3 Life History and Early Development of Fishes

Xinjun Chen and Bilin Liu

Abstract

The study of life history of fish is one of the important contents of fishery biology. The life history of fish refers to the life course of individual fish from fertilized eggs to adult fish, and then to aging. The life cycle of fish can be divided into several different developmental stages. Each developmental stage has its own characteristics in morphological structure, ecological habit, and relation with environment. The development process has its own particularity because of the difference of fish species and ecological type. The early stage in the life cycle of fish, that is, from eggs to young fish, is the sensitive period when the fish population is the largest and the death rate is the highest. How much it remains will determine the generation and recruitment of fish. Therefore, it is of great practical significance to study the rule of fish early development in order to clarify the change of fish population and to develop the resource multiplication and protection. This chapter describes in detail the life history of fish and the division and characteristics of the development period, the classification of the life history types of fish, the types of fish eggs, and the morphological characteristics and identification of larvae and juveniles. Moreover, the environmental factors affecting larval survival were also analyzed. The emphasis of this chapter is to master the division and characteristics of different stages of the life cycle of fish and to master the morphological characteristics and identification of eggs, larvae, and juveniles. Mastery of the above knowledge will be of great importance for future research and management in the fields of fishery resources and fishery ecology.

Keywords

Life history of fish · Early development of fish · Egg · Larvae · Juvenile

Abbreviations

PH *pondus hydrogenii*

3.1 Life History of Fish and Their Life Spans

3.1.1 Life History and Division of Developmental Stages

The life history of a fish is its entire life from a fertilized egg to an adult fish to senescence, and this process is also known as the life cycle. The life history of fish can be divided into several

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different developmental stages. Each developmental stage has its own characteristics in terms of morphology, ecological habits, and connection with the environment. The developmental process of fish differs depending on the fish species and ecological type.

The life history process and its developmental stages are described as follows, using the vast majority of oviparous osteichthyes as examples (Yin 1995):

1. Embryo stage. This is the period when individual fish develop within the egg membrane. The embryo stage begins when the sperm enters the pore of the egg membrane and the sperm-egg union process is completed. This period is characterized by the development of the embryo being confined to the egg membrane, and therefore, it is also called the egg development stage. The embryo is entirely dependent on the yolk for its nutrition and is associated with the environment, mainly with respiration and predation by enemies.
2. Larval stage. This is the period when the fry hatch out of the membrane and change from developing inside the egg membrane to developing outside the egg membrane, before the mouth is opened, and this stage is endogenous in nature (relying on yolk and oil globules) and changes based on the internal environment of the parent to developing directly in the external environment. When the embryo hatches out of the membrane, it enters the pup stage. The ex-hatchling is transparent, blood is often unpigmented, eye pigment is partially formed or unformed, each fin is membranous and finless, the mouth and digestive tract are incompletely developed, and there is a large yolk sac as a source of nutrition. This stage is also known as the yolk sac stage pups, or prelarva. Unlike the embryonic stage, which is still dominated by respiration and defense against predation by enemies, the yolk sac stage pups begin to acquire the ability to avoid enemies and behavioral characteristics. Thereafter, as the young develop further, eye, fin, mouth, and digestive tract functions are gradually formed; gill development begins; roving patterns are established; and the young begin to obtain food from the outside world. At this stage, young fish are generally pelagic in the same water layer, dissolved oxygen conditions improve, and contact with the outside world gradually shifts to nutrition and protection from enemies.
3. Juvenile stage. This is the period when the body shape rapidly approaches that of an adult fish. The juvenile stage is marked by the disappearance of juvenile characteristics such as transparency, the initial formation of fins, and, in particular, the beginning of the scale formation process. Early juvenile fish generally still live a planktonic life and only at a later stage do they shift to the inherent lifestyle of each group. Contact with the outside world during this period is mainly for nutrition purposes and defense against enemies. At this stage, the digestive organs develop qualitatively into the basic types of adult fish, and the stomach, intestine, pyloric pendulum, etc. reach the type and number inherent to each "species." The complete development of the scutum and the completion of metamorphosis are the signs that this stage is ending. A major feature of the ecological habits of this period is the significant increase in clustering.
4. Young stage. This stage represents the fastest growing period in the life of an individual, and the appearance of a fish at this stage is identical to adult fish in body shape; however, the markings and coloration are still in the process of change. At this stage, all scales are formed, the fins and lateral lines are fully developed, and body color, markings, proportion of various parts of the body, and habitat habits are consistent with those of adults, and at this point, the fish enter the juvenile stage. The few species that are ovoviviparous or fecund are often produced from the mother as juveniles. During the juvenile stage, the gonads are not yet developed, and secondary sexual characteristics are not obvious or are absent. This period is usually a period of rapid growth, and as the fish grow rapidly,

the adaptive relationship with the external world becomes increasingly weaker in terms of defending against enemies, natural mortality decreases, and nutritional relationships become increasingly important.

