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Developmental stages of *Echinometra mathaei* (Blainville, 1825) reared under laboratory conditions from Karachi coast (northern Arabian Sea)

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Abstract: The sea urchins (Echinoidea) are keystone species in an ecosystem with the simplest form of development. The mature specimens of *Echinometra mathaei* (Blainville, 1825) were collected from Cape Monze on 17th March and kept in the laboratory. Spawning occurred after same day, at room temperature 28°C in filtered seawater with a salinity of 37 ppt and a pH of 8. After fertilization the developmental stages of embryos and the timing of each stage including cleavage, morula, blastula, gastrula, prism and pluteus larvae were studied under the microscope. This study represents the first successful analysis on embryonic, larval, and pre- juvenile development of *E. mathaei*. Understanding of ontogeny and life-history strategies will make it easier to develop techniques for breeding, seed production, and culture of sea urchins in captivity conditions also the findings would greatly be helpful for future biologist.

Keywords: *Echinometra mathaei; developmental stages; Karachi coast (northern Arabian sea);*

1. Introduction

Sea urchins belongs to class Echinoidea, they are small, spiny, and globular animals also known as sea hedgehogs due to their superficial resemblance to the spiny mammalian species. sea-urchin grazing exerts a major control on the structure and functioning of the coastal benthic ecosystems (Hill *et al*., 2003; Tuya *et al*., 2004a; Hereu Fina, 2007; Eklof *et al*., 2008; Gianni *et al*., 2017; Yorke *et al*., 2019). They are also modifying agents for erect algae community structure is well known (Watanabe and Harrold, 1991; Filbee-Dexter and Scheibling, 2014; Miller *et al*., 2018). Although there are other herbivores recognized as relevant grazing agents, their functional activity is lower or insignificant compared to sea urchins (Cordeiro *et al*., 2020).

The biodiversity of sea urchins is ecologically important since they retain levels of heavy metals in their bodies (Freeman, 2004). The sea urchin aquaculture is mainly based on the production of marketable gonads, which are valuable seafood product in Asian and European markets (Klumpp*etal*., 1993; Buitrago *et al*., 2005; Tsuchiya *et al*., 2009).

Echinometramathaei (Blainville, 1825) is one of the world's most abundant sea urchin distributed both in tropical and sub-tropical zones (Mortensen, 1943; Clark, 1973). The feeding behavior, ecology, and growth lines of sea urchins, especially *E mathaei*, were studied by Kelso, 1971, Ebert 1975, 1982, 1988; Muthiga, 1996; Lawrence and Bazhin, 1998; Drummond, 2020. Most of echinoderms have a planktonic larvae stage and an adult benthic stage. The planktonic period can last from hours to months and its duration differs between species. Most echinoids are free spawners and produce large numbers of small, yolk-poor eggs that develop into planktonic, obligate planktotrophic larvae known as **echinoplutei** (McEdward and Miner, 2001). After the planktonic stages, larvae seek a suitable substrate to settle on and undergo metamorphosis. The development from post-larvae to juvenile and adult and consequent sexual maturation will give start to a new cycle. The life cycle of the sea urchin can be divided into six more-or-less distinct phases. (1) The fertilized egg, (2) development through blastula and gastrula to pluteus, at which time egg nutrients are usually consumed, (3) growth and development of the feeding pluteus to a mature larva, (4) development of the embryonic urchin inside the growing larva, (5) metamorphosis, and (6) growth of the young urchin to a reproductive adult. Most other Echinoderm groups develop in a similar way.

No data available on ecology, reproductive biology, and developmental stages on *E.mathaei* from Pakistan except (Siddique and Ayub, 2019, 2021) who have studied reproduction and population dynamics of the *E.mathaei*, thus this is first attempt to report the developmental stages (embryonic, larval, and pre-juvenile)of *E.mathaei* under controlled laboratory conditions.

2. Methodology

2.1 Sample collection

Six adult specimens of *E. mathaei* were collected from the rocky beach of Cape Monze (Lat. 24°50'02"N Long. 66°39'24"E) (**Figure 1**) on 17th March, 2022 from intertidal zone during low tide (0.2m) with a salinity of 37 (ppt) , pH of 7.9 and water temperature (27 °C). The urchins were taken in plastic containers and filled with seawater. The specimens were immediately transported to laboratory and shifted with aerated aquarium.

