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Larval Fish Assemblages in The Littoral Zone of Pre-developed Hybrid OTEC (H-OTEC) Facility Area

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Ocean Thermal Energy Conversion (OTEC) promotes clean and green renewable energy for the future. Despite great advantages it offers to the environment, ecological baseline datasets within the coastal vicinity of the power plant should still be documented before its operation. The datasets are needed to plan effective strategies to avoid adverse impacts that OTEC would have on natural ecosystems. For this purpose, larval fish was used as a biological marker to detect possible environmental changes. The abundance, distribution and diversity of fish larvae in terms of diurnal and lunar cycles were investigated at eight stations. The stations were nearly equally distanced from each other on the seashore of the soon to-be developed H-OTEC in Port Dickson, Malaysia. A sampling program was carried during two contrasting lunar cycles of full moon and new moon, and diurnal variation of day and night. Samples were collected using a set of 300μm mesh Bongo net, with a flow meter. Total larval mean density 22.83/100m^3. Larval fish abundance was significantly higher ($P < 0.01$) during the new moon (mean±1se density 9.72±2.16 larvae/100m^3) than during the full moon (mean density 1.73±0.38 larvae/100m3). But in terms of diurnal changes, there is no significant difference between day and night fish larval density. Although the larval fish abundance was influenced by temporal variation (lunar cycles), but the study also did not find enough evidence to associate the abundance with spatial variation (stations and distance from the shore), perhaps due to micro-scale of the study area. The outcomes necessitate the H-OTEC pilot plant to consider these environmental variations when it is in operations.

Keywords: Larval fish, Diurnal, New Moon, Full Moon, Nearshore, Offshore, Hybrid OTEC

1. Introduction

Energy crisis and global warming has become the greatest challenge for the current world. Renewable energy supply has emerged to solve these concerns. Ocean Thermal Energy Conversion (OTEC) is among the various sources that are gaining popularity in some countries worldwide The Hybrid OTEC (H-OTEC) is the technology for renewable energy in the field of ocean energy science. Hybrid OTEC combines the features of both closed and open cycle OTEC systems. The Hybrid cycle take advantage of the benefits of both systems. As the OTEC plant needs large flows of ocean water and oceans are in full accessibility with about zero chances of over running out. Basically, it exploits the temperature difference of deep-sea water and surface water to produce energy(Vega, 2002). As the same time, it discharges high volume of water, and it is possible to produce as much 0.5 million gal/D for each MW of electricity generated (Plocek *et al*., 2009). So it is essential to investigate environmental impacts due to the discharged water which has lower temperature and higher nutrient concentration than the surrounding sea water(Wang & Tabeta, 2017). But this study is conducted at the pre-developed hybrid OTEC facility area to investigate the possible environmental consequences. For this purpose, fish larvae have selected as for biological marker and for future comparison.

Basically, larval fish ecology refers to the early stage of fishes and their interactions with the physical and living components of their environments. Ecologists are indicated that the study of larval fish life history in ecology is distinguished by the specific eco-morphophysiological characteristics of early fish life stages (*Catalán et al.,* 2020). Moreover, the term ‘fish larva’ represents the larval stage in the life history from hatching to attainment of complete fin

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ray counts and beginning of squamation, at which stage the fish reaches to a juvenile*(*Kendall *et al.,* 1984).The larval early developmental stage is divided into three phages on the basis of the flexion of the notochord such as Pre-flexion, flexion and post-flexion (Ahlstrom & Ball, 1954);(Lies &Carson-Ewart, 2004). The initial stage of the fish life cycle is critical, with massive mortality due to sensitivity to predators, bioavailability and natural environmental changes which has a negative effect on fish populations (*Ridho et al.,* 2021). At this stage the survival rate of fish larvae is relatively low from hatching (10%) to first feeding (2-3%) (*Ferreira et al.,* 2020). In addition, the survival of fish larvae depends on abiotic and biotic factors like as prey (copepods) and predators (young fish) availability or bioavailability (Ferreira *et al*., 2020), larval habitat ecology (Ara *et al.*, 2020), feeding ecology (Hure & Mustać, 2020), water quality, environmental factors (Colombano *et al*., 2021). Normally fish larvae are found in the littoral zone during ontogenetic developmental stage (Polte *et al*., 2017). The littoral zone or nearshore coastal region serves as an important nursery ground for the development of early stages of marine and estuarine fishes due to its high bioavailability, low predation risk, suitable physio-chemical characteristics and promote larval retention hypothesis (Pattrick & Strydom, 2014;Díaz-Astudillo *et al*., 2017).Some ecologists stated that larval fish assemblages mainly in the coastal upwelling front(Tiedemann & Brehmer, 2017). That's why hybrid OTEC power plant construction and operation may have the possibility to disrupt fish habitat in the littoral zone or may reduce larval fish & eggs in nearshore water. Discharge of biocides can reduce fish populations and affect commercial and recreational fishing (Octaviani *et al*., 2016). In spite of these, OTEC discharged water can enhance productivity due to redistribution of nutrient rich deep sea water (Octaviani *et al*., 2016) and also can use for multiple purpose such as mariculture, aquaculture, agriculture field as well as for drinking water. Moreover, this research provides baseline study in the vicinity of hybrid OTEC prior to its construction. It also provides knowledge on fish larvae in terms of biology, morphology, spawning period, spawning peak, spawning ground and rearing ground in the coastal area where is needed for proper fishery management. In addition, fish larvae research is an important for understanding of the ecology and evolution of fish species and their populations. The aim of this study is to determine the larval fish abundance and density in the littoral zone and to investigate the effects of diurnal, lunar phase, spatial distance, selected water quality and geographic parameters on larval fish assemblages.