5. Immature stage. This is the period when the morphology is identical to that of the adult fish but the gonads have not yet matured, and this is generally the period of transition from juvenile fish to sexually mature fish.
6. Mature stage. The adult stage begins when the gonads first mature. Mature individuals are able to reproduce in the appropriate season and reproduce offspring; if there are secondary sexual characteristics, they have already appeared at this time. Some large and medium fish that reach sexual maturity late do not yet have mature gonads when they reach food size, so they are called food fish. Another extremely important relationship between this stage and the outside world, in addition to nutrition, is reproduction. Most of the nutrients consumed by an individual are used for gonad development and accumulation of reserves of fat and other substances for offspring needs during migration, overwintering, and reproduction. Natural mortality is minimized, while fishing mortality increases sharply. Reproductive capacity develops, and secondary sexual characteristics develop during a certain season of the year when reproductive development takes place.
7. Aging stage. This stage has no clear boundaries. It is generally the period when sexual function begins to decline, fertility decreases significantly, and growth in terms of length is extremely slow. The nutrients consumed by a fish are mainly used to sustain life and accumulate energy substances such as fat to maintain metabolic activities in case of an urgent need. In unfished waters, natural mortality rates begin to rise again.

Studies have concluded that individual development in fish, in general, proceeds in a continuous and progressive manner. However, the transition from one developmental stage to another is often accomplished in an abrupt manner within a fairly short period of time. This means that at the various developmental stages, fish undergo slow and gradual changes, such as the accumulation of material, without experiencing essential changes in morphology, ecology, and physiology. When this gradual change has reached a certain point, a fish body often completes a sudden change to another developmental stage within a short period of time, sometimes in just a few hours, when the morphology, ecology, and physiology of the fish body have all experience essential changes. Thus, fish of the same species at different developmental stages maintain a certain degree of independence in their morphology, ecology, and physiology, as well as in the way they relate to the external environment, and this independence is expressed in very different ways among different species and ecological types of fish.

3.1.2 Types of Fish Life Histories

During the long evolution of fish, the specific environment in which they live and their inherent morphological, physiological, and ecological characteristics have led to differences in the lengths of the life cycles of various species of fish. Some sturgeon species are known to live for hundreds of years, while small tropical fish have a shorter life span; some gobies even live for only a few months. The life cycles of different populations of the same species also tend to vary markedly; for example, the life cycles of the Daiqu, Min-Yuedong, and Naozhou groups on the Chinese coast are approximately 30 years, 12 years, and 9 years, respectively.

In general, the life cycle of fish lengthens with increasing geographical latitude; i.e., fish living in tropical low-latitude waters have a shorter life cycle than those living in midlatitude and high-latitude waters. Since there are more significant differences in ecological habits between fish with long life cycles and those with short life cycles, the life cycles of fish have been further classified into three different types based on studies (Chen 2014; Chen and Liu 2017).

1. Single-cycle fish. Single-cycle fish are sexually mature at 1 week of age, reproduce only once in their lifetime, die after giving birth, and consist of only one age class; examples of single-cycle fish are silverfish (*Protosalanx hyalocranius*), yellowfin goby (*Acanthogobius hasta*), etc. For single-cycle fish, the reproductive population consists entirely of recruitment, and essentially all individuals who participate in reproductive activities die afterwards. Therefore, the number of recruitments each year determines the number of reproductive groups, and the abundance and failure of generations profoundly affect the population size. Therefore, this type of fish has more dramatic population size changes, and its variability is large. Intensively fished, the stock is vulnerable not only to destruction but also to recovery.
2. Short-cycle fish. Although short-cycle fish can sexually mature repeatedly, they have a short life span and simple age groups, and examples of short-cycle fish include Japanese scad, sardines, anchovies, and some common small fish. However, the population structure and timing of sexual maturity vary considerably among species. The variability in their numbers is often large, which also means that fish resources are vulnerable to damage, such as overfishing. However, with adequate management measures, stocks can be easily restored.
3. Long-cycle fish. Some large and medium carnivorous fishes, such as large yellow croaker and bastard halibut, have a long life cycle, a large number of repeated spawning events during their lifetimes, and a complex age structure, and their resources change relatively smoothly from year to year, with a moderate process of change and a small range of change; however, the rate of recovery is also slow after the destruction of this type of fish resource.

The main significance of the different life histories of fish, which are inherent biological characteristics of individual species, is that they serve as basic information for studying population characteristics and determining the number of fish in a population and their dynamics of change. With the development of and improvements in fisheries resource science, research in this area has become even more important, and a large number of research results have been obtained.

3.1.3 Longevity

The durations of the early stages of individual fish development are usually much shorter than the durations of the later stages. Early developmental stages are usually completed in a few days to a few months, while later developmental stages are related to longevity. Life span is the amount of time that a fish lives, and it depends on the genetic characteristics of the fish and the external environmental conditions where it lives. In nature, only a very small number of adult fish produce offspring that can complete their entire life history and live their physiological life span, while the vast majority of fish cannot complete their entire life history due to unsuitable external environmental conditions. The life span of a fish is called its ecological longevity.

