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Reproductive cycles and factors influencing reproductive cycle in shellfish and their application for aquaculture

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Abstract

Shellfish reproductive cycles have a major impact on species management and production efficiency, making them essential for sustainable aquaculture. Examining numerous physiological, biological, and environmental elements that affect gamete development and spawning is necessary to comprehend these cycles. Shellfish, including clams, mussels, and oysters, are important components of maritime ecosystems and economy. Their ability to reproduce is essential to their survival and, consequently, to the long-term viability of aquaculture methods that depend on them. Comprehending these cycles is not merely a scholarly endeavor; it serves as a means of optimizing shellfish farming and augmenting productivity. The complex life cycles of shellfish, examining how elements like as salinity, temperature, and nutrient availability affect their mating habits.

Keywords: Shellfish, reproductive cycle, aquaculture, spawning, environmental factors

Introduction

Shellfish, which comprise mollusks like clams, oysters, and mussels as well as crustaceans like shrimp and lobsters, have a variety of interesting reproductive techniques. Males and females of crustaceans, which include shrimp and lobsters, mate directly. The female receives sperm from the male during mating, and she stores it until eggs are ready for fertilization. The fertilized eggs are subsequently laid by the female, carries them attached to her abdomen until they hatch into larvae.

Reproductive cycle of *Penaeus monodon* (Black tiger shrimp)

1. Egg

0-3 mm in diameter-narrow Perivitelline space-Embryonic development fast-nauplius hatches out within 16-17hrs after fertilization.

2. Nauplius

First hatched nauplius, pear shaped with 3 pairs of appendages. Nauplius moults every 3-5 hrs. Passes through 6 naupliar substages. Nauplius swims actively; no mouth; Alimentary canal is inside the body.

3. Protozoa (Zoea)

After about 2 days nauplius metamorphose into protozoa - 3 substages.

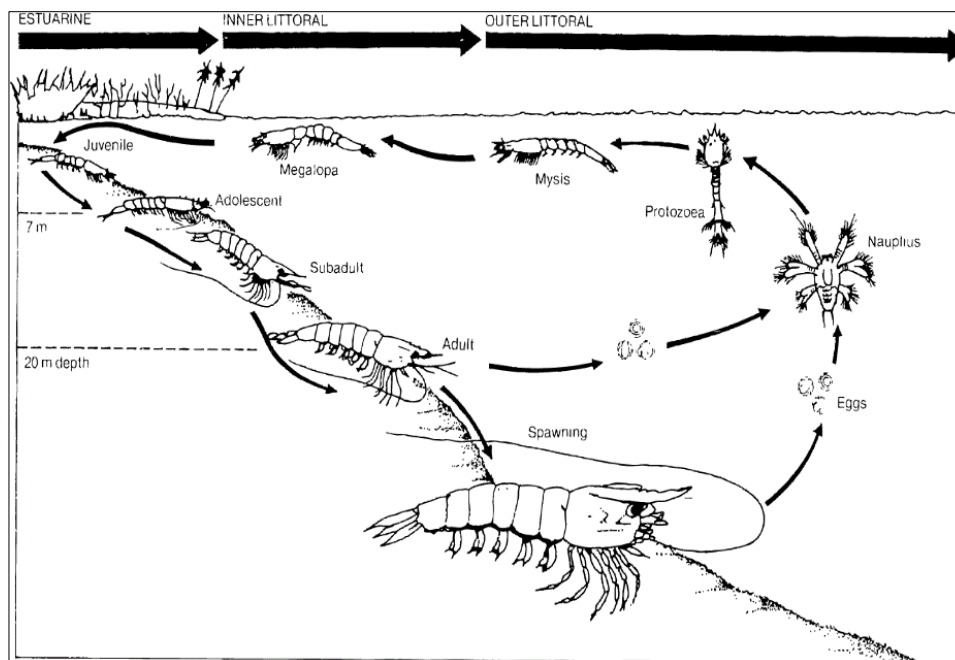
Protozoa swims actively; strongly attracted towards light; mouth, Alimentary canal, feeding apparatus present; feeding on unicellular algae. Protozoa I Protozoa II Protozoa III

4. Mysis

3 substages, look very much alike except pleopod buds (swimming leg rudiments) in the later 2 stages. Mysis retain filtering mechanism, feeding on algal cells. 1st 3 walking legs not functional; don't swim actively like protozoa; less responsive to light; swim in the water column with head pointing downwards. Mysis I Mysis II Mysis III

5. Post larva

Filtering mechanism is lost/mandibles have cutting edge; walking legs have claws-unctional; capable of capturing/eating zooplankton; attraction to light lost.