2. Materials and methods

2.1 Study area and sites

The study area (Fig 1), which is adjacent to the International Institute of Aquaculture and Aquatic Sciences (i-AQUAS) Universiti Putra Malaysia (UPM) (02°29'19"N, 101°50'40"E) in Negri Sembilan. Negeri Sembilan is one of eight states located on the west coast of Peninsular Malaysia, which is also geo-politically flanked by two of the states along the Straits of Malacca coastline. Negri Sembilan coastline accounts for about 5% of the Peninsular Malaysia total coastline length of 48 km on the strait. The whole Peninsular Malaysia is of tropical climate, where the coastal environment is largely affected by monsoon winds throughout the year, southwest monsoon and northeast monsoon. The southwest monsoon occurs from May to August affecting mostly the west coast, while the northeast monsoon occurs from November to February affecting the east coast of the peninsular both of which bring significant downpour during the periods respectively.

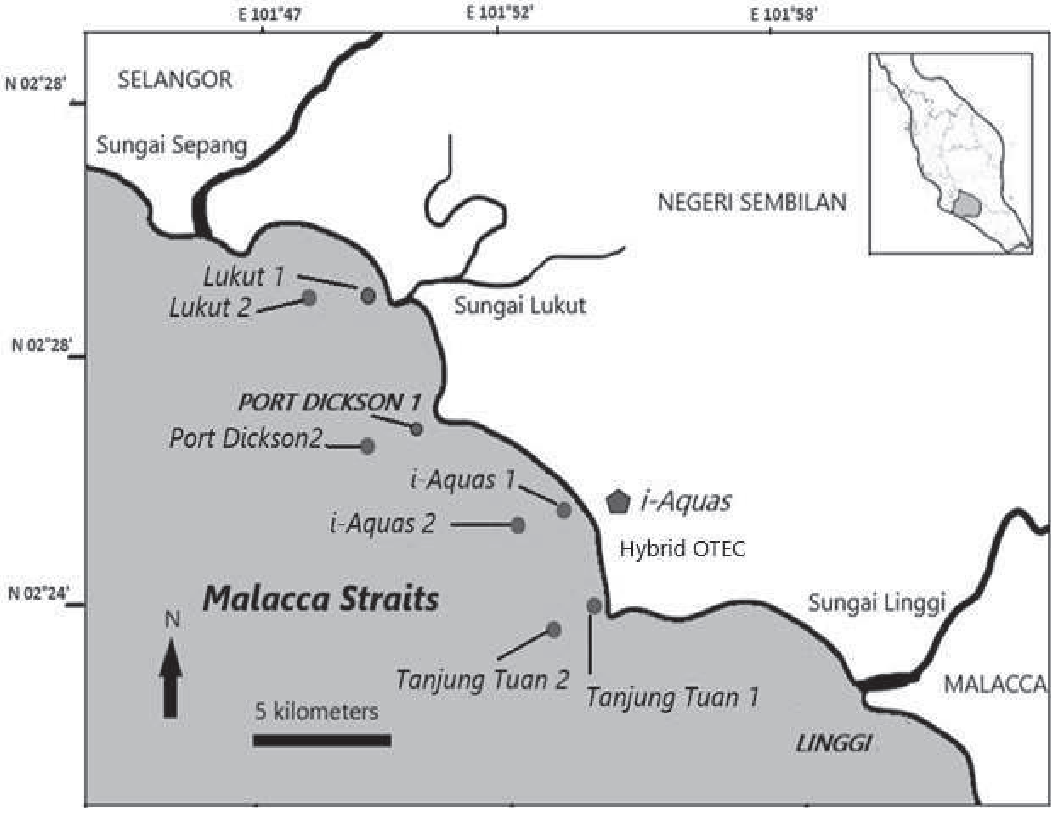


Figure 2.1: i-AQUAS UPM Negeri Sembilan

Sampling stations were primarily selected based on the following limits: 1) in fishing Zone A which is designated by Department of Fisheries Malaysia (DOF), essentially within less than 2.5 km offshore, 2) representative of different coastal habitats or ecosystems, where two distinct ecosystems have been identified namely, mangrove and seashore (Table 2.1), and 3) two replicates from each sampling station or habitat or ecosystem, was spatially distanced by at least 2 km (Figure 2.1).

Table 2.1 Sampling points

Division	Station code	Geo-coordinate	Distance from shore	Types of ecosystems
Lukut station 1	LKST1	02°34´13"N, 101°47´20"E	.5km	Nearshore Mangrove
Lukut station 2	LKST2	02°33´58"N, 101°48´7"E	2.5km	Offshore
Port Dickson1	LNST3	02°31´16"N, 101°49´14"E	.5km	Nearshore
Port Dickson2	PDST1	02°31´35"N, 101°49´50"E	2.5km	Offshore
i-AQUAS 1	PDST2	02°30´15"N, 101°50´25"E	.5km	Nearshore
i-AQUAS2	PDST3	02°29´19"N, 101°50´40"E	2.5km	Offshore
Tanjung Tuan1	LKST1	02°25´18"N, 101°51´29"E	.5km	Nearshore
Tanjung Tuan2	LKST2	02°26´19"N, 101°51´56"E	2.5km	Offshore

2.2 Sample collection

Larval fish sample was collected in the month of March and April 2021 during daylight and nighttime based on lunar cycle (full moon and new moon). Sampling trip was two day and night during high tides. Larval fish was collected by a Bongo net of both 300µm mesh size (mouth diameter 0.60m and 3m long). The net was towed horizontally at the water sub-surface from a stalled boat. Trawling method was performed at a constant boat speed 2.5km/h. Tow duration was 10 minutes depending on the net plugging. Larval fish sample was preserved into 5% formalin of 450 mL containing plastic bottle. 5% formalin solution was buffered with sodium tetraborate de-carbohydrate (borax, Sigma-Aldrich). All collected samples were transported to the laboratory for sorting and taxonomic identification purpose.

The following *in situ* environmental variables were measured at every sampling station, sea water dissolved oxygen (mg/L, DO), Air & water temperature (°C, TEMP), salinity (ppt, SAL), pH (pH) and turbidity (mg/L, TDS).