Various fish species have different life spans, and their individual sizes vary. Generally, long-lived fish are large individuals; short-lived fish are small individuals. The differences in the life spans and maximum sizes of different fish are very large. The largest known fish in the world is the cartilaginous fish living in the ocean, the whale shark (*Rhincodon typus*), which can reach 18–20 m in length and weigh over 10 tons, and its life span is unknown. Among bony fishes, species of sturgeon (Acipenseridae) and paddlefish (Polyodontidae) experience longevity and are large in size. The European sturgeon of the Caspian and Black Seas are reported to reach 9 m in length, weigh approximately 1.5 tons, and live to be >100 years old; Chinese paddlefish (*Psephurus gladius*) in China is the largest freshwater fish in the world, with a maximum individual size of 7 m, a weight of over 1 ton, and a typical life span of 20–30 years, with a maximum life span of over 100 years. However, some fish of the family Gobiidae and Scopelidae, Japanese killifish, and silverfish only live for 1 year or less. Most small and medium cephalopods also only live for 1 year or less. These species generally die after reproduction. The smallest known fish in the world is the goby (*Trimmatom nanus*) living in the Philippines, with sexually mature individuals measuring only 0.75–1.15 cm (Chen 2014; Chen and Liu 2017).

Although the lengths of the life spans of fish vary greatly between species, the vast majority of fish live between 2 and 20 years, with approximately 60 percent of them living between 5 and 20 years, no more than 10 percent living for more than 30 years, and approximately 5 percent living less than 2 years. There are many species of Chinese freshwater fish that live 2–4 years; anadromous salmon generally live 3–6 years; many medium and large freshwater fishes, such as black carp, grass carp, silver carp, and bighead carp, generally live 7–8 years. Few fish live more than 10 years old, but some can live up to 15–20 years. In comparison to other fish species, sturgeon fish species have longer life spans, generally reaching 20–30 years of age, with sexual maturity occurring only at 10 years of age or older. Marine fishes have shorter life spans, such as anchovies that generally only live to 3 years old, but large yellow croaker *Larimichthys crocea* off China can live up to 29 years old (Chen 2014; Chen and Liu 2017).

Different geographical populations of the same species of fish have different life spans. For example, the maximum life span of the large yellow croaker inhabiting the coast of Zhejiang, China, is 29 years; those living off the coast of Fujian and Guangdong can live up to 17 years, while those living in the eastern waters of Hainan Island live only to 9 years old. This difference is the result of the influence of different living environments on the life cycles of the populations. Another example is the maximum body length of herring populations in Icelandic and Norwegian sea areas that can reach 37–38 cm and live to 22–23 years old, while herring living in the English Channel, North Sea, and Baltic Sea have a maximum body length of 20–32 cm and a maximum age of 10–13 years old; Kuril Islands herring length and age are between those of the above two populations, with a maximum body length of approximately 35 cm and a maximum age of 15–17 (Chen 2014; Chen and Liu 2017).

3.2 Early Development of Fish

3.2.1 General Characteristics and Processes of Early Fish Development

The early stages of the fish life cycle, from egg to juvenile, are sensitive periods when fish numbers are greatest and mortality is highest, that is, when the rate of change in fish numbers is highest. The amount of its residuals will determine the amount of occurrence and replenishment of fish generations. Therefore, it is of great practical importance to conduct research on the early developmental patterns of fish to elucidate the changes in fish populations and to carry out resource enhancement and conservation. Taking dotted gizzard shad *Konosirus punctatus* as an example, we briefly describe the main morphological characteristics and ecological habits during its early development (Fig. 3.1).

Dotted gizzard shad is a species of herrings with a long, oval, laterally flattened body that is approximately 20 cm long and is found from India to the East Indies and in Korea and southern Japan. Dotted gizzard shad is distributed along the coast of China and is a pelagic fish in China's coastal waters, preferring to inhabit coastal harbors and estuaries at depths of 5–15 m. It can live in both seawater and salty water and sometimes can enter freshwater without dying. It spawns offshore and in estuaries and feeds on phytoplankton and zooplankton, many algae species, shellfish, crustaceans and copepod larvae, foraminifera, sand shell ciliates, etc. Sometimes, it also feeds on benthic organisms, plankton, and small crustaceans.