2.2 Spawning and fertilization in laboratory

Same day after settlement in the aquarium *E. mathaei* started to shed their gametes (Time; 6:00pm), room temperature (28°C), water temperature (26°C), salinity of 37 and a pH of (8). The male urchin starts releasing creamy white mass from the dorsal side and then female spilled the eggs through the aboral side as yellowish color solution. The sperms and eggs were fertilized at room temperature. Fertilized eggs were transferred in to beaker mild aeration was provided and the beaker was partially covered with black cloth to reduce the light penetration (technique followed by Jose *et al.,* 2007). Free-swimming blastula stages obtained after 12 hours of fertilization were transferred to glass aquarium filled with disinfected seawater the aquarium containing the fertilized eggs were maintained at temperature 27- 28°C and the salinity was 37 – 38ppt for the growth and development of eggs. One day after fertilization, 4 triplicate sets with 100 numbers of 'prism stage' larvae were monitored. Water exchange was carried out at the rate of 50% in two days using suitable filter and the aquarium were covered using black cloth.

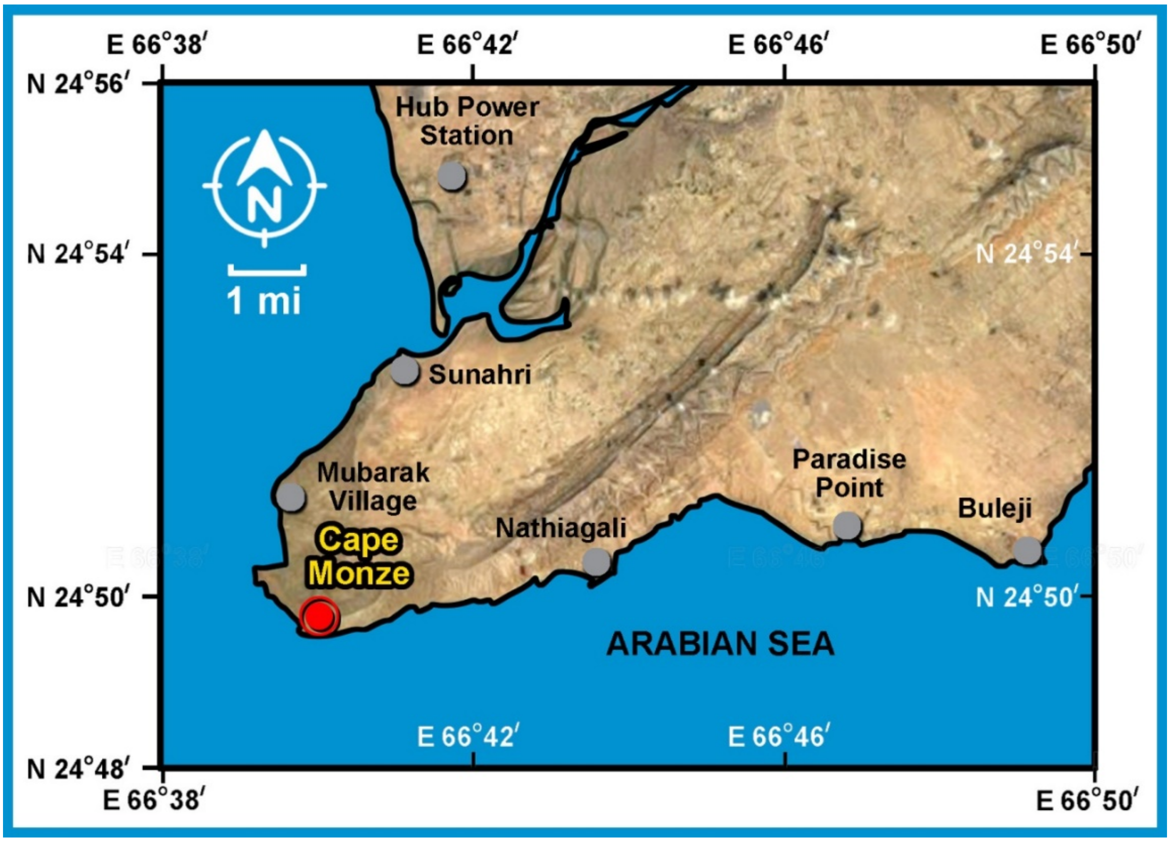

Figure 1. Map showing the collection site (Map developed by Abrar Ali, Marine Reference Collection and Resource Centre, University of Karachi).