2.3 Larval fish density of abundance estimation and identification keys

Larval fish abundance was determined by quantifying number of individuals unit volume of water (m^3). Dilution depends on turbidity of the collected samples, where more turbid water required higher dilution factor as compared to the less turbid water samples. Then Taxonomic identification began with grouping a few preliminary water samples containing larval fish into generic groups based on their morphological characteristics; pre-flexion, flexion and post-flexion. Larval fish were then identified to the lowest possible taxa by using identification keys provided by preceding researchers: Konishi (2012), Bouillon et al. (2006), Kawaguchi (2003), Leis and Carson-Ewart (2004) and Jeyaseelan (1998).

Data analysis

To determine the importance of the factors considered in the experimental design on fish larval abundance and distribution variation was performed by using Analysis of variance (ANOVA). For statistical analysis use (SPSS version 21) parametric tests for continuous variables-one-way ANOVA. Three models were tested using the variance of components to compare abundance across months (Diurnal, lunar phase, nearshore and offshore distance from shore (2.5km).

Results

Environmental conditions

Air temperature ranged at the study area varies diurnally (Night air temperature ranged 26-27 °C and day air temperature ranged 29-29.9 °C (Mean ± SE, 28.07 ± 0.12°C). On the other hand, mean water temperature (Mean ± SE, 29.28 ± 0.09°C) is higher than Air temperature (Mean ± SE, 28.07 ± 0.12°C). Dissolved oxygen ranged at day from 4.5 to 6.6 mg L^{-1}(6.23 ± 0.06 mg L^{-1}) and at night ranged 4.88 to 6.7 mg L^{-1} (5.97 ± 0.18 mg L^{-1}). Maximum mean dissolved oxygen observed at daylight. However, there was no salinity fluctuation at the study area ranged from 29.34 and 29.98 ppt (29.86 ± 0.04 ppt). There was pH fluctuation during month of April at daylight 7.97 whereas at night 8.13. (8.09 ± 0.047). At the end, the total dissolve solid (TDS) in water turbidity range was around 28.81 to 30.14 mg/L (29.88 ± 0.13 mg/L) (Fig.2.1 water quality on diurnal cycle). But during lunar cycle, the mean air temperature, mean DO and mean salinity was significantly higher during new moon phase than full moon phase. On the other hand, the opposite scenario was observed in terms of mean TDS, mean pH and mean water temperature (Fig.2.2 water quality based on lunar phase).

Larval fish composition and density

In total 892 larvae belonging to 7 families were recorded (Table 2.1). Total larval mean density abundance in the study was 22.83/100m^3. Ambassidae was the most numerically dominant family which contributed 36.08% of total fish abundance in the study area. Then Clupeidae was the second highest abundant family that contributed 22.85% and the rest was followed by Gobiidae(13.32%), Carangidae (8.19%), Engraulidae (7.34%), Sciaenidae (1.47%) and Blennidae (.03%). Most unidentified individuals (10.69% of the total catch) were yolk-sac larvae (Table 2).

Larval fish abundance and density during lunar patterns

The number of larvae sampled during full moon 232 in which 660 larvae was found during new moon phase. Larval fish mean density 15.09% during full moon whereas 84.91% during new moon (Table 2.2). The highest number of fish larval family was found during both moon phases at Lukut and Tanjung Tuan station (Fig. 2.3 a, b, c & d). So, moon phase has direct effect on larval fish distribution. That means larval fish was more active during new moon at dark night. They come out for feeding purpose during new moon and avoid predation risk during full moon.

Larval fish abundance and distribution during diurnal cycle

Total 892 fish larvae were sampled at the study area during daytime sampled 350 larvae and nighttime 542 larave. Larval fish abundance and distribution was observed during daylight 36% whereas during night was found 63.99% (Table 2.2). The highest number of fish larval abundance and distribution was found at lukut during night (Fig:2.4). So, larval fish was more active at nighttime than daytime. At daytime, daylight is the barrier for fish larval fish vertical movements.

Fish larval distribution & abundance inshore vs offshore

Fish larval distribution and abundance in nearshore vs offshore was observed. The highest mean density was observed at Tanjung Tuan station (TTST1) (Fig.2.5) which was inshore region, and the lowest mean density was observed at Port Dickson station (PDST1). On the other hand, in offshore Lukut station (LKST2) was observed the second highest mean density of total fish larvae and the lowest mean density was found i-AQUAS2. From the observation, it can be concluded that there was no significant difference for nearshore vs offshore as sampling was conducted in the fishing zone A.