(Source: Semantic scholar M. Shailender, D. Amarnath, Published 30 March 2013)

Fig 1: Reproductive cycle of *Penaeus monodon*

Reproduction in freshwater prawn (*Macrobrachium rosenbergii*)

Mating: Take place between hard shelled males and mature soft shelled females which have just completed their premating moult. Time between moulting and mating varies from 1.2 to 21.8 hrs (avg. 9.1 hrs). Male gonopore brought close to sperm receptacle of female on thoracic region and transfer the sperm to receptacle as spermatophore. Spermatophore adheres to the sperm receptacle because of the glutinous nature of attachment matrix. After mating female may spend several hours in prespawning preening behavior.

Spawning

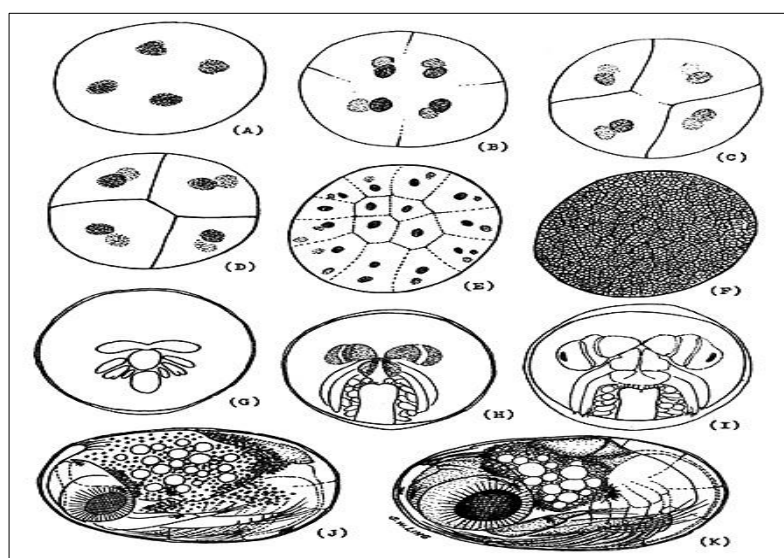
Spawning occurs after few hrs of mating. Eggs laid by female are fertilized by sperm attached to underside of thorax. The fertilized eggs are transferred to the ventral side

of abdomen (brood chamber). Ovipository setae are attached to the ovigerous setae of 1st 4 pleopods and kept in place by a membrane. Movements of pleopods helps in aerating the eggs. Adult females carrying eggs on the ventral side of abdomen is called berried female. Fecundity varies from 20000-100000 eggs. However, their first broods, (i.e. those which are produced within their first year of life), are often not more than 5 000 to 20 000.

Incubation

Initially eggs are slightly elliptical (0.6-0.7 mm in long axis) and bright orange in color. Embryonic development proceeds. Incubation period average 19 days. Turns grey black 2-3 days before hatching. Freshly hatched larvae are called zoea.

Segmentation and embryonic development



(source: Semantic scholar DOI:10.1007/s10499-021-00649-x)