3. Results and Discussion

3.1 Larval and pre-juvenile development

The morphological changes that occurred during the embryonic development of *E. mathaei* were observed in captivity (**Figure 2A, B.** and **Table 1.**). Photographed were made by using a Nikon (LABOPHOT-2) upright microscope at (10 x 20 magnifications). The mature eggs are transparent, spherical in shape, loose, and yellowish, while the sperm are whitish. Sperm and eggs have come closer, the sperm penetrated the egg and fertilization occurred in 5 minutes after contact of sperm and egg. The formation of the fertilization membrane around the egg is the most visible feature of the fertilization process. The first cleavage was observed after one hour of fertilization, and the second cleavage was known to be four to eight cells of equal size 80µmin diameter after 2:50 hours, followed by a 16-cell embryo as the fourth cleavage after 3:30hrs. Cell division took 5 hours, after which cell masses were transformed into a morula. Notice further development in the cells as a blastula at 6:35 hours after observing the morula. The embryo, observed after 15 hours of fertilization, formed a gastrula through invaginating at the vegetal pole. Embryos entered the prism size 13µm, after fertilization for 24 hours and formed the skeletal elements. In such conditions, the stage of the embryo was prismatic, and the primitive gut was observed. The development of the 2-armed pluteus larvae with the size 175 µm began in the prism stage, and after a calculation of 34 hours, the 4-armed pluteus larvae having size 275 µm formed on the third day. In this stage, the pluteus front, short arms, and a pair of dorsal long arms of larvae were observed, and pigmented cells were visible under the upright microscope. The temperature was maintained at 26- 30°C and the salinity was 37ppt for the growth and development of an embryo. The following larval stages 6-arm with size 265µm and 8-arm was 300 µm stages were observed on the 15th and 20th day of post-fertilization.

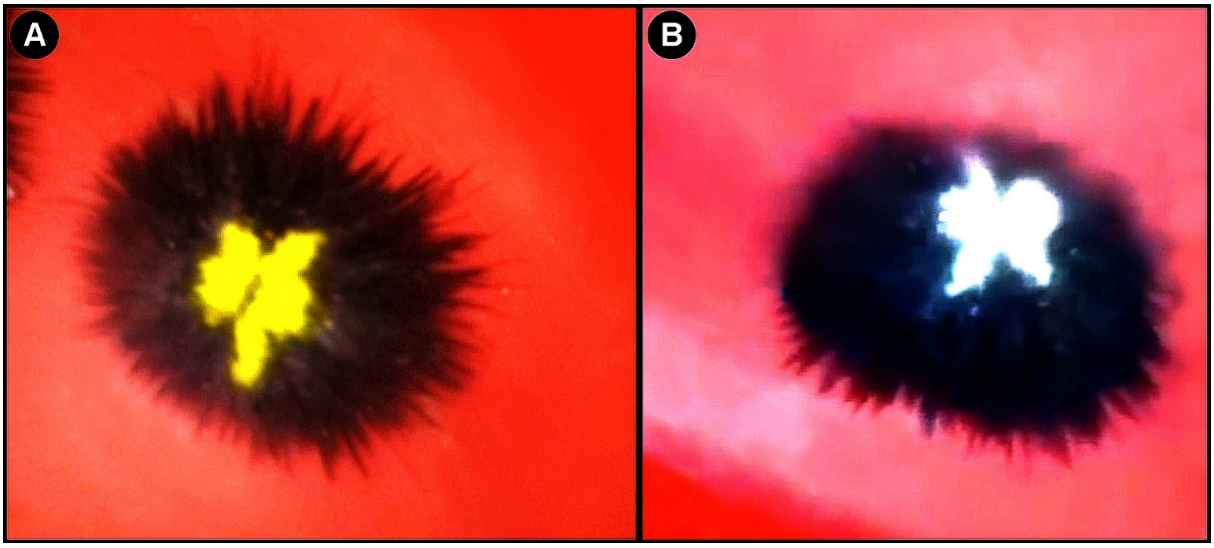

Figure 2. A. Mature Female **B.** Mature Male of *E. Mathaei* (Blainville, 1825).