Water quality based on diurnal cycle

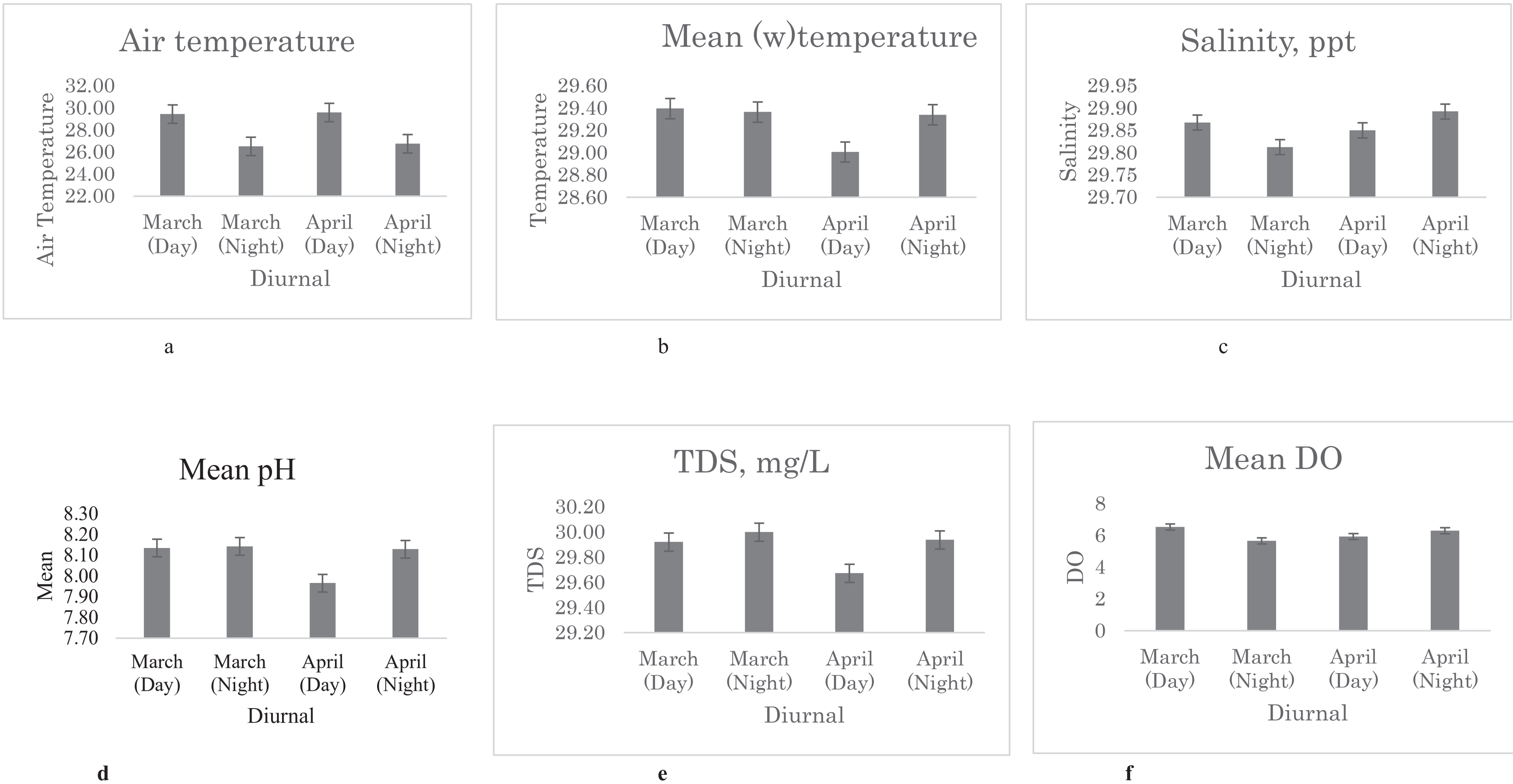


Figure 2.1 water quality based on diurnal cycle (a) Mean air temperature, (b) Mean water temperature, (c) Mean salinity ,(d) Mean pH, (e) Mean TDS and (f) Mean DO.

Water quality based on new moon and full moon

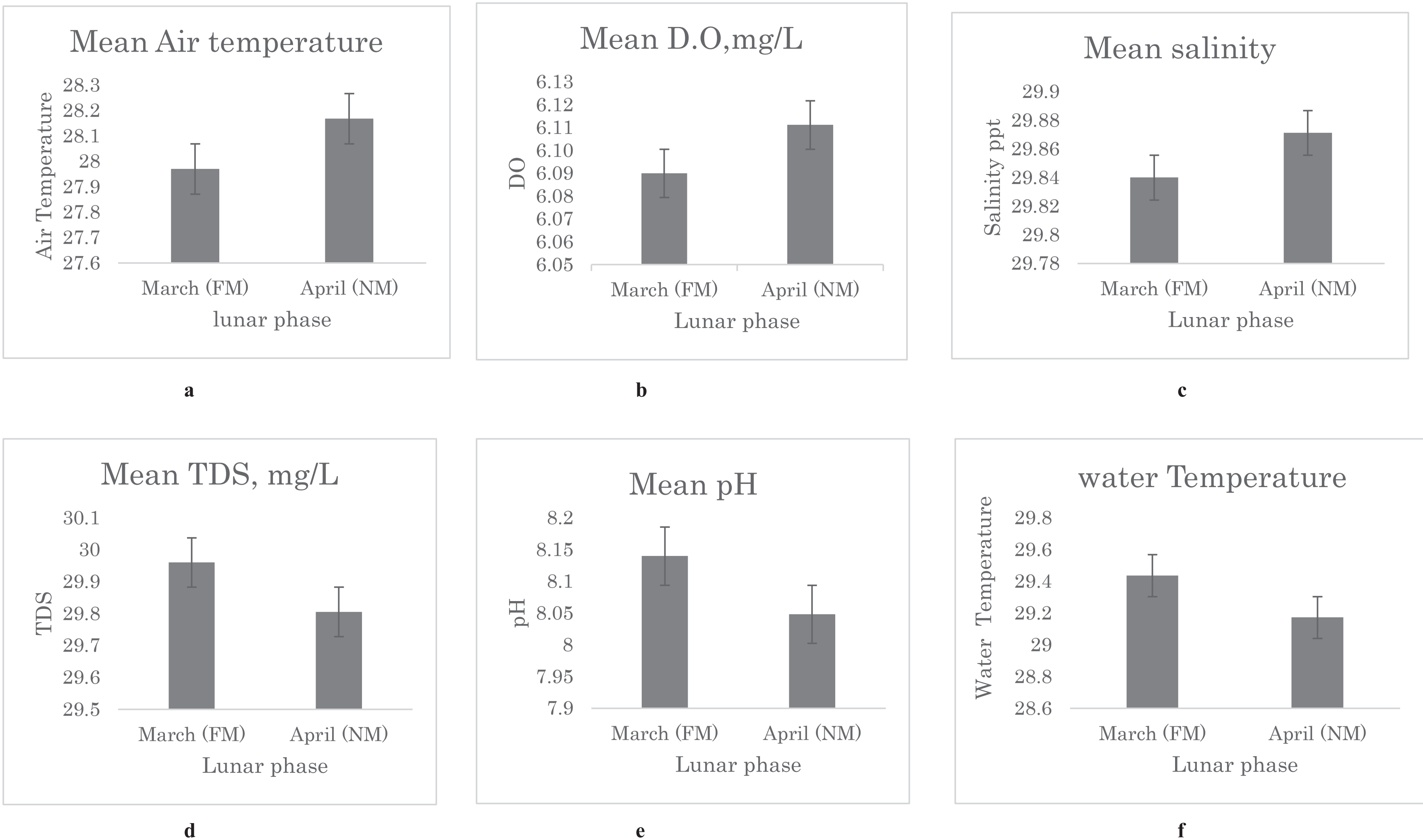


Figure. 2.2 water quality based on new and full moon phase (a) Mean air temperature, (b) Mean dissolve oxygen, (c) Mean salinity, (d) Mean total dissolve solid, TDS, (e) Mean pH and (f) Mean water temperature.

