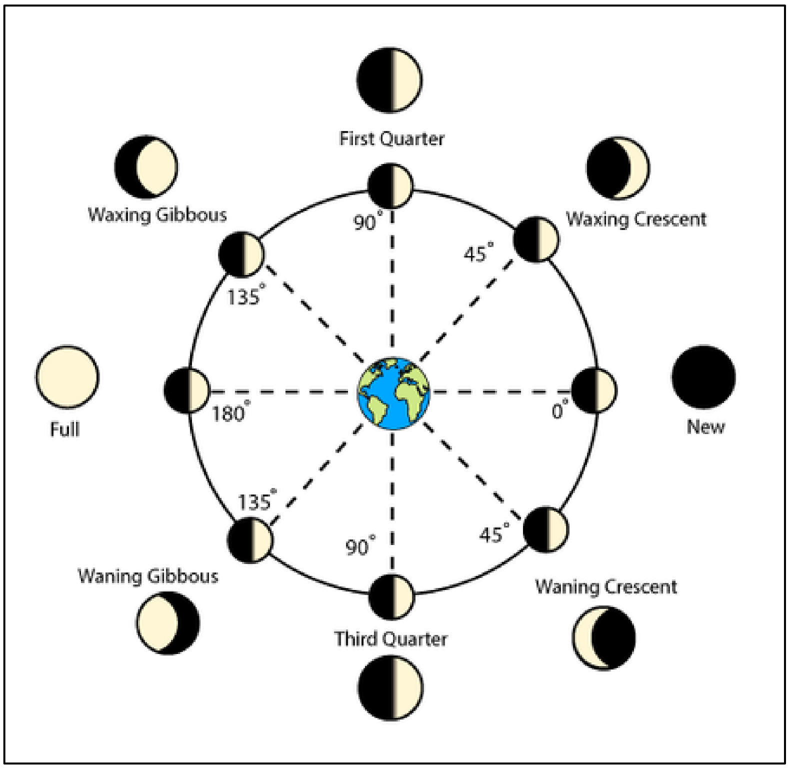
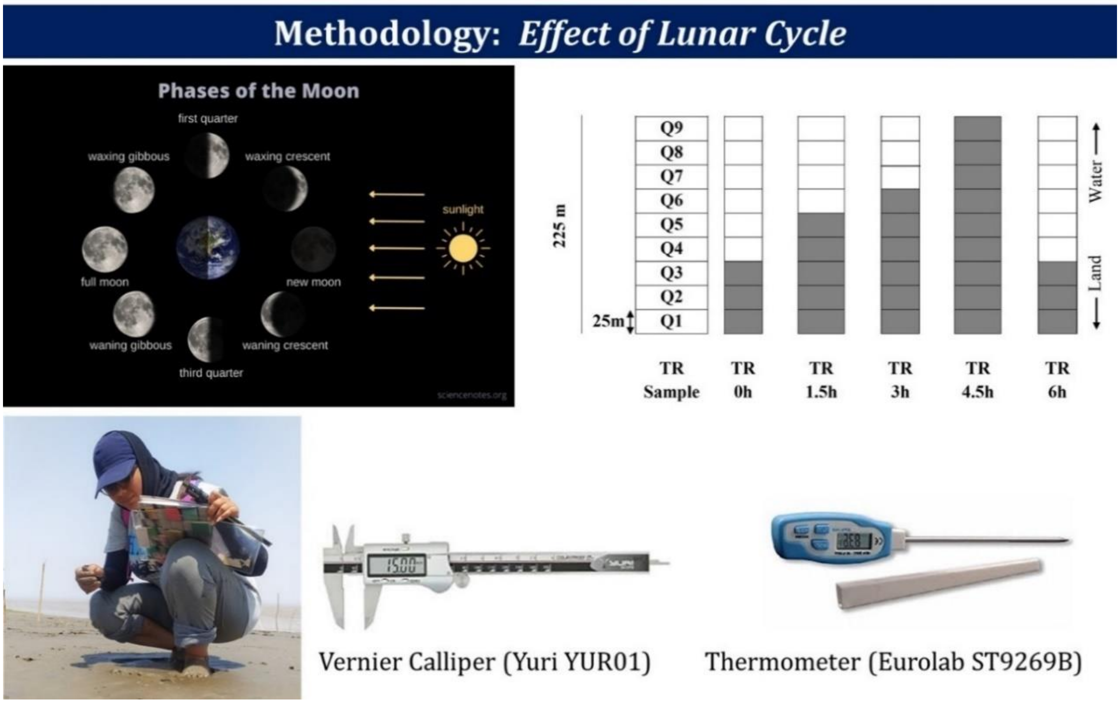


Figure 6.1: Representative image of eight phase of Lunar cycle

[Source:https://qph.cf2.quoracdn.net/main-qimg-f362c57da770655edb6a97c49e1c39fe]

The detail methodology for data collection has been described in materials and methods chapter (page no. 31). Following flow chart shows summary of methodology used in the present chapter.