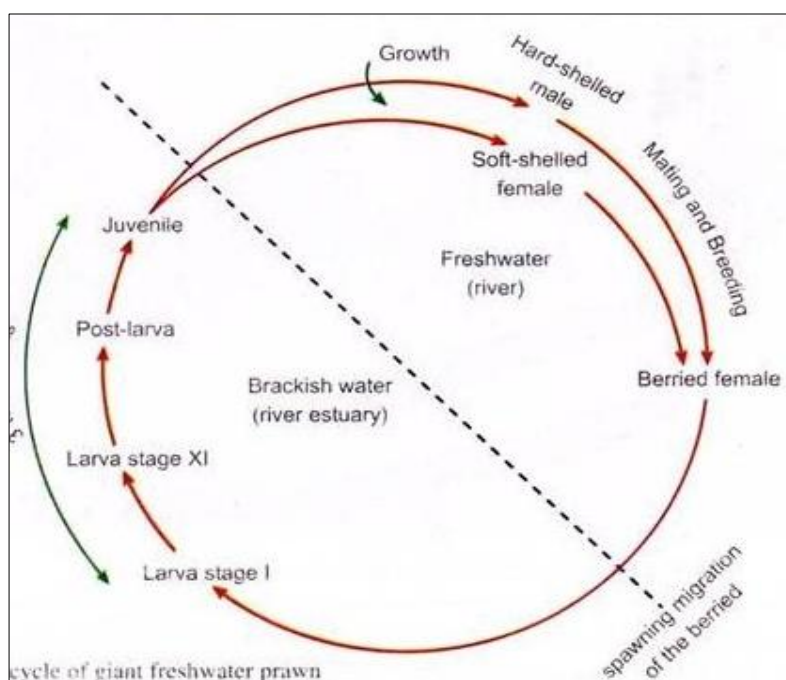
Fig 2: Times refer to period since fertilization

A) 7 h - completion of second nuclear division. (B) 8 h 45 min - third nuclear division nearly completed, appearance of 4 cleavage furrows. (C) 8 h 55 min - third nuclear division completed, tips of the 4 cleavage furrows have met at 2 points from which the median furrow is developing. (D) 9h - complete formation of 4 quadrants (blastomeres). (E) 14 h - 32 nuclei. (F) 24 h - completion of segmentation. (G) 6 days-formation of caudal papilla. (H) 7 days- formation of optic vesicle.(I) 9 days eye pigment development.(J)14days larva fully formed.(K)19 days larva ready to hatch.

Development of larvae

Newly hatched zoea about 1.92mm in length. It has the

zoeal characteristics such as a body distinguishable into cephalothorax and abdomen. The segmented body is without pleopods. Larvae swim upside down by using their thoracic appendages and are positively attracted to light. By stage XI they are about 7.7 mm long. Newly metamorphosed post larvae (PL) are also about 7.7 mm long and are characterized by the fact that they move and swim in the same way as adult prawns. They are generally translucent and have a light orange-pink head area. Larvae require salinity from 11-13 ppt for survival and growth. Larval passes through 11 zoeal stages within 23-32 days depending on temperature, food, and water quality to become PL.



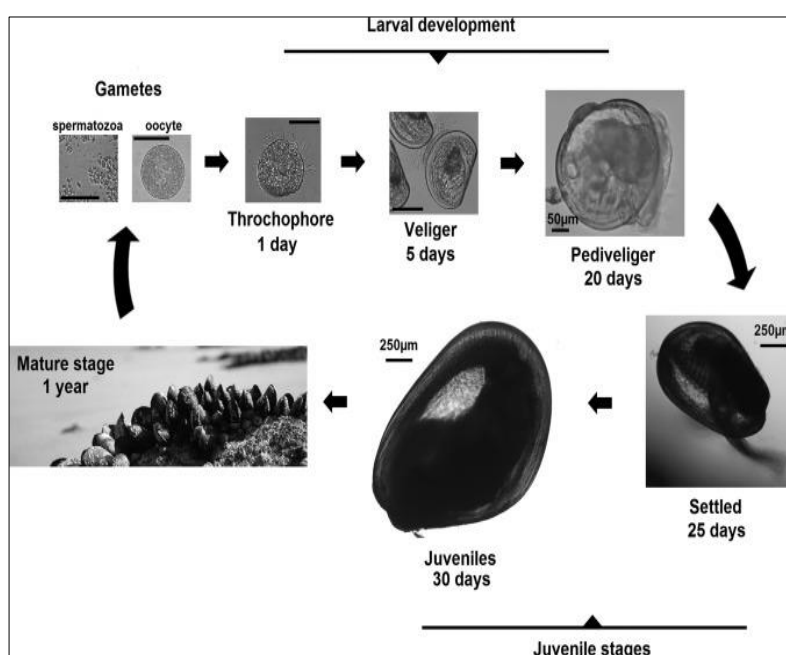
(Source: Research gate DOI: 10.31018/jans.v11i1.1966 ISBN: 0974-941)

Fig 3: Reproductive cycle of Fresh water prawn

Reproduction in Bivalves

Bivalves like clams, oysters, and mussels undergo seasonal cycles of reproductive activity. Gametes are produced and released,

fertilization occurs, and larvae develop. The larvae go through several stages, including a free-swimming veliger stage, before settling and metamorphosing into juvenile bivalves.