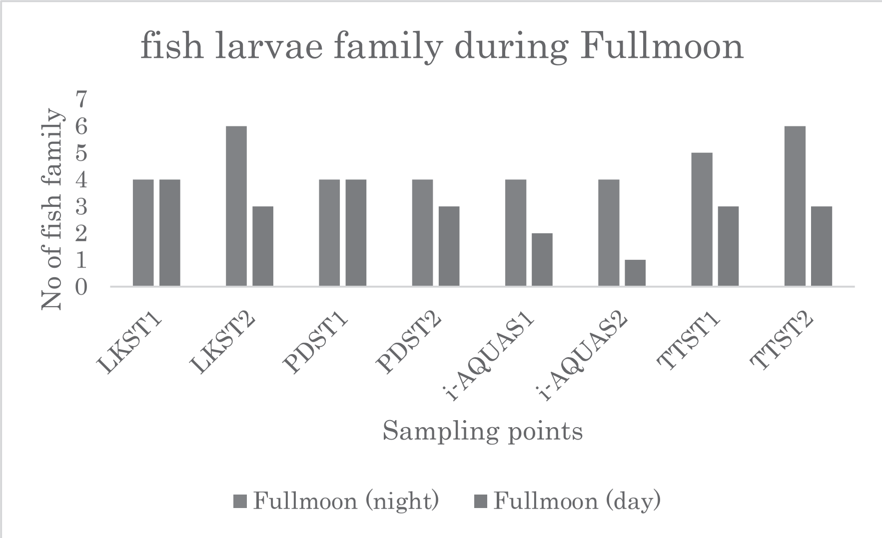


Figure 2.3 showing the larval fish abundance during fullmoon, day/night (a)

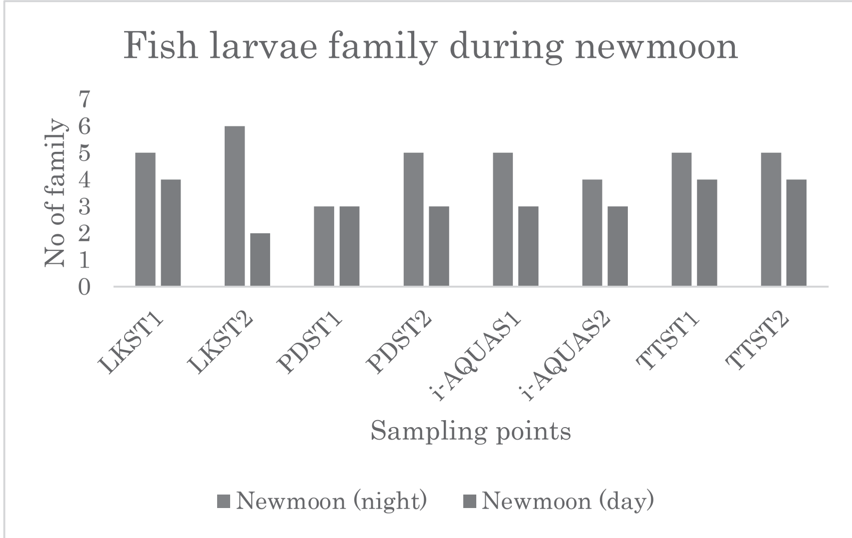


Figure 2.3 showing the larval fish abundance during new moon and diuranl (b) phase

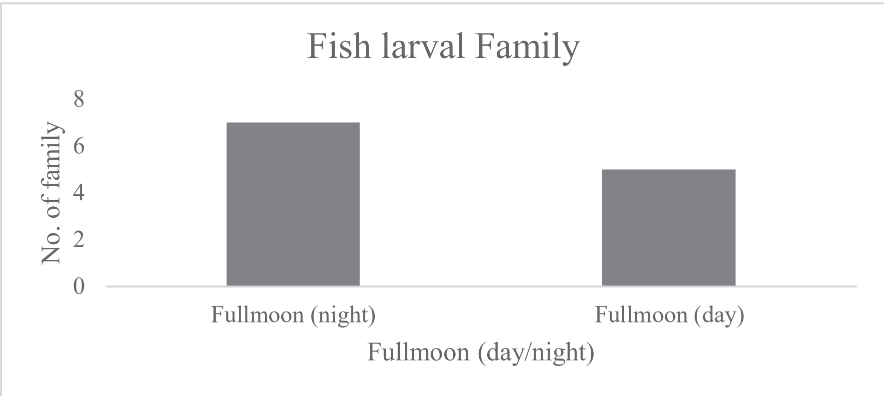


Figure 2.3 showing the larval fish abundance during fullmoon (c)

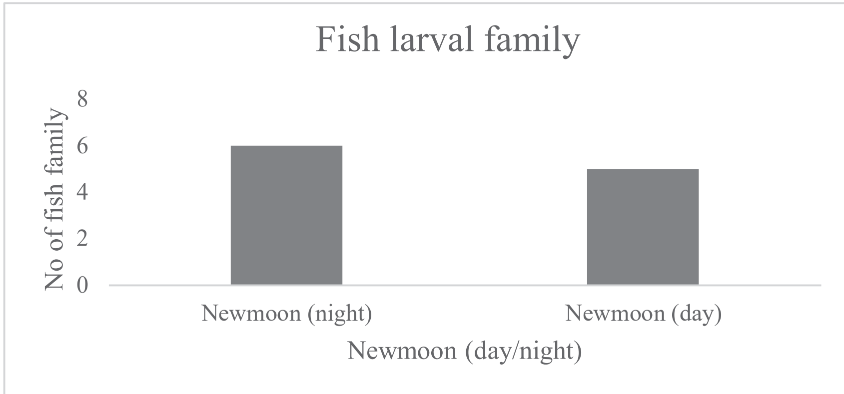


Figure 2.3 showing the larval fish abundance during new moon (d)