6.2 RESULTS

The highest values of nocturnal luminosity were observed during full moon (93 to 100%), intermediate values during waning gibbous to third quarter moon (36 to 71%) and waxing crescent to first quarter moon (25 to 67%), and a near absence of light during new moon (0 to 5 %). Throughout the lunar cycles, significant differences were observed between the lowest and highest temperature recorded during sampling hours (ANOVA test: $p < 0.005$) (Table 6.1).

Table 6.1: Temperature variation (maximum and minimum) observed on Kamboi coast, Gulf of Khambhat, Gujarat, during each lunar phase

Campaign	Moon Phase	Temperature °C	
		Lowest	Highest
1	Waxing crescent	27.5	38.2
1	First quarter	31.5	36.5
1	Waxing gibbous	17.3	29.2
1	Full moon	22.4	39.6
1	Waning gibbous	28.5	39.6
1	Third quarter	37.7	40.5
1	Waning crescent	16.2	39.6
1	New moon	21.2	40.4
2	Waxing crescent	29.4	35.8
2	First quarter	13.9	29.6
2	Waxing gibbous	14.3	31.7
2	Full moon	23.4	34.7
2	Waning gibbous	28.1	37.3
2	Third quarter	25.1	37.6
2	Waning crescent	17	33.2
2	New moon	20.5	31.9

6.2.1 Density and diameter of burrows openings

The primary objective of the current study was to determine how the moon cycle affected the burrowing behaviour of *Austruca sindensis*, *Ilyoplax sayajiraoi*, and *Dotilla blanfordi*, three common crab species. Total number of burrows of *A. sindensis*, *I. sayajiraoi*, and *D. blanfordi* were counted around 2134, 3625, and 2715 throughout the sampling periods, with average densities of 2.27±1.47, 4.29±2.32, and 3.41±1.98 burrows/m^2, respectively.

Every species under study had different burrow densities during different lunar phases. For *A. sindensis*, the full moon day had the highest density and the waning crescent day had the lowest density. The waxing gibbous day had the highest burrow density for *I. sayajiraoi*, while the new moon day had the lowest density. Regarding *D. blanfordi*, full moon day was the day with the highest density and new moon day was the day with the lowest density (Fig. 6.2–6.4). *A. sindensis* burrows have a mean diameter of 7.89±4.3 mm, which varies depending on the moon phase. Likewise, the mean burrow diameters for *D. blanfordi* and *I. sayajiraoi* were measured at 3.98±2.67 mm and 4.51±2.87 mm, respectively. In the current investigation, *A. sindensis* and *D. blanfordi* burrows showed little variation in diameter on full moon day, while *I. sayajiraoi* burrows showed less variance on waxing gibbous day (Fig. 6.5-6.7).