Table 1. Developmental stages of *Echinometra mathaei* under laboratory condition.

Developmental stages	Time after insemination
Fertilization occur	5 minutes
First cleavage	01:00 hrs.
Second cleavage	02:50 hrs.
16 Cells	03:30 hrs.
Morula	5 hrs.
Blastula	6:35 hrs.
Gastrula	15:00 hrs.
Prism	24 hrs.
Pluteus 2-armed	34 hrs.
Pluteus 4-armed	3rd day
Pluteus 6-armed	15th day
Pluteus 8-armed	20th day
Pre-juvenile	33rd day

On day 22, when the larvae reached the 8-arm stage, they demonstrated "competence" by observing the bottom of the beaker or aquarium (**Figure 3**). Microalgae were offered as food. The larval survival rate did not differ significantly during the first days of feeding during the competency stage, the rudiment developed tube feet and spines that became active inside the larval body, but no pedicellariae were formed on the larval surface body, as is common in competent larvae of regular echinoids. After the third day of observation of competency, newly settled juvenile sea urchins are nearly 630µm in width, have developed mouth parts, and have begun feeding on benthic diatoms. The present study investigated the larval developmental stages of *E. mathaei* under laboratory conditions from Karachi coast (northern Arabian Sea). The developmental timing of the hatching blastulae period (6:35 hrs. at 27–28°C), Similar to other echinoids with planktotrophic larvae *E. mathaei* embryo, and larval development undergo cleavages (6 h at 29°C) by Ghorani*et al.* (2013), *Lytechinus variegatus* (6 h at 23°C) (Strathmann,1987) and *Clypeastersub depressus* (7 h at 26°C) (Vellutini and Migotto, 2010) the developmental timing of *Salmacis sphaeroides* hatching blastulae took longer to mature (08.45 h at 24°C) (Rahman *et al*., 2012).