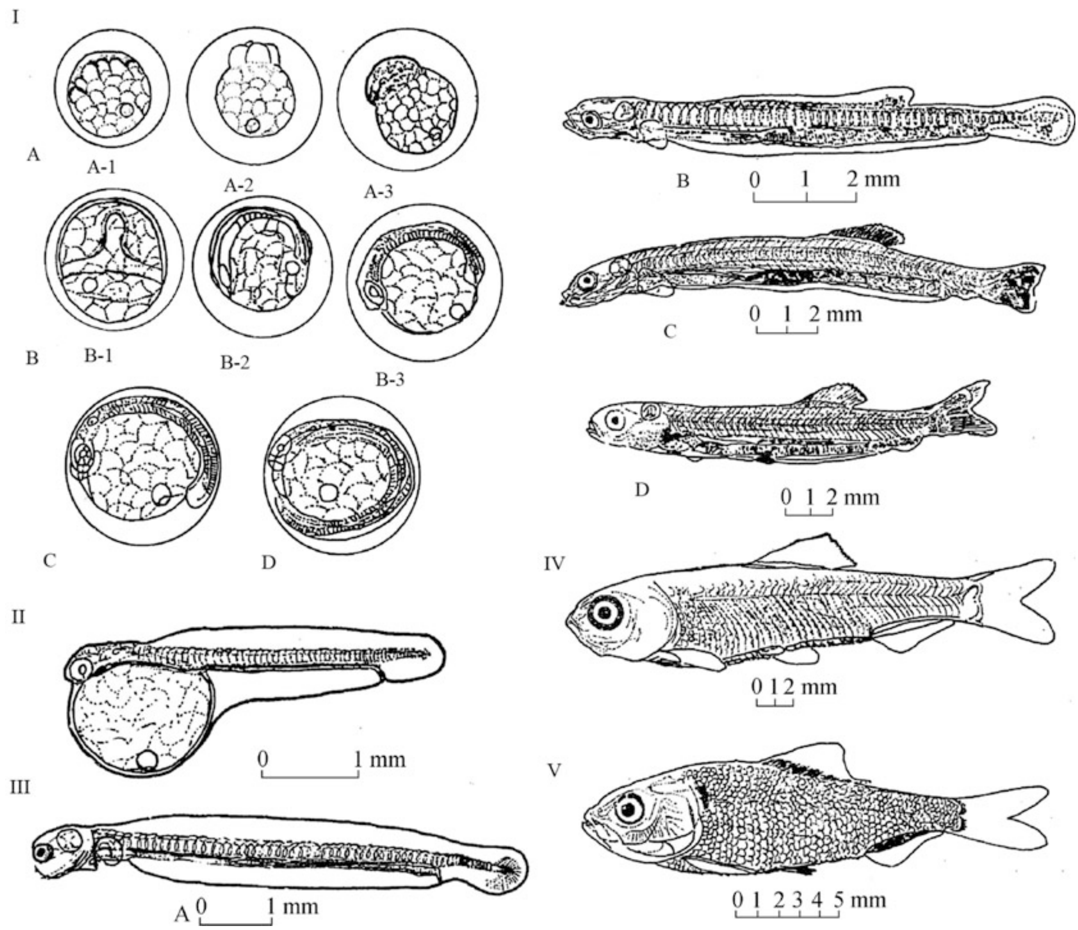

Fig. 3.1 Map of early development of dotted gizzard shad in the Yellow Sea and Bohai Sea (Chen 1997)
Stage I – intraovarian development: *A* oogenesis stage, *A-1* unicellular phase, *A-2* quadruplet phase, *A-3* early embryonic phase, *B* protointestine formation stage, *B-1* postembryonic phase, *B-2* optic vesicle phase, *B-3* phase of closure of embryo hole, *C* embryo formation stage, *D* hatching stage. Stage II – early juvenile. Stage III – late juvenile: *A* oocyst disappearance stage, *B* dorsal fin bar emergence stage, *C* anal fin bar emergence stage, and *D* ventral fin bar emergence stage. Stage IV – juvenile stage. Stage V – young stage

(1) Egg stage. The gizzard shad had round, floating eggs with smooth, colorless, and transparent membranes, with a diameter of 1.15–1.55 mm. The eggs are yellowish and transparent, covered with reticulated textures and containing a light brownish red oil ball, with a yolk diameter of 0.8–1.0 mm. The development of fertilized eggs can be divided into the following four different developmental stages (developmental water temperature of 15.5–18.0 °C):

1. Oogenesis stage. The period from the fertilized egg to the end of the blastocyst stage. It is characterized by one single-celled organism that undergoes frequent divisions to become a multicellular body at the blastocyst stage. This stage lasts approximately 10–12 h, with the one- to four-celled early segmented embryo stage lasting approximately 3–4 h.
2. Protoderm formation stage. This stage starts from the beginning of protointestinal action until the closure of the embryonic pore. This stage continues for the longest time and has more complex changes, such as mesodermal differentiation and the

appearance of neuroectoderm and myotomes, and it takes approximately 18–22 h to complete this stage.

3. Embryo formation stage. This stage occurs from the formation of the tail bud to the beginning of the heart beating. This stage is characterized by the separation of the progenitors of the major organ systems and the differentiation of tissue structures and the beginning of the appearance of pigment cells. The duration is approximately 13–16 h.
4. Incubation stage. This stage occurs from the time the heart starts beating to the time the embryo breaks the membrane and hatches. The duration is approximately about 6–8 h. It is characterized by significant growth of the embryo in terms of length, with accelerated growth of the tail bud in particular; separation of the head from the yolk; the emergence of hatching glands; and the constant contraction and oscillation of the embryo body within the egg membrane, which is about to break the membrane for hatching. At this point, the embryonic stage ends, and the duration of this stage is 51–57 h.

(2) Juvenile stage. The whole length of the first hatchling of dotted gizzard shad is only 0.4–4.0 mm and 52 (44 + 8) muscular segments. There is a well-developed yolk sac that is transparent and sparsely pigmented. The young fish float on the surface and swim in waves occasionally. When the water temperature is 18–22.6 °C, the fish body appears with the pectoral fin bud, melanin increases, and the yolk sac is gradually absorbed. By the time the mouth is first opened, the intestinal canal is obvious, and after 3 days, the full length of the fish is 5.5–6 mm, thus ending the juvenile period. The fry also swim in the water with a supine to vertical posture to vertical upside down, and finally, they began to turn flat, entering the late juvenile stage.