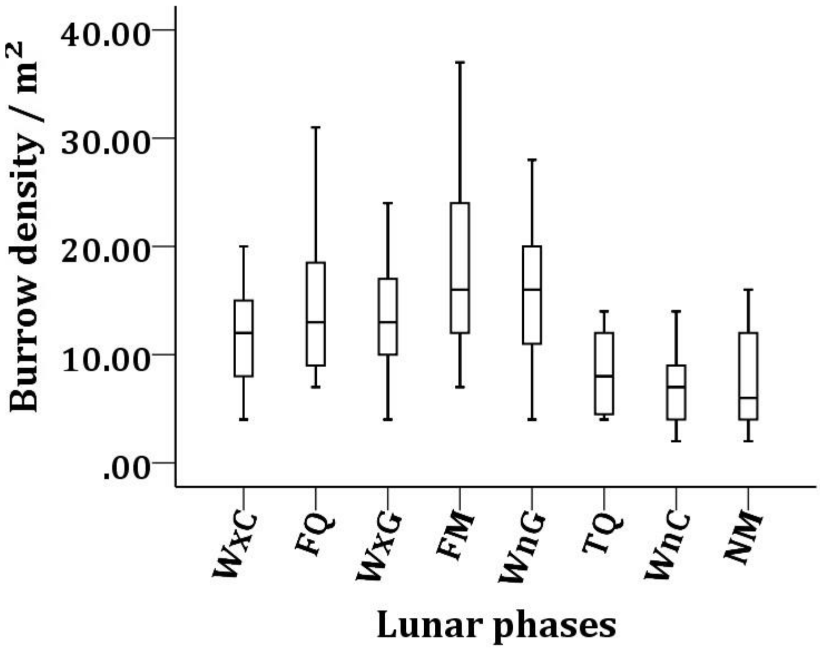


Figure 6.2: Average densities of *Austruca sindensis* burrows during the lunar cycle on Kamboi coast, Gulf of Khambhat, Gujarat

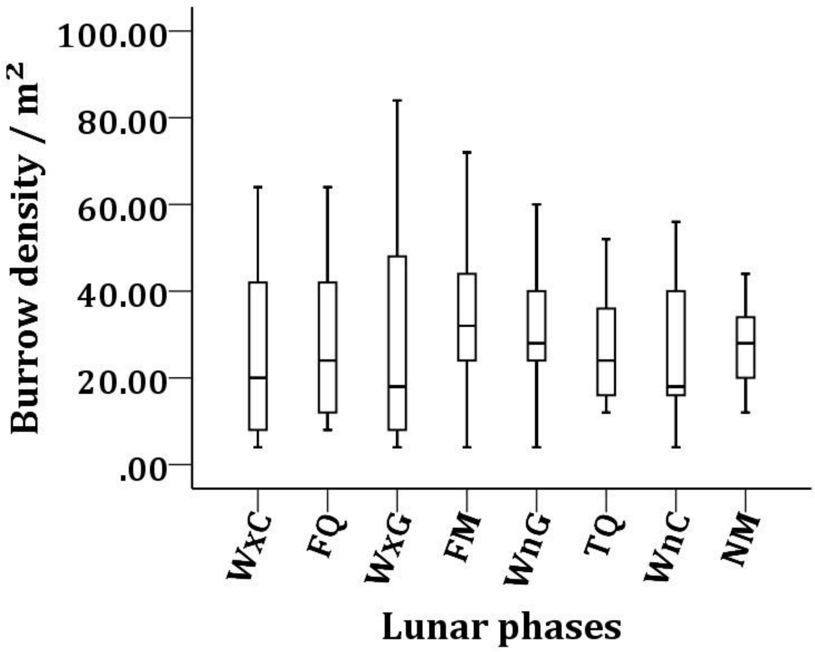


Figure 6.3: Average densities of *Ilyoplax sayajiraoi* burrows during the lunar cycle on Kamboi coast, Gulf of Khambhat, Gujarat

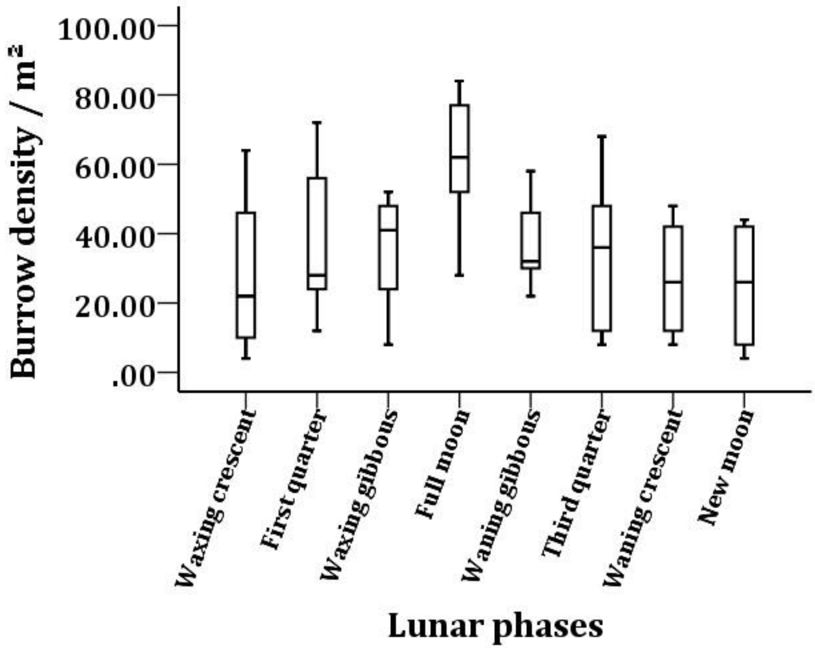


Figure 6.4: Average densities of *Dotilla blanfordi* burrows during the lunar cycle on Kamboi coast, Gulf of Khambhat, Gujarat