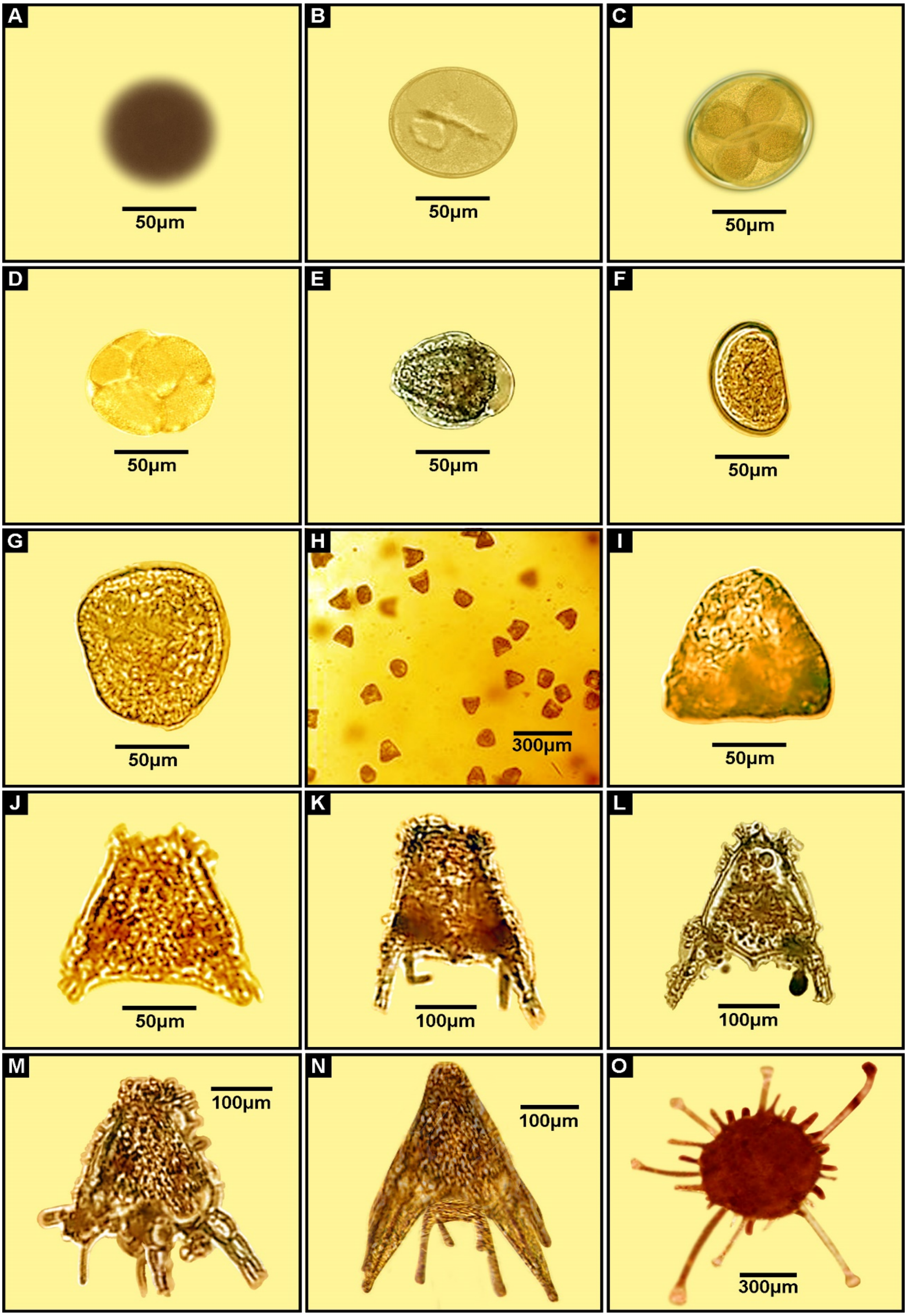

Figure 3. Embryonic developmental stages of *E. mathaei*(A) Ovum after fertilization (B) Fertilized egg with complete fertilization membrane (C) 4-cell stage (D) 8-cell stage (E) Morula stage enclosed with fertilization membrane (F) Blastula stage (G) Gastrula stage (H, I) Prism stage (J) 2-arm pluteus (K, L) 4-arm pluteus (M) 6-arm pluteus (N) 8-arm pluteus (O) Juvenile stage.

Later stages of development exhibited the same patterns but somewhat varied from those of *Lytechinus variegatus* species from the Caribbean at 23°C (Strathmann,1987) and other Echinoidea species *Colobocentrotus mertensii* species from the Pacific at 27°C (Thet *et al*., 2004). Gastrulation is strong with red-pigmented cells starting at the vegetal pole and moving through the ectoderm to the apical plate as the archenteron continues to elongate. Comparable events were seen in the tropical sea urchin *E. mathaei* (Takata and Kominami, 2004) and the sea biscuit *Clypeastersub depressus* (Vellutini and Migotto,2010). These cells may be involved in the morphological alterations that take place during pluteus larvae's prism development and early axis determination (Thet *et al*., 2004;Takata and Kominami, 2004).

The ideal salinity and temperature for the growth of *E. mathaei* embryos, in the port city Bandar Abbas, a warm region of Iran, respectively, were 29°C and 39 ppt. whereas we observed the growth and development of the embryo at 27–28°C and 37ppt salinity. *E. Mathaei* (Ghorani*et al*., 2013) and similar to the *Arbacia punctulata* (sea urchin), the first cleavage happened after 60 minutes of fertilization (Shimek, 2003). Moreover, King and Riddle (2001) demonstrated that the blastula develops into the embryo in *Sterechinus neumayeri* 2-3 days after fertilization, but in *Paracentrotus lividus* in 12 hrs. (Russo et al., 2003) and while *E. mathaei*, in 6 hours (Ghorani*et al*., 2013) respectively. In the present study, the embryos developed into the gastrula 15 hours after fertilization, whereas the *E. mathaei* developed into gastrula in 14hrs. *E. mathaei* (Ghorani, 2011) and the *Arbacia punctulata* embryos grew into the gastrula after 24 hrs. (Shimek, 2003).

Prism in *E. mathaei* happened 24 hrs. after conception, but Shimek (2003) stated that embryos mature into prism after 20 hours. According to the studies, *Paracentrotus lividus* and *Sterechinus neumayeri* need 48 hours and 20 days after fertilization to reach the pluteus larvae (Russo *et al*., 2003; King and Riddle, 2001), but *E. mathaei* takes 34 hours, in comparison to other sea urchin species, *E. mathaei*has a shorter developmental period and the larvae develop in a shorter period, according to Ghorani*et al*. (2013) findings.