(3) Late broodstock stage. From this time onwards, the fry are transformed into a period of exogenous nutrition. Because of the complex metamorphosis of the fry and its long duration, this stage can be divided into the following four specific stages (developmental water temperature of 18.0–28.20 °C):

1. Yolk sac disappearance stage. This stage involves 4–5 days into hatching with the full length of this stage at 5.5–6.5 mm and 55 (43 + 12) muscular segments. At this time, the fish is elongated, the mouth is obvious, the intestinal lumen folds are visible, and the young fish turns to wavelike flat swimming. Ingestion of tiny organisms such as yeast begins.
2. Dorsal caudal fin primordia and fin emergence stage. This stage is entered 6–10 days after hatching. The fish are at full length at 6.5–8.5 mm or 10–11 mm (post), with 54 (43 + 11) muscular segments. The lower jaw exceeds the upper jaw in length at this time. The auditory capsule reaches its maximum, the anal and caudal fins each have a tuft of melanophores, and the dorsal and caudal fin primordia appear. By the time the dorsal and caudal fin bars emerge, two clumps of melanin also appear on the posterior edge of the head. The fry are feeding on bivalve, such as trochophore.
3. Anal fin primordium and fin emergence stage. This stage is entered 12–16 days after hatching. The full length at this stage is 10.5–11 mm (pre) or 11–14 mm (post), with 52 (42 + 10) muscular segments. When the anal fin primordium appears, the melanin of the fish increases, but except for the deepening of the anal pigment tufts, pigment bands have not yet formed at the upper and lower margins of the intestinal canal. Twelve dorsal fin strips and 12 anal fin strips appear, the pigment at the auditory capsule has become a "\ /" type pigment tuft, and the caudal fin also begins to divide into upper and lower lobes. At this stage, bivalve larvae, marine copepods, and their larvae are consumed in large numbers.
4. Ventral fin bud and ventral fin stripe emergence stage. This stage is entered 18–23 days after hatching. The full length

at this stage is 15.5–17 mm (pre) or 17–20 mm (post), with 50 (41 + 9) muscular segments. When ventral fin buds appear, 15–16 dorsal fins and 13–15 anal fin bars appear, and yellow pigment spots appear on the mid-axis part of the fish. With the appearance of ventral fin bars, the mid-axis yellow pigment spots gradually become yellow pigment bands, and the swim bladder starts to inflate. The number of odd fins also stabilizes (16–18 dorsal fins and 12–19 anal fins). At this stage, in addition to feeding on copepods, the fry also feed heavily on haloarchaeal larvae during artificial breeding, which results in strong feeding and rapid growth.

(4) Juvenile fish stage. The fry enter this developmental stage approximately 28 days after hatching, and the water temperature is 23–25.0 °C. The body height of the 22 mm fry increases significantly, and the odd and even fins resemble those of adult fish, reaching a fixed number (dorsal fins 16–17, anal fins 22–24, pectoral fins 15, and ventral fins 7). The prismatic scales appear, and the body is gradually opaque, which is the stage of juvenile fish. When the full length reaches 30 mm, the body length reaches 25 mm, the muscular segments reach 19 + 14, and juvenile development is complete. When scales begin to appear and the body is greenish green on the back and silvery white on the ventral side, the fish has reached the late juvenile stage. At this time, the fry are large and active, and they begin to feed in groups. In addition to swallowing copepods in large quantities, they also strongly feed on artificially fed brine shrimp larvae.

(5) Young stage. After approximately 35 days, the fry reached 36 mm in length and 30 mm in body length. Scales cover the body surface, the fins at the posterior end of the dorsal fin begin to lengthen, and the black spot above the posterior gill cover is not yet obvious; that is, they have entered the young stage. This is the end of the early development of dotted gizzard shad.

The morphological and ecological characteristics of the early development of fish vary from species to species, especially the descending riverine eel, the deep-sea monkfish, and the bottom-dwelling flounder and other fishes, whose early developmental morphology differs greatly from that of the dotted gizzard shad, but they usually go through the abovementioned major developmental stages and have the abovementioned basic characteristics. Therefore, it is possible to identify a wide variety of young and juvenile fish in the ocean by following their patterns and observing them carefully.

3.2.2 Implications for Research on Early Development in Fish

Synthesizing the state of national and international research, the significance of research on eggs and young individuals can be summarized into the following four areas:

1. Eggs and young fish are used as the object of study to learn about embryonic development and the morphology and classification of juvenile fish and their growth, mortality, physiology, and ecological habits. The reason for this focus of study is that an egg, whether it is floating, sinking, or adhering, and its development and hatching, from an almost passive yolk sac-bearing young fish to the passive drifting prefish that depends on the yolk sac for nutrition to a later young fish that can swim freely and can actively suck and feed, and even further to a young fish that can swim on the surface of the water body or reside on the bottom, have several morphological, physiological, and developmental stages with different characteristics such as their ecology.
2. The ecology of marine waters (or freshwater) is studied in terms of studying eggs and juvenile fishes as predators and indicators to evaluate the role of pollution.
3. As a breeding object, in addition to studying fry needs related to aquaculture, it is also

necessary to study the selection of eggs and young of good species.

4. In terms of natural resource recruitment or fishery forecasts, studying the growth and survival numbers of eggs and juvenile fishes provides the basic data for measuring the size of parental resources and forecasting the recruitment, so spawning ground surveys are important information for conducting accurate resource forecasts and analyses.