(source: Research gate DOI: 10.2307/1539787 ISBN: 0006-3185)

Fig 4: Reproductive cycle of Clams

Reproductive cycle of mussel

Mating and Fertilization

Male freshwater mussels release sperm into the water. Females draw this sperm into their bodies through their siphons, where fertilization of the eggs occurs within specialized structures called marsupia, located in their gills.

Brooding

After fertilization, the eggs develop into glochidia, which are the larval stage of freshwater mussels. This brooding period lasts about 4 to 6 weeks.

Release of glochidia

Between late spring and early summer, typically from May to June, the glochidia are expelled into the water. At this stage, they are microscopic and approximately 0.2 mm in size.

Attachment to host fish

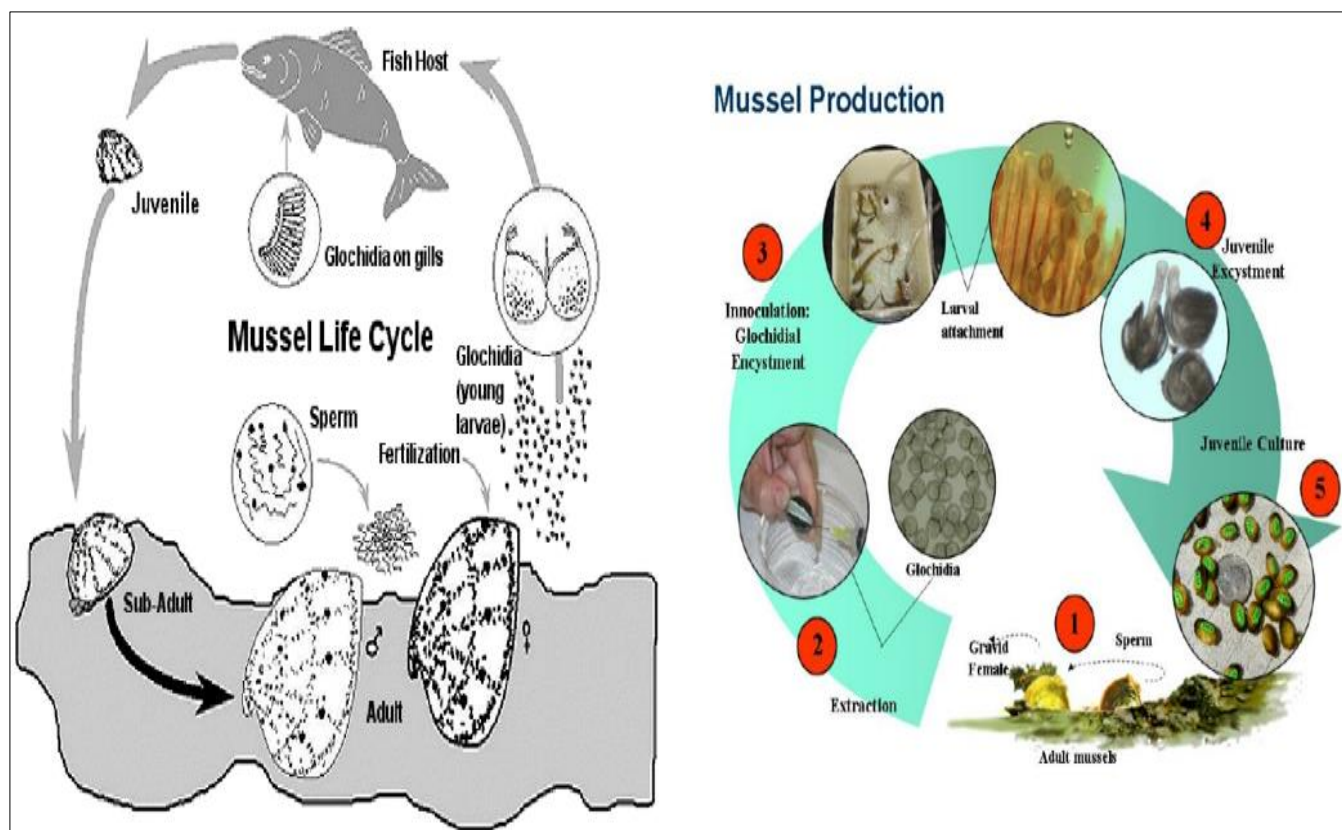
Glochidia must attach to the gills or fins of a host fish to continue their development. Some species release glochidia directly into the water, while others use specialized structures called mantle lures that mimic prey to attract fish.