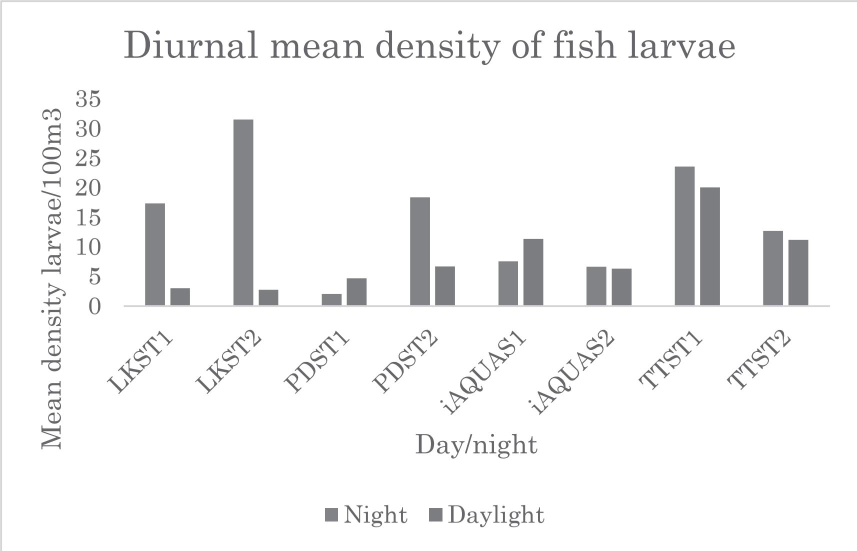


Figure 2.4 Fish larval mean density during diurnal cycle

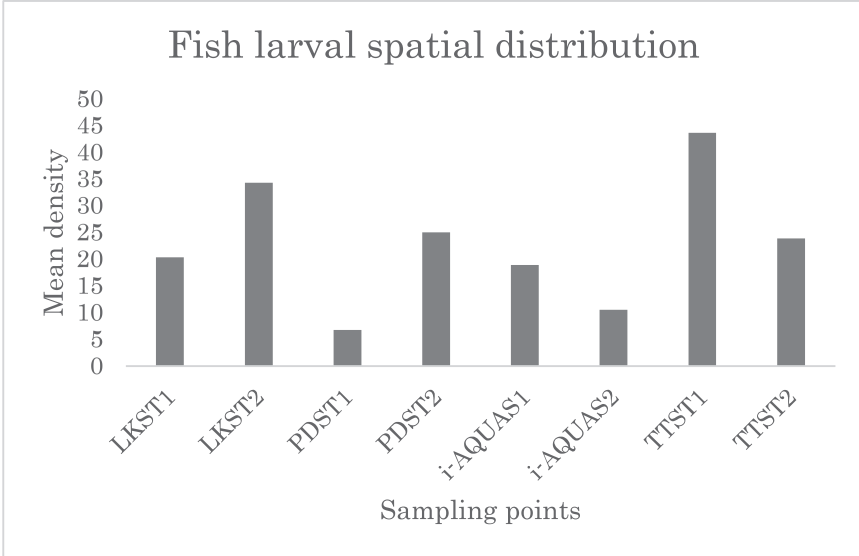
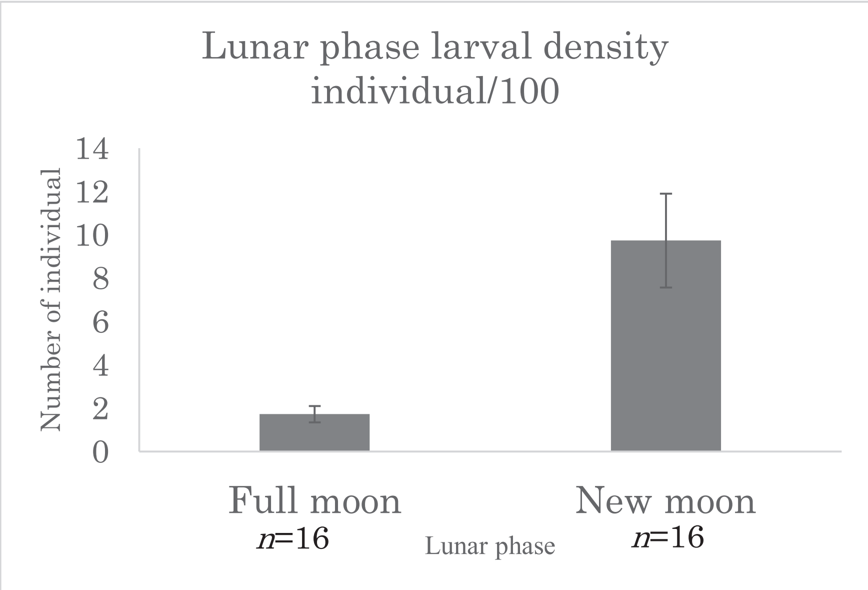


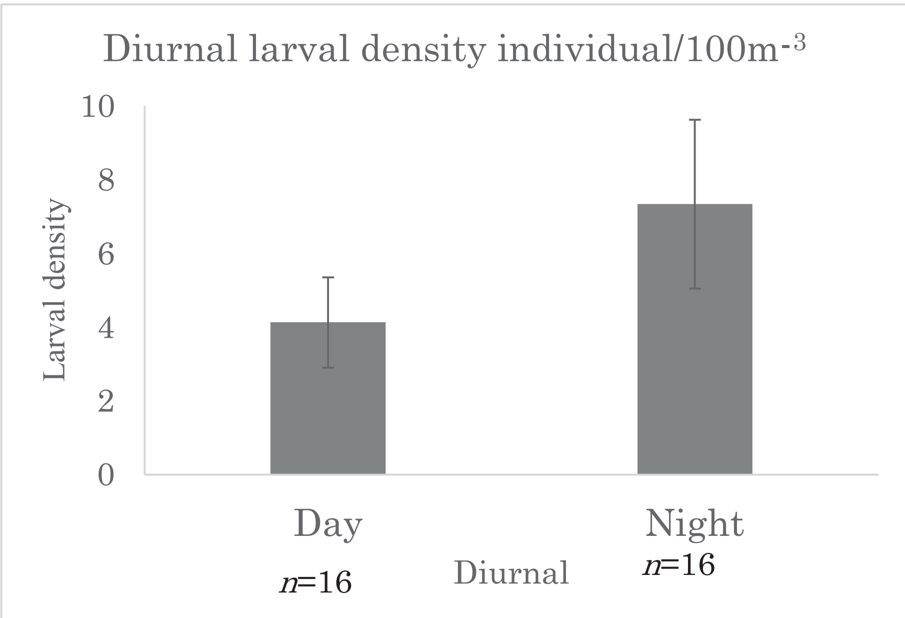
Figure 2.5 Fish larval mean density from nearshore (station1) to offshore (station2)