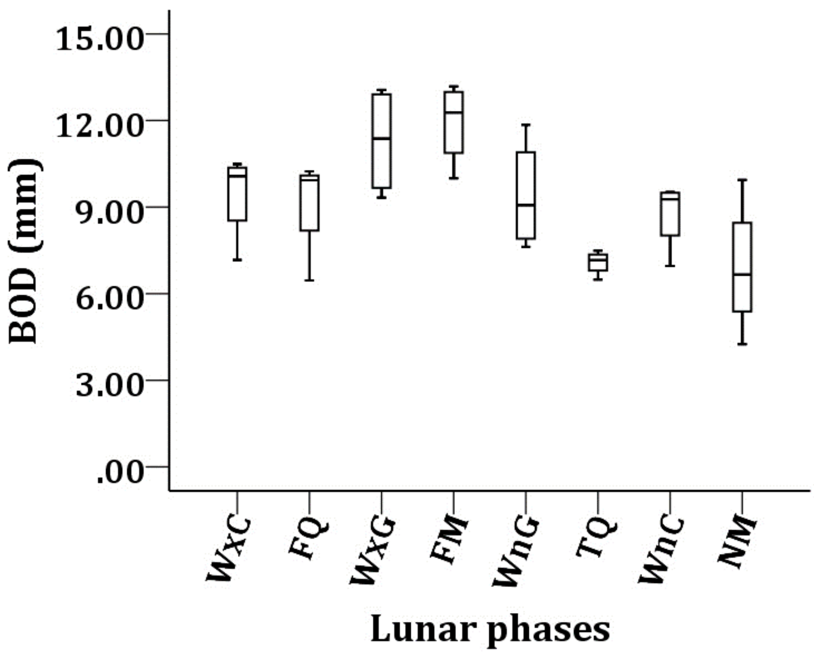


Figure 6.5: Average diameter of *Austruca sindensis* burrows during the lunar cycle on Kamboi coast, Gulf of Khambhat, Gujarat

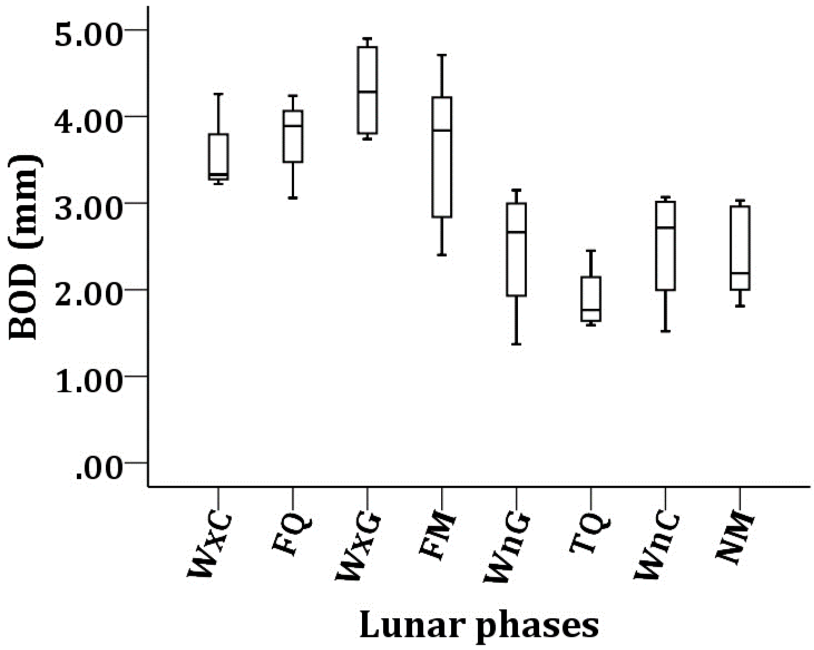


Figure 6.6: Average diameter of *Ilyoplax sayajiraoi* burrows during the lunar cycle on Kamboi coast, Gulf of Khambhat, Gujarat