Encystment and Development

Once attached, the glochidia encyst within the fish's tissues. The fish's immune response facilitates this process, leading to the formation of a cyst around the glochidia within 2 days.

Detachment and settlement

After completing their metamorphosis, juvenile mussels detach from the host fish and settle into the substrate of their aquatic environment. They continue to grow and develop into mature mussels over several years.



(source:Research gate DOI: 10.1007/s 40071-017-0180-3ISBN: 2008-4935)

Fig 5: Reproductive cycle of Mussel

Factors influencing reproduction and their application for Aquaculture

1. Environmental factors

Light, photoperiod, temperature, change in water quality and quantity, Lunar cycle etc.

2. Biological factors

Genetic variability, stress, age and size.

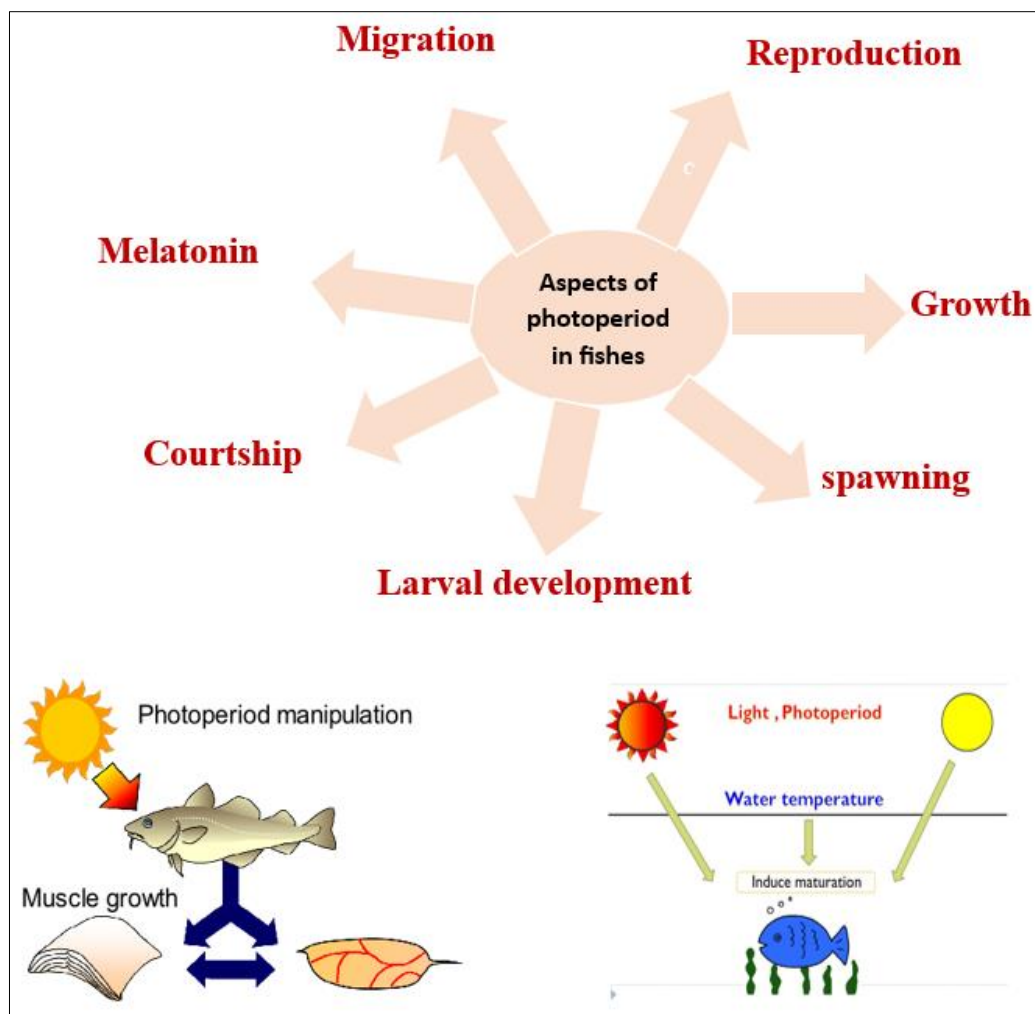
3. Intrinsic physiological factors

neurohormonal and hormonal stimulation, genetic and nutritional factors.

1. Environmental factors

Photoperiod

The length of a 24-hour cycle of light and dark. It is an organism's capacity to timing seasonal events in their life histories by using body length as an anticipatory cue. Many different kinds of animals utilize the length of the day or photoperiod as a preemptive cue to plan their seasonal activities. Photoperiod is most beneficial in forecasting future environmental conditions or situations at remote locations; it sends out a signal to begin physiological and developmental processes that lead to migration, dormancy, and reproduction.