Competent larvae of *Salmacissphaeroides*contain pedicellariae during the late larval phase and after metamorphosis, as in *Paracentrotus lividus* (Gosselin and Jangoux, 1998), and *Strongylocentrotus franciscanus* (Miller and Emlet,1999), but pedicellariae of *Strongylocentrotus* sometime after metamorphosis. On the other hand, competent larvae of *Echinocardium cordatum* lack spines and pedicellariae (De Amaral P. Nunes and Jangoux, 2007), whilst those of *Clypeastersub depressus* have spines but no pedicellariae (Vellutini and Migotto, 2010). Similar to *Colobocentrotus mertensii* (Thet *et al*., 2004), *Paracentrotus lividus* (Gosselin and Jangoux, 1998), and *Lytechinus pictus* (Hinegardner, 1969), the digestive system and maybe other internal organs developed approximately 4-5 days after settling, and the urchin began to eat, while in the present study the newly settled young sea urchins, *E. mathaei* are nearly competent after the third day of observation. *E. mathaei*, newly settled juvenile sea urchins, are almost 630µm wide, have grown mouth parts, and have begun eating on benthic diatoms. Siddique and Ayub, (2019) studies reproduction of the sea urchin of *E. mathaei* from Pakistani coastal waters, results showed that the spawning season of *E. mathaei* were recorded from autumn to winter (September to January). However, the present results indicated that the male and female were spawn in March.

In conclusion, this is the first productive examination of the embryonic, larval, and post-metamorphic juvenile development of *E. mathaei* in Karachi, Pakistan.

Conclusion

The present study represents the first successful analysis on embryonic, larval, and pre- juvenile development of *Echinometra mathaei* (Blainville, 1825) from Karachi coast of the northern Arabian Sea reared under laboratory conditions. Detailed descriptions of embryonic and larval development led to preliminary results that are very promising for domesticating this species and advancing future production diversification. The results will also be of tremendous use to future biologists.

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Compliance with Ethical Standards: This article does not contain any studies involving human subjects.

References

Buitrago E., Lodeiros C., Lunar K., Alvarado D., Indorf F., Frontado K. & Vasquez Z. (2005). Mass production of competent larvae of the sea urchin Lytechinus variegatus (Echinodermata: Echinoidea). *Aquaculture International*, 13, 359-367.https://doi.org/10.1007/s10499-004-6551-y

Clark A. M. (1973). Echinoderms of coral reefs. *Biology and geology of coral reefs*, 3, 95-123.

Cordeiro C. A. M. M., Harborne A. R., and Ferreira C. E. L. (2020). The biophysical controls of macroalgal growth on subtropical reefs. *Frontiers in Marine Science*, 7, 488. https://doi.org/10.3389/fmars.2020.00488

De Amaral P. Nunes C., & Jangoux M. (2007). Larval growth and perimetamorphosis in the echinoid Echinocardiumcordatum (Echinodermata): the spatangoid way to become a sea urchin. *Zoomorphology*, 126, 103-119.https://doi.org/10.1007/s00435-007-0032-6

Drummond A. E. (2020). Aspects of the life history biology of three species of sea urchin on the South African east coast. In *Echinoderms through time*, 637-641, CRC Press.

Ebert T. A. (1975). Growth and mortality of post-larval echinoids. *American Zoologist*, 15(3), 755-775.https://doi.org/10.1093/icb/15.3.755

Ebert T. A. (1982). Longevity, life history, and relative body wall size in sea urchins. *Ecological Monographs*, 52(4), 353-394.https://doi.org/10.2307/2937351

Ebert T.A. (1988). Calibration of natural growth lines in ossicles of two sea urchins, Strongylocentrotus purpuratus and Echinometramathaei, using tetracycline. In *Echinoderm biology: proceedings of the sixth international echinoderm conference* (RD Burke, PV Mladenov, P. Lambert, and RL Parsley, eds.), 435-443

Eklöf J. S., de la Torre-Castro M., Gullström M., Uku J., Muthiga N., Lyimo T., et al. (2008). Sea urchin overgrazing of seagrasses: a review of current knowledge on causes, consequences, and management. *Estuarine, Coastal and Shelf Science*,79, 569–580. https://doi.org/10.1016/j.ecss.2008.05.005