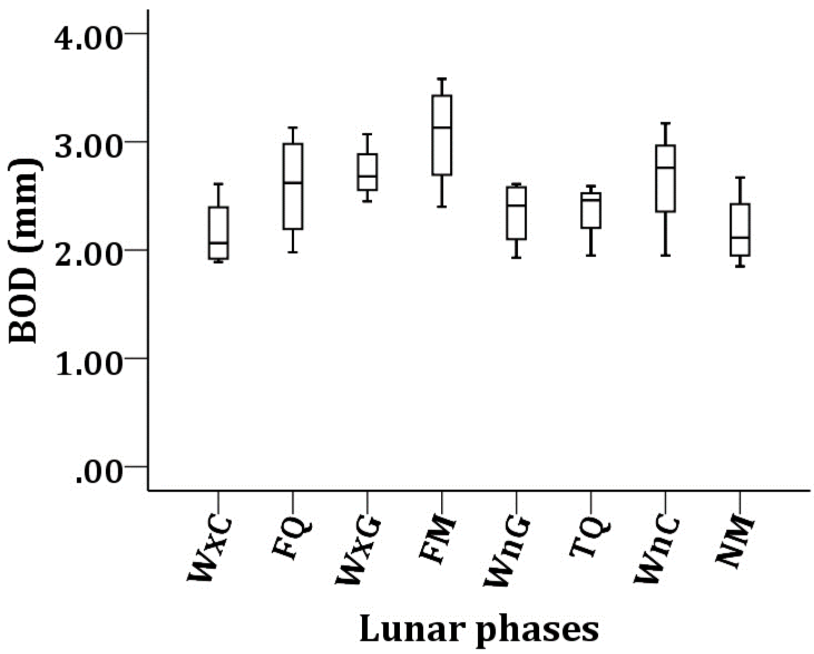


Figure 6.7: Average diameter of *Dotilla blanfordi* burrows during the lunar cycle on Kamboi coast, Gulf of Khambhat, Gujarat

6.2.2 Hour variation in burrow density

Individual *A. sindensis* was observed actively participating in burrowing activity over the 6-hour sampling period (from one hour after high tide to two hours after low tide). In contrast, *I. sayajiraoi* was found to be burrowing for up to 4.5 hours during the collection period (from one hour after high tide to 1.5 hours after low tide). In contrast, *D. blanfordi* engaged in burrowing for around three hours (that is, two hours following high tide and one hour following low tide).

A. sindensis burrow densities were at their highest on full moon days, and at their lowest on new moon days following receding tide (0 hours), 1.5 hours, and 4.5 hours during sampling. In contrast, the highest burrow density was observed on full moon and waxing crescent days, while the lowest was observed on new moon days, during 3 hr. On the other hand, after six hours, the full moon day had the highest burrow density, whereas the waning crescent day had the lowest density (Fig. 6.8).