To integrate morphology, function, and environment, the theory of morphological developmental stages of fish can be summarized as follows: (1) the individual development process of fish can be divided into many small developmental stages according to their morphological characteristics; (2) within one developmental stage (based on a certain body length change), there is usually only quantitative growth and no qualitative changes in morphology and ecology, but when moving to the next stage, almost all organ systems grow; and (3) in each developmental stage, fish have a special relationship with their environment, and their morphological characteristics are the result adapting to the environment.

Therefore, it is of great importance to conduct in-depth research on the life cycles of fish, to determine the interrelationship between each developmental stage and the environment and to elucidate the basic laws of their life activities for exploiting fishery resources, scientifically managing, and stocking.

3.3 Morphology and Identification of Eggs and Juvenile Fish

3.3.1 Morphological Structure and Identification Points of Fish Eggs

(1) Morphological Structure of Fish Eggs

The egg is a highly specialized cell with specific adaptations for fertilization, embryonic development, and nutrition, and its structure consists of the following components:

1. Ovum. The membranes are located in the outermost layer of the egg, protecting the oocyte from external factors and maintaining the egg in a certain shape, acting as a barrier to the external environment to ensure proper development of the embryo. The thickness and configuration of the egg membrane vary depending on the species and the conditions under which the cells mature.

The surface of the egg membrane is generally smooth, clear, and hornlike, but some species have special structures on the egg membrane, such as Rajiformes (skates, etc.), where the ovoid shape is very large and covered with a horny eggshell. The largest eggshells are 180 mm long and 140 mm wide and have a boxy, spiral shape, often with curling filaments wrapped around the outside of the eggshell on algae or rocks to provide a stable incubation environment. Lizard fishes have wrinkled or irregularly fragmented egg membranes. The egg membranes of deep-sea luminous fishes have many triangular columnar protrusions, and the protrusions vary by species. The eggs of *Cypselurus agoo* are sticky, with thick egg membranes and 30 to 50 rice-like strips on the surface, by which the eggs attach to the seaweed (Figs. 3.2 and 3.3). The egg membranes of *Trichiurus lepturus* are pale red. The egg membranes of Japanese sardinella are slightly light blue.

2. Yolk. A yolk is a special protein that is formed from the vesicles of egg cytoplasm and is a nutrient required for embryonic development. The size of a yolk is generally related to the length of time an embryo has been developing. Embryos with large yolks take longer to develop, while those with small yolks take less time to develop.

A yolk can be various colors, ranging from light red to pale green, but the vast majority of yolks are yellow and transparent and opaque. The shape of a yolk varies with the amount of yolk and is often finely granular in eggs that are not

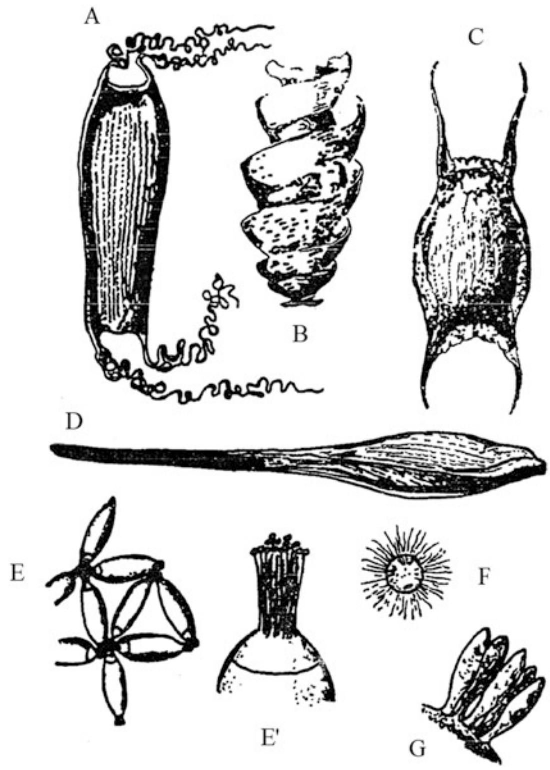

Fig. 3.2 Morphology of marine fish eggs (Chen 1997) *A* Brownbanded bamboo shark, *B* tiger shark, *C* yellowing flying fish, *D* eggshell of ratfish, *E* egg of Pacific hagfish, *E* animal pole of one egg, *F* needlefishes, and *G* black goby

very rich in yolk and spherical in eggs that have many yolks and a large egg mass. The amount of yolk content and its distribution determine the manner of subsequent oogenesis and the size of the divisions. Depending on the amount of yolk and the location of the yolk distribution, the eggs can be divided into four types: even-yolked, inter-yolked, medium-yolked, and telangiectatic eggs.

The surface structure of a yolk varies according to the species; some are uniform; others have a cracked surface, e.g., irregular reticulated cracks on the yolk surface of dotted gizzard shad. The surface of the yolk of Carangidae is neatly cracked in the form of vesicles, and the yolk of the milkfish *Chanos chanos* has small, finely arranged dots.

3. Oil globules. A special component of the eggs of many species of Scleractinian fishes is the small globular body containing fat that is surrounded by a protoplasmic film, which not only is a nutrient store for floating eggs but also acts as a "float" to keep the eggs in a certain layer of water; however, it is only a nutrient store for sinking eggs.