(source: Science direct [Aquaculture Reports](#) April 2024 Md Al-EmranMd, Mahiuddin,1 Zahangir Md Shahjahan)

Fig 6: Photoperiod in Fishes

Temperature

Major carps breed within a range of 24-31 °C. If an effective dose of pituitary, HCG, or ovaprim is given to fish, they will spawn successfully even if there is a significant increase or decrease in water temperature. Warm temperature plays a primary role in stimulating the maturation of gonads in many fish species. Temperature has a direct effect on gonads regulating their ability to respond to pituitary stimulation and effects on primary synthesis and release of gonadotropins.

Salinity: Major carps breed within a range of 24-31 °C. If an effective dose of pituitary, HCG, or ovaprim is given to fish, they will spawn successfully even if there is a significant increase or decrease in water temperature. Warm temperature plays a primary role in stimulating the maturation of gonads in many fish species. Temperature has a direct effect on gonads regulating their ability to respond to pituitary stimulation and effects on primary synthesis and release of gonadotropins.

Water Depth

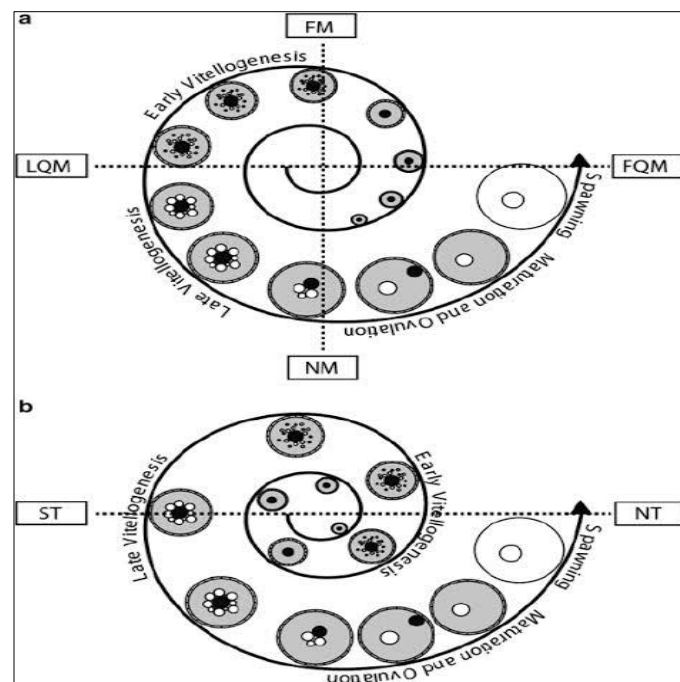
For effective reproduction, a number of fish species are dependent on particular substrate types and water depths. Changes in the water level can modify the flow pattern, which can impact the movement of fish larvae and eggs.