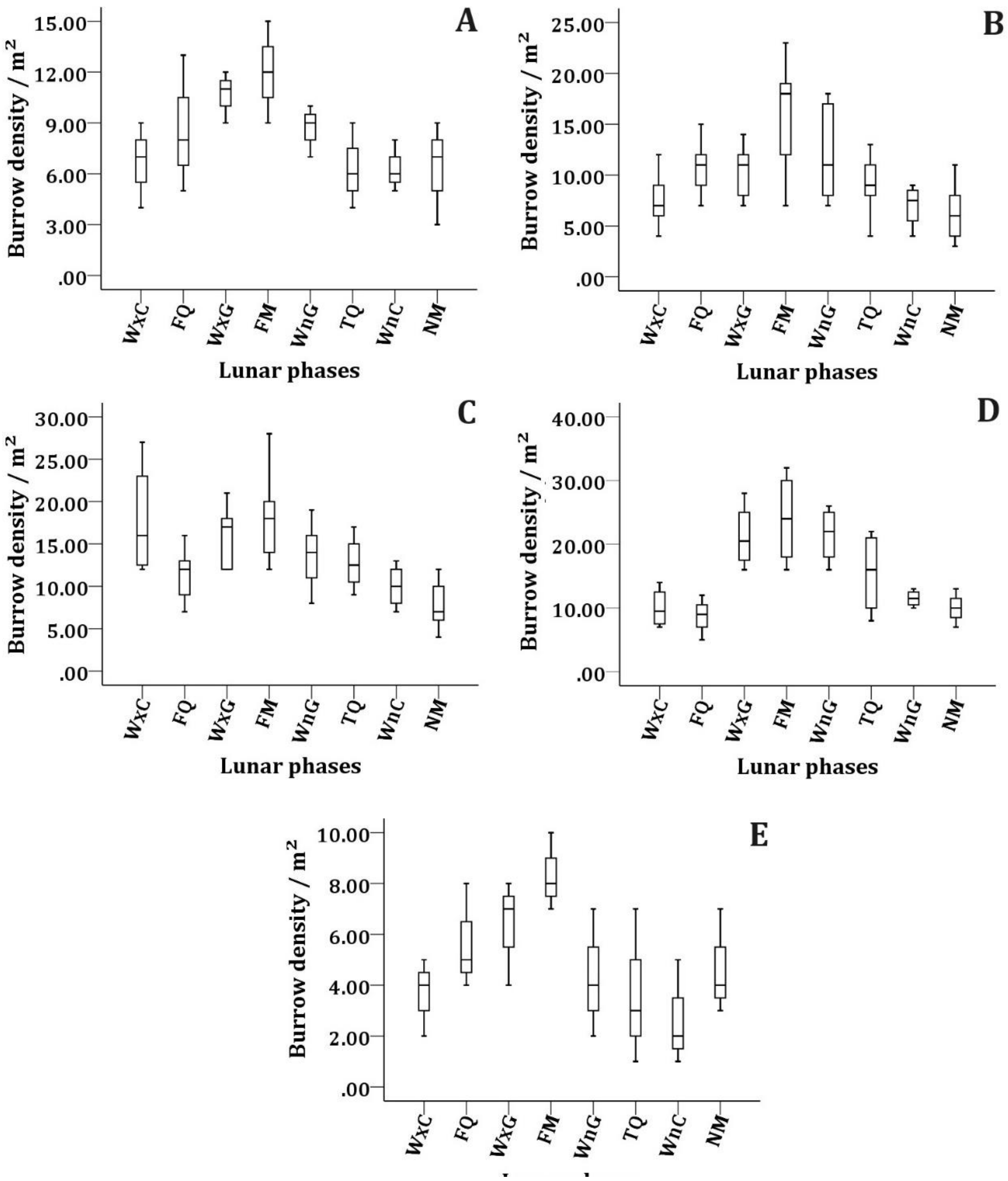


Figure 6.8: Hour wised variation in densities of *Austruca sindensis* burrows during the lunar cycle on Kamboi coast, Gulf of Khambhat, Gujarat. A- 0hr; B- 1.5hr; C-3hr; D-4.5hr; E-6hr

The maximum burrow density for *I. sayajiraoi* was observed for 0 and 1.5 hours on full moon days, and for 3 and 4.5 hours on waxing gibbous days. The new moon day had the lowest burrow density at 0 hours and 4.5 hours, and the waxing crescent day and third quarter had the lowest burrow density at 1.5 hours and 3 hours, respectively (Fig. 6.9). For *D. blanfordi*, the highest burrow density was observed on full moon day between the 3rd and 4.5 hours of sampling, whereas the lowest number of burrows was observed on new moon and waxing crescent day, respectively (Fig. 6.10).