Generally, the oil globules are round and spherical, but some species have deformed oil globules that occur during development. Some eggs contain only one oil globule (e.g., mackerel), while others contain multiple oil globules of different sizes (e.g., shad and *Coilia*) or more and smaller oil globules (e.g., puffer, *Tetraodon fluviatilis*).

Some species have no oil globules, although they are floating eggs, such as those of the lizard fish and *Fistularia villosa*. In addition to the differences in the number of oil globules between various species, the color of the oil globules varies, from pale yellow to dark green and orange, but they are generally very transparent.

4. Ooplasm. The ooplasm is the cytoplasm (protoplasm) of the egg, which is the main part of the oocyte body and is the center of nutrition and vital activity of the oocyte. The amount of

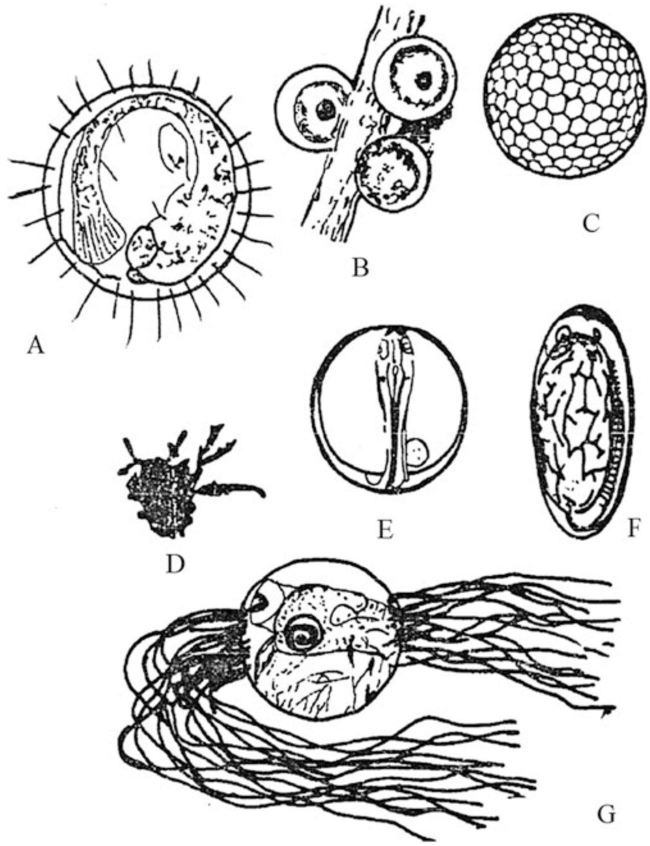

Fig. 3.3 Morphology of marine fish eggs (Chen 1997) *1* flying fish eggs, *2* pufferfish eggs; *3* striped sole eggs, 4. greenlings eggs attached to seaweed, *5* silver croaker eggs, *6* anchovy eggs, and *7* *Cypselurus agoo* eggs

cytoplasm within a fish egg determines the size of the cell.

5. Egg nucleus. Additionally, as the reproductive nucleus or nucleus, the nucleus is directly related to egg cleavage, growth, and metabolism. The nucleus is usually round or rod-shaped and relatively large, and its location is not visible under normal conditions, sometimes on the lateral side of the egg, sometimes in the middle, but usually on the more polar side where the cytoplasm is abundant.
6. Polarity. The polarity of an egg is due to the uneven distribution of yolk in the ooplasm (cytoplasm). The end with more yolk is called the vegetative pole, and the end with less yolk or no yolk (i.e., the end where the cytoplasm is mainly concentrated) is called the animal pole. When resting, the animal pole always faces down, and the vegetative pole faces up. A fertilized egg forms the germinal disc at the animal pole, and cell division begins at the germinal disc, at which point the position of the animal pole is more easily seen.
7. Yolk gap or perivitelline cavity. This refers to the space between the oolemma and the oocyte proper. The perivitelline cavity of a fertilized egg will increase in size as the sperm enters and swells with water absorption.

(2) Types of Fish Eggs

Fish egg types can generally be divided into two main categories according to ecology and morphology. The following two types of eggs can be distinguished on the basis of their different specific gravities and properties, the presence or absence of adhesion, and the strength of adhesion:

1. Floating eggs (pelagic eggs). The specific gravity of this type of egg is less than that of

water, and its buoyancy is produced in various ways. The eggs of many fishes contain oil globules that lower the specific gravity, and some have large egg diameters and small grains but large yolk gaps that facilitate floating. In this way, the eggs float in the water or on the surface after they are produced and drift with the wind and current. China's major marine economic fish, such as large yellow croaker, small yellow croaker, *Trichiurus lepturus*, mackerel, and red snapper, lay floating eggs.

Most floating eggs are nonadhesive and float freely. However, there are a few species whose eggs adhere together, some in egg bands and some in egg sacs or egg masses; for example, the eggs of monkfish are attached to a band of egg sacs and float on the surface of water, and some of these masses can be several meters long.