Table 1: Fish Distribution by Water Depth

Depth	Example
Off shore area (300-400 m)	Petrale sole (<i>Eopsetta jordani</i>)
Near shore area (up to 200 m)	Atlantic Herring
Deepest area	Tuna

Lunar Cycle

Many fish species, most of which live in coastal regions, have been found to exhibit apparent spawning cycles at intervals of 14.7 days during a specific lunar phase. These cycles are the explanation for lunar reproductive events. For instance, only at spring tide does a common coastal puffer species in Japan congregate at specific beachfront areas and spawn several hours before the morning or evening high tide. Every year and every two weeks during the spawning season, the grass puffer group spawns at the same spot.



(source: Research gate DOI: 10.1007/s00338-024-02534-4ISBN: 1432-0975)

Fig 7: Lunar cycle

2. Biological factors

Genetic variability

It can affect the success of reproduction within populations. Advantages in reproductive techniques, like as timing and spawning success rates, may result from specific genetic features. Hermaphrodite animals, for instance, might gain from genetic diversity through outcrossing, which would increase their flexibility and resilience.

Stress

Environmental stressors that have an adverse effect on reproductive health include pollution and habitat deterioration. Stress can interfere with hormone pathways that are necessary for reproduction, which lowers fertility and the amount of offspring produced. It has been demonstrated that acute stress in fish inhibits ovarian sterogenesis, which impacts egg production.

Age and Size

An individual's age and size have a big impact on the success of their reproductive process. Bigger and more mature females frequently lay more eggs and better-quality progeny. Furthermore, maturation period varies amongst species, which affects overall population dynamics and reproduction.

3. Intrinsic physiological factors

3.1 Intrinsic physiological factors

Refer to internal biological processes that influence the growth, development, and reproduction of shellfish. These factors are primarily regulated by the nervous and endocrine systems and can be influenced by genetic, and nutritional factors. Intrinsic Physiological Factors involve:

3.1.1 Nervous system

Sensory Perception: Shellfish employ their chemoreceptors, antennae, and eyes to sense changes in their surroundings, including the presence of predators, food sources, and water quality. The brain receives this information and uses it to

coordinate the right reactions. **Neurohormones:** The nervous system secretes neurohormones that have the ability to affect a number of physiological functions, such as stress reactions, growth, and reproduction.

3.1.2 Endocrine system

Hormones: Hormones, produced by endocrine glands are essential for controlling a wide range of physiological processes. As examples, consider: **Growth hormones:** Encourage expansion and maturation. **Hormones involved in reproduction:** regulate the life cycle. **Stress hormones:** Aid in the organism's ability to handle stress. **Hormonal Regulation:** Feedback mechanisms ensure that hormone levels stay within proper ranges, and the endocrine system is carefully regulated.

3.1.3 Genetic factors

Heredity: An individual's hereditary features, such as growth rate, capacity for reproduction, and illness resistance, are determined by genetic factors. **Genetic variety:** Distinct physiological traits and responses to external stimuli can result from genetic variety within a species.

3.1.4 Nutritional factors

Nutritional Factors: Shellfish necessitate particular nutrients for their growth and development. For the body to function at its best, an adequate intake of vital nutrients—such as proteins, carbs, fats, vitamins, and minerals—is required. **Nutritional Deficiencies:** Lack of some vital nutrients can cause stunted growth, decreased fertility, and heightened illness susceptibility.

Applications in aquaculture

Hormone treatments with LH, HCG or synthetic analogs are used to induce precocious spawning in many aquaculture species.

Manipulating photoperiod and temperature is used to control timing of reproduction and induce spawning out of season.

Providing appropriate spawning substrates helps control reproduction.

Inducing sterility using techniques like triploidy is used for genetic containment and improved production in aquaculture.

Conclusion

The success of finfish and shellfish in generating progeny is determined by a multitude of biological and environmental factors that are closely tied to their reproductive cycles. Effective management and conservation efforts depend on an understanding of these reproductive dynamics, especially in light of continuous environmental changes and human impacts on aquatic ecosystems. The complex interactions between reproductive cycles and environmental conditions require ongoing study in order to create management plans for fish and shellfish populations in a world that is changing quickly.

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