2.5 Discussion

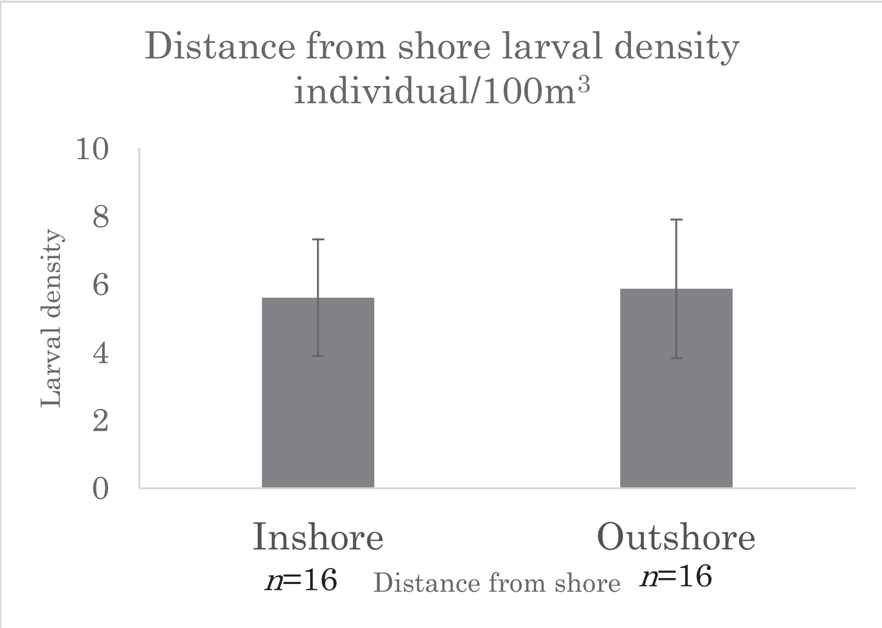
Our finding was highlighted that fish larval abundance and distribution in the littoral zone/ upwelling area was appeared as an identical pattern during lunar phase. Number of fish larvae were sampled at the study area during new moon 660 and full moon 232. From the statistical analysis, it was shown that fish larval mean abundance during full moon 1.73 and new-moon 9.73 and p-value < 0.01. Statistically, fish larval abundance and distribution was significantly higher during new moon phase than full moon phase.



In accordance with previous studies, fish larvae were spawned or dispersed maximum number during new moon than full moon and it occur due to feeding strategy at dark night during new moon or perhaps strategy to avoid predation risk during full moon (Mwaluma *et al*.,2014; Díaz-Astudillo *et al*., 2017).



Among surface samples, collected night fish larvae samples were significantly greater number than daytime collected fish larvae. Number of larval fish were sampled at day 350 and at night 542. From the statistical analysis, it was shown that fish larval mean abundance at day 4.13 and at night 7.34 and p-value = 0.211. So, statistically it can be concluded that there was not enough evidence to say the diurnal effects on fish larvae abundance. Though there were some previous studies which recorded that larval fish abundance is supposed to be higher during high tides at night than during the day(Thayer *et al*., 2012; Ricardo *et al*., 2014; Islam *et al*., 2007; Mwaluma, 2014). However, in the future, it may need more data to support the diurnal hypothesis.



Spatial distribution of fish larvae in terms of inshore and offshore region, collected sample has consistency with each other sampling points. From the statistical analysis, it was found that fish larval mean abundance at inshore region 5.60 whereas offshore region was 5.86 and p-value = 0.92. So, it can be concluded that there was no significant difference between nearshore vs. offshore larval fish abundance. The possible reason is that micro scale sampling of the study area. Nearshore vs. far-shore distance different 2.5km from shore which is still considered as fishing zone A.

3. Conclusion

In summary, at present, many countries are trying to supply green and clean energy, which is reliable, sustainable, low maintenance and environmentally friendly. Malaysia is also going to set up a pilot power plant at i-AQUAS UPM in Port Dickson Negeri Sembilan. So, this research is conducted at the pre-developed hybrid OTEC facility area where need to find the possible environmental changes for comparing pre and post development of hybrid OTEC operations. This initial finding has been shown that fish larval abundance is significantly different during new-moon vs. full-moon. There are not enough findings to say that diurnal and spatial variation have effect on fish larval abundance and distribution. The possible reason is that it needs further sampling for diurnal comparison at the study area. Sampling point distance may need to increase at the study area to find the enough evidence because it is still counted as fishing zone A.

Acknowledgement

I would like to express my sincere gratitude to my supervisor & co supervisor, other research members of SATREP OTEC for helping to my research work. My special thanks to SATREPS-OTEC Project for funding this research work.