Filbee-Dexter K., and Scheibling R. (2014). Sea urchin barrens as alternative stable states of collapsed kelp ecosystems. *Marine ecology progress series*, 495, 1–25. https://doi.org/10.3354/meps10573

Freeman S.M. (2004). Echinoidea. In B. Grzimek,S. F. Craig, D. A. Thoney, N. Schlager, and M.Hutchins. *Grzimek's Animal Life Encyclopedia, 2nd Edition*. Detroit, MI: Thompson/Gale. ISBN

Ghorani V., Shahri N. M., Ghassemzadeh F., & Mortazavi M. S. (2013). The effect of lead toxicity on embryonic development and early larval growth of the Echinometramathaei sea urchin (Persian Gulf), morphologic and morphometric studies.*Indian Journal of Geo-Marine Sciences*,42(1), 29-34.

Gianni F., Bartolini F., Pey A., Laurent M., Martins G. M., Airoldi L., &Mangialajo L. (2017). Threats to large brown algal forests in temperate seas: the overlooked role of native herbivorous fish. *Scientific reports*, 7(1), 1-13.https://doi.org/10.1038/s41598-017-06394-7

Gosselin P., & Jangoux M. (1998). From competent larva to exotrophic juvenile: a morphofunctional study of the perimetamorphic period of Paracentrotuslividus (Echinodermata, Echinoida). *Zoomorphology*, 118(1), 31-43.https://doi.org/10.1007/s004350050054

Hereu Fina B. (2007). *Role of trophic interactions between fishes, sea urchins and algae in the northwestern Mediterranean rocky infralittoral,* TheUniversitat de Barcelona.

Hill N. A., Blount C., Poore A. G., Worthington D., & Steinberg P. D. (2003). Grazing effects of the sea urchin Centrostephanusrodgersii in two contrasting rocky reef habitats: effects of urchin density and its implications for the fishery. *Marine and Freshwater Research*, 54(6), 691-700. doi: 10.1071/MF03052

Hinegardner R. T. (1969). Growth and development of the laboratory cultured sea urchin. *The Biological Bulletin*, 137(3), 465-475.https://doi.org/10.2307/1540168

Jose J. J., Lipton A. P. & Anil, M. K. (2007). Induced spawning and larval rearing of sea urchin *Echinometra mathaei* (de Blainville, 1825). Journal of Marine Biological Association, India, 49 (2), 230 – 233.

Kelso D. P. (1971). Morphological variation, reproductive periodicity, gamete compatibility and habitat specialization in two species of the sea urchin Echinometra in Hawaii. *University of Hawaii, Honolulu*.

King C. K., & Riddle M. J. (2001). Effects of metal contaminants on the development of the common Antarctic sea urchin Sterechinusneumayeri and comparisons of sensitivity with tropical and temperate echinoids. *Marine Ecology Progress Series*, 215, 143-154. doi:10.3354/meps215143

Klumpp D. W., Salita-Espinosa J. T., & Fortes M. D. (1993). Feeding ecology and trophic role of sea urchins in a tropical seagrass community. *Aquatic Botany*, 45(2-3), 205-229.https://doi.org/10.1016/0304-3770(93)90022-O

Lawrence J. M., & Bazhin A. (1998). Life-history strategies and the potential of sea urchins for aquaculture. *Journal of Shellfish Research*, 17(5), 1515-1522.

McEdward L. R., & Miner B. G. (2001). Echinoid larval ecology. *Developments in Aquaculture and Fisheries Science*, 32, 59-78.

Miller B. A., & Emlet R. B. (1999). Development of newly metamorphosed juvenile sea urchins (Strongylocentrotus franciscanus and S. purpuratus): morphology, the effects of temperature and larval food ration, and a method for determining age. *Journal of Experimental Marine Biology and Ecology*, 235(1), 67-90. https://doi.org/10.1016/S0022-0981(98)00164-6

Miller R. J., Lafferty K. D., Lamy T., Kui L., Rassweiler A., & Reed D. C. (2018). Giant kelp, Macrocystis pyrifera, increases faunal diversity through physical engineering. *Proceedings of the Royal Society B: Biological Sciences*, 285(1874), 20172571. https://doi.org/10.1098/rspb.2017.2571

Mortensen T. (1943). A Monograph of the Echinoidea. III, 3. Camarodonta. II. Echinidæ, Strongylocentrotidæ, Parasaleniidæ, Echinometridæ. 446 pp., C. A. Reitzel, Copenhagen.