2. Sinking eggs (demersal eggs). The specific gravity of this type of egg is greater than that of water, and the eggs sink to the bottom of the water after they are produced. The eggs are generally larger than those of floating eggs, with smaller yolk gaps. Demersal eggs can be subdivided into (1) nonattached demersal eggs, the eggs sink to the bottom or in pits dug by the parent fish and are not attached to objects, and (2) attached demersal eggs, of the attached type, there are two types: adherent and attached. The egg membrane, which is attached to the egg, has its own mucus and is attached to other objects; the attached egg has an attachment on it and is fixed to other objects by the attachment. (3) Filamentous twining eggs. These eggs are spherical, without oil globules, with a thick egg membrane and 30–50 filaments on the surface, which are approximately five to ten times as long as the diameter of the egg, and they are distributed at the two poles of the egg membrane, by which the eggs attach to the seaweed. The number of fish with sinker eggs is small.

Some fish eggs have intermediate characteristics between those listed two egg types, with slightly sticky egg membranes. For pikes living in brackish water and freshwater, eggs float in seawater with a salinity of 0.015 or more, are suspended in the middle layer of water in semisaline water with a salinity of 0.008 to 0.01, and sink to the bottom in freshwater. The eggs of other fish species are distributed over a wide range of depths; for example, the eggs of some species of the cod can be trawled in the range of 1000–2000 m in the deep sea and in the 100 m deep sea, which makes it difficult to classify them.

(3) Points for Identification of Fish Eggs

Due to the diversity of fish species and their variability during early development, the identification of fish species can be difficult, and it is difficult to find a systematic and practical searchable list of eggs and young fish. To identify eggs, the first step is to know and understand the species and their spawning period, the area of the sea where it occurs, and the season during which it occurs to determine the possible species of eggs and the "stable" morphological and ecological characteristics of the eggs at different developmental stages, especially the external characteristics of the eggs. Other identification characteristics are briefly listed below:

1. Types of fish eggs. Eggs can float (free eggs, e.g., gizzard shad, or cohesive eggs, e.g., monkfish) or sink (attached eggs, e.g., *Hemiramphus far*, or nonadherent eggs, e.g., salmon and trout).
2. Egg size and shape. Egg diameter size and shape are one of the main bases for identifying fish species, such as anchovy and goby whose eggs are oval; however, the former has the free-type floating eggs, while the latter has sunken eggs with fixed filaments that attach to the spawning chamber on the wall of the chamber hole (*Acanthogobius hasta*) or empty shells (*Tridentiger trigonocephalus*). For example, the species in the Yellow and Bohai Sea have the same round floating eggs; however, *Trichiurus lepturus* eggs have diameters of 1.79–2.20 mm, and small yellow croaker in the Bohai Sea eggs have diameter of 1–1.65 mm.
3. Egg membrane characteristics. The egg membranes of marine fish are usually thin,

smooth, and transparent. However, some species have hexagonal fissures and netlike patterns on their egg membranes (striped sole); some have small spinelike protrusions on their egg membranes; others have finer filaments on the surface of their egg membranes (*Cypselurus agoo*, large silverfish, etc.).

4. Yolk structure. The structure and morphology of yolks vary depending on the abundance of yolk content; e.g., most floating eggs have evenly distributed, transparent, slightly yellow yolks, but the dotted gizzard shad, etc. have yolks with irregular reticulate textures due to coarser yolk grains.
5. Oil globules. The presence or absence of oil globules within eggs and their number, size, color, and distribution are important in identifying eggs; e.g., bastard halibut has only one large oil globule. Striped sole, on the other hand, has dozens of small oil globules.
6. Yolk gap. The size of a yolk gap (perivitelline cavity) varies among fish of the same species or different species.
7. Embryo characteristics. After the formation of an embryo, which is the more "stable" stage of the egg's external morphology throughout its development, a very important period for identifying an egg occurs because the shape and size of the embryo body and the early and late appearance, shape, and distribution of pigmentation are the most important basis for egg identification.

3.3.2 Young and Juvenile Fish and Their Identification Points

The main points and methods for identifying young and juvenile fish are the same as those for eggs. Knowledge of the shape and characteristics of fry at each stage of development is the basis for identifying young and juvenile fish.

1. Young fish stage. The shape of the fish, the shape of the yolk sac, the position of the oil bulb in the sac, the position of the anus, the shape of the fin membrane, the number of myotomes, and the shape, color, and distribution of pigmentation are the main characteristics for identifying species of young fish.
2. Late juvenile fish. The length of the fish, the ratio of body length to each part, the position of the anal opening, the number of myotomes, the type and arrangement of pigmentation, and the shape and position of each fin primordium or fin strip are the main characteristics for identifying species of late juvenile fish.
3. Juvenile stage. In addition to the same points of identification for the late juveniles, more attention should be given to countable traits and measurements such as the shape of the head and tail, the number of fins, and the number of vertebrae (Fig. 3.4).

The three most common methods currently used nationally and internationally in studying morphological changes in marine fishes at various stages of development are briefly described as follows:

1. Artificial intelligence method. Information obtained on an adult fish by artificial intelligence can be compared with naturally collected samples and used to identify the species. Species identification with this method is reliable.
2. Dynamic study method. A large number of specimens of different sizes are used to follow the developmental stages in sequence, to compare morphology and organ development, and to classify them according to morphological aspects.
3. Static research method. This research method focuses on the integrity of a single individual and traces the main features of the morphological developmental stage of an individual. It has the advantage that even if only a few specimens are available, they can be identified and classified. However, the use of this method requires familiarity with the morphological characteristics of juveniles of various families, genera, and species.