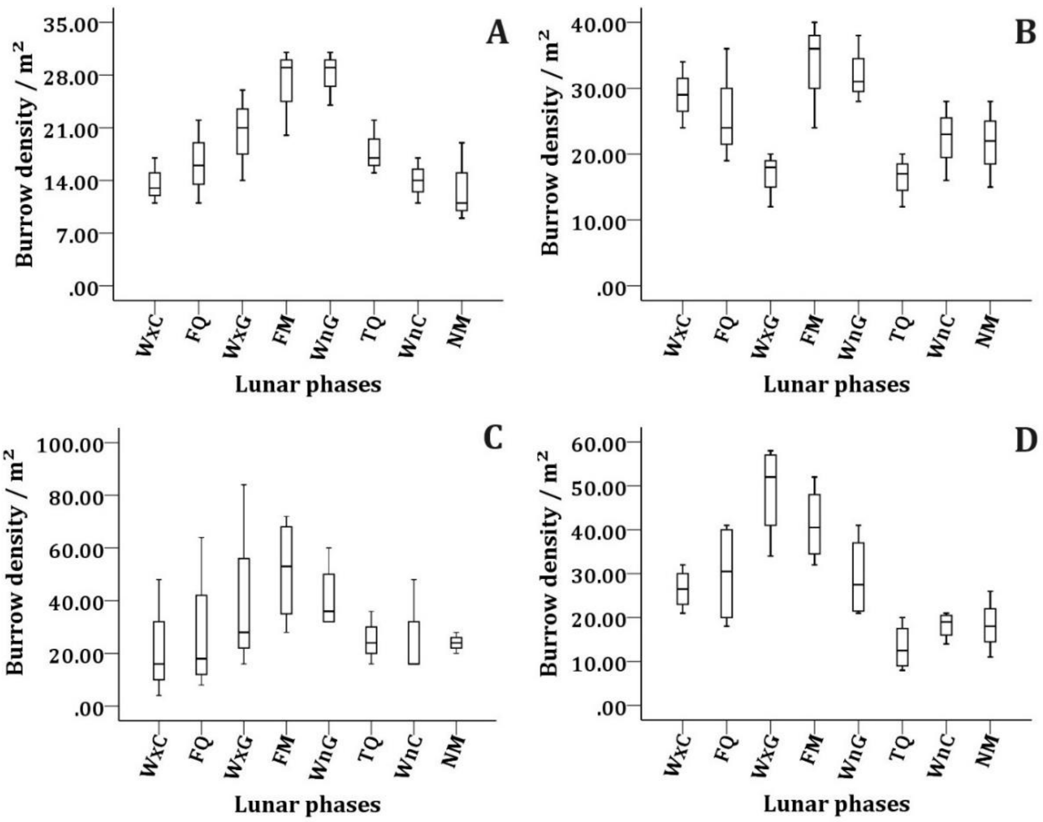


Figure 6.9: Hour wised variation in densities of *Austruca sindensis* burrows during the lunar cycle on Kamboi coast, Gulf of Khambhat, Gujarat: A- 0hr; B- 1.5hr; C-3hr; D-4.5hr

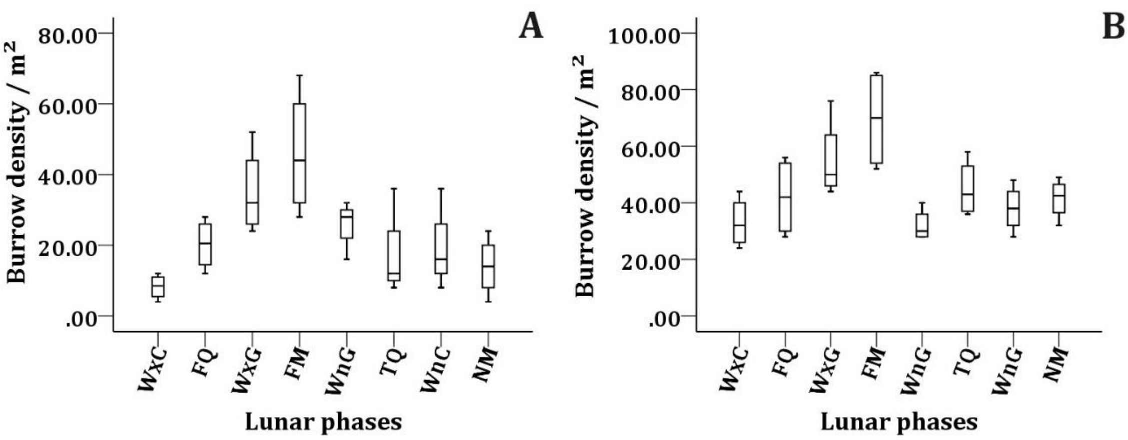


Figure 6.10: Hour wised variation in densities of *Austruca sindensis* burrows during the lunar cycle on Kamboi coast, Gulf of Khambhat, Gujarat: A- 3hr; B- 4.5hr

6.3 DISCUSSION

Lunar and semilunar periodicities affect the rhythmic behavioural patterns of marine invertebrates, especially those occurring in intertidal zones. These patterns include feeding, moulting, breeding, and movement (Naylor, 2001). Numerous elements, including as tidal range, hydrostatic pressure, wave action, temperature, salinity, and moon light, can affect the observed patterns (Naylor, 1982; Naylor and Williams, 1984). Present investigation revealed that the behaviour of *A. sindensis*, *I. sayajiraoi* and *D. blanfordi* is influenced by lunar cycles, resulting in variations in the number, width, and distribution of burrows at the Kamboi coast. Variations in the tidal conditions and nocturnal illumination could be the causes of these shifts (Fortaleza et al., 2019). Where maximum density of burrows was recorded on or before/ after full moon day. This variation was recorded may be because of the variation of the luminosity (night light).