Muthiga N. A. (1996). The role of early life history strategies on the population dynamics of the sea urchin Echinometramathaei (de Blainville) on reefs' in Kenya (Doctoral dissertation, *University of Nairobi*).

Rahman M. A., Yusoff F. M., Arshad A., Shamsudin M.N., Amin S.M.N. (2012). Embryonic, larval, and early juvenile development of the tropical sea urchin, Salmacissphaeroides (Echinodermata: Echinoidea). *The Scientific World Journal*, 2012, Article ID 938482. doi.org/10.1100/2012/938482

Russo R., Bonaventura R., Zito F., Schröder H. C., Müller I., Müller W. E., &Matranga V. (2003). Stress to cadmium monitored by metallothionein gene induction in Paracentrotuslividusembryos. *Cell Stress & Chaperones*, 8(3), 232. doi: 10.1379/1466-1268(2003)008<0232:stcmbm>2.0.co;2

Shimek R. L. (2003). The toxicity of some freshly mixed artificial sea water; A bad beginning for a reef aquarium. *Reefkeeping Online Magazine*, 6(10).

Siddique S., &Ayub Z. (2019). Reproduction of the Sea Urchin *Echinometra mathaei* (Echinoidea: Echinodermata) Found on Buleji, Rocky Coast, Pakistan, North Arabian Sea. *Thalassas: An International Journal of Marine Sciences*, 35, 551-560. https://doi.org/10.1007/s41208-019-0125-2

Siddique S., &Ayub Z. (2021). Population Dynamics of Echinometramathaei (Echinoidea: Echinodermata) Found on Buleji, Pakistan, North Arabian Sea. *Pakistan Journal of Zoology*, 53(2), 507.

https://dx.doi.org/10.17582/journal.pjz/20180926190946
Strathmann M. F. (1987). Reproduction and development of marine invertebrates of the northern Pacific coast: data and methods for the study of eggs, embryos, and larvae. *University of Washington Press*.
Takata H., &Kominami, T. (2004). Behavior of pigment cells closely correlates the manner of gastrulation in sea urchin embryos. *Zoological science*, 21(10), 1025-1035. https://doi.org/10.2108/zsj.21.1025
Thet M. M., Noguchi M., & Yazaki I. (2004). Larval and juvenile development of the echinometrid sea urchin Colobocentrotusmertensii: emergence of the peculiar form of spines. *Zoological Science*, 21(3), 265-274. https://doi.org/10.2108/zsj.21.265
Tsuchiya M., Nishihira M., Poung-In S., & Choohabandit S. (2009). Feeding behavior of the urchin-eating urchin Salmacissphaeroides. Galaxea, *Journal of Coral Reef Studies*, 11(2), 149-153. https://doi.org/10.3755/galaxea.11.149
Tuya F., Boyra A., Sanchez-Jerez P., Barbera C., and Haroun R. (2004a). Can one species determine the structure of the benthic community on a temperate rocky reef? The case of the long-spined sea-urchin Diademaantillarum (Echinodermata: Echinoidea) in the eastern Atlantic. *Hydrobiologia,* 519, 211–214. https://doi.org/10.1023/B:HYDR.0000026599.57603.bf
Vellutini B. C., & Migotto A. E. (2010). Embryonic, larval, and juvenile development of the sea biscuit Clypeastersubdepressus (Echinodermata: Clypeasteroida). *PLoS One*, 5(3), e9654. https://doi.org/10.1371/journal.pone.0009654
Watanabe J. M., & Harrold C. (1991). Destructive grazing by sea urchins Strongylocentrotus spp. in a central California kelp forest: potential roles of recruitment, depth, and predation. *Marine ecology progress series. Oldendorf*, *71*(2), 125-141.
Yorke C. E., Page H. M., & Miller R. J. (2019). Sea urchins mediate the availability of kelp detritus to benthic consumers. *Proceedings of the Royal Society B*, 286(1906), 20190846. https://doi.org/10.1098/rspb.2019.0846