Appendixes
Fish larvae from the study site

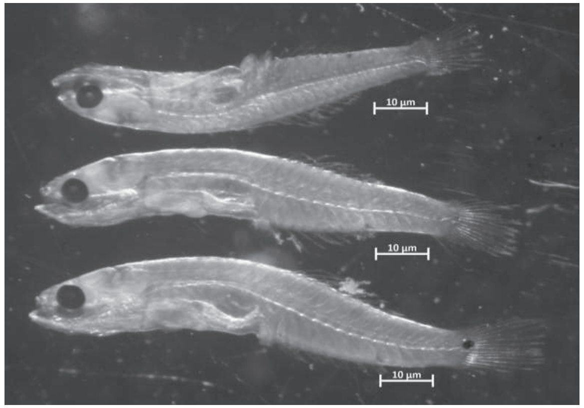


Figure: Family Gobiidae

Figure: Family Ambassidae

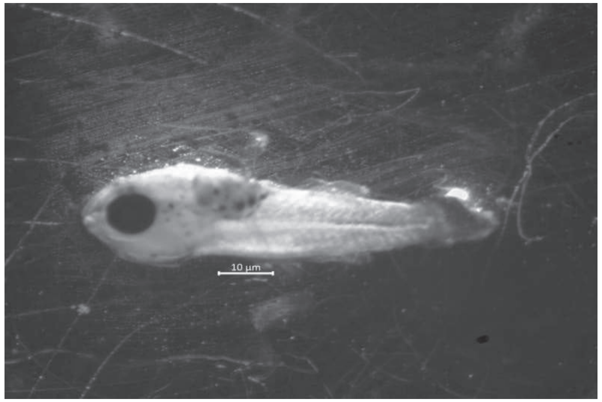


Figure: Family Sciaenidae

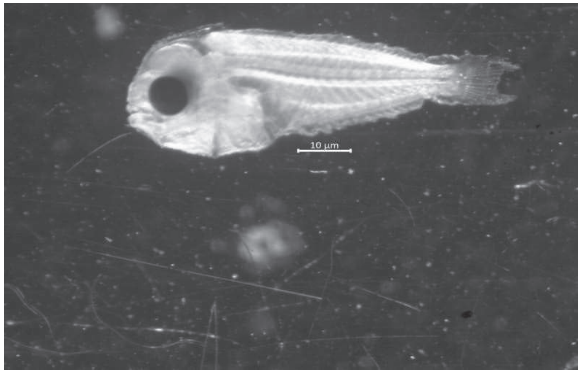


Figure: Family Carangidae

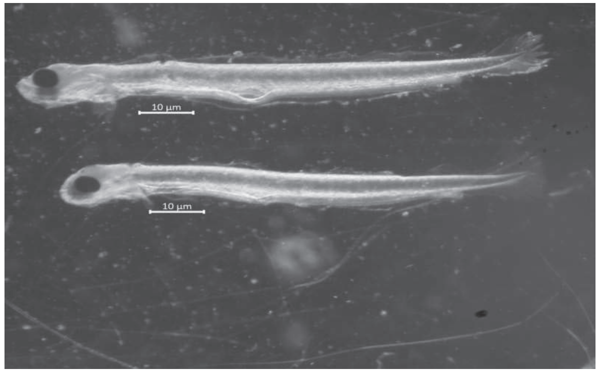


Figure: Family Clupeidae

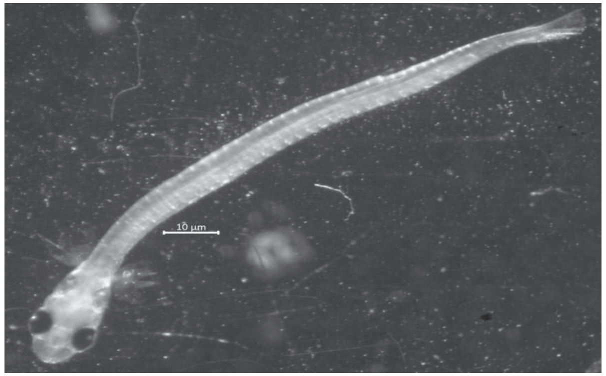


Figure: Family Engraulidae

Fish larvae from the study site

Figure: Family Blennidae

Table 2.1 showing mean density of fish larvae (larvae/100m^3)

	Mean density (larvae/100m^3)									
Family	LKST1	LKST2	PDST1	PDST2	iAQUAS 1	iAQUAS 2	TTST1	TTST2	Mean	(mean %)
Ambassidae	2.243	7.92	2.804	9.89	7.74	4.579	23.065	7.95	8.2385	36.08609
Blennidae	0	0.057	0	0	0	0	0	0	0.007125	0.031209
Carangidae	1.183	2.237	0.211	3.29	0.464	1.55	2.234	3.792	1.870125	8.191479
Clupeidae	0.573	9.94	0.868	8.28	5.48	2.149	7.503	6.942	5.216875	22.85084
Engraulidae	1.122	2.173	0.914	1.354	1.477	2.053	3.03	1.291	1.67675	7.344463
Gobiidae	13.727	6.267	0.54	0.051	0.27	0.086	3.11	1.282	3.041625	13.32286
Sciaenidae	0	2.16	0.33	0	0	0	0	0.211	0.337625	1.478857
Unidentified	1.501	3.172	1.093	1.827	3.46	1.292	4.767	2.42	2.4415	10.6942
Mean total larvae									22.83013	100
Total number	157	127	48	166	63	56	169	106		
Total family	5	7	6	5	5	5	5	6		
Total fish larval density	20.349	34.313	6.714	25.063	18.902	10.543	43.659	23.877		

Table 2.2 showing the fish larval density during diurnal and lunar cycle.

		Mean density (Larvae/ 100m3)									
Diurnal	Lunar cycle	LKST1	LKST2	PDST1	PDST2	i-AQUAS1	i-AQUAS2	TTST1	TTST2	Mean	Mean(%)
Night	Full moon	3.58	1.213	0.774	0.26	0.2	0.6	3.186	4.44	1.782	7.771
Daylight	Full moon	0.909	1.63	1.01	3.58	0.462	0.29	1.763	3.794	1.680	7.326
Night	New moon	13.78	30.36	1.24	17.4	7.34	3.61	20.41	8.263	12.890	56.222
Daylight	New moon	2.08	1.11	3.69	3.103	10.9	6.043	18.3	7.30	6.576	28.681
		20.349	34.313	6.714	25.063	18.902	10.543	43.659	23.877	22.83	100

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