Numerous writers claim that brightness affects the capacity of predators that hunt at night to locate and seize food, as well as controlling circadian rhythms and pelagic animal movements (Lima and Dill, 1990; Ringelberg, 1999). Number of Crab burrows were counted more during brighter nights (full and waning) in the current study. There was a high density of burrows during full moon, when beach extension varies more because to spring tides. On the third quarter moon, the density was still high but tended to decline as the amount of light radiated dropped. Despite the high tide range, there were fewer crabs with the new moon (low light intensity). Similar variation in burrowing activity was observed by Fortaleza et al. (2019). They have concluded that because of variations in tidal conditions and night-time illumination, the lunar cycles affect the activity of *Ocypode quadrata* crabs, causing variations in the density, diameter, and distribution of their burrows on the Canto Verde beach.

Present study revealed that, sediment temperature varied significantly between various lunar phases which may influences the burrowing activity of the studied crab species. Few studies have been concluded that burrowing brachyuran crab, mainly ghost crab build their burrows more intensely on the warmest days (Fortaleza et al., 2019). Nonetheless, a number of researchers

(Steiner and Leatherman, 1981; Blankensteyn, 2006; Alberto and Fontoura, 1999) assert that the cooler night-time temperatures encourage the activity of crabs. Cameron (1966) studied behavioural aspect of *Mictyris longicarpus* and concluded that *M. longicarpus* was more active on "warm sunny days" as opposed to "cold overcast days" on the sand flats of Moreton Bay, Queensland. Hughes (1966) noted that when the air temperature fell to roughly 12.0°C, populations of *0. ceratophthalmus*, which were nocturnally active on Mocambique's beaches, were dormant for two weeks. When the temperature reached roughly 16°C, surface activity was resumed. Takahasi (1935) observed that *Ocypode* spp. were dormant on the surface of Formosa when air temperatures fell below 15.0°C. The results of the current study, however, highlight the influence of the lunar cycle on the burrowing behaviour of the brachyuran crab species under inquiry. No such variation in densities of brachyuran crab with respect to the sediment temperature was found (Table 6.1). There were noticeable variations in the number of burrows for each species of crab on full moon and new moon days, despite the fact that the temperature of the sediment in the current study ranged from 22 to 40°C on these days.

In the current study, burrow densities of all the crab species under investigation showed hourly fluctuation, with densities rising from high tide to low tide. It implies that crabs are coming out of their burrows in order to fulfil their physiological needs during low tide. There were notable variations in the beach's extension at Kamboi coast between neap and spring tides. According to Musawi and Wagner (2012), a strong relationship between the emergence time and low tides explain the fact that these animals follow a tidal cycle all year long. Pombo et al. (2017) state that crabs sense a falling tide due to a decrease in moisture and groundwater. Additionally, crab behaviour is influenced by tidal movement. The foraging area and the nutritional supplies left by the preceding high tide expand as the tide lowers. However, high tide limits the area available for foraging, which increases competition and leads to agonistic behaviours. As a result, crabs seek protection in their burrows. Thus, the observation of a decrease in burrow density during the high tide period validates the proposal put forth by Pombo et al. (2017).

According to Fortaleza et al. (2019), the distribution of burrow diameter varies with the phases of the moon. This suggests that while larger individuals can inhabit upper areas, juveniles choose to situate themselves closer to the intertidal zone. The ontogenetic nature of the dispersal of these crabs is supported by the studies carried out by Milne and Milne, 1946; Williams, 1984; Hill and Hunter, 1973. It appears that adult crabs are more resilient to desiccation and high ambient temperatures because they are able to hold onto more moisture in their gill chambers than juvenile crab (Alberto and Fontoura, 1999).

The results of this study clearly showed that burrow diameter varied less on full moon day, suggesting that larger crabs were more frequently seen at this time. The increased prevalence of adults during full moons may possibly be explained by the above-mentioned crabs' enhanced visual acuity. Even though spring tides occur during full and new moons, increasing the amount of intertidal space available for foraging, burrowing activity appears to be controlled by night-time brightness (Fortaleza et al., 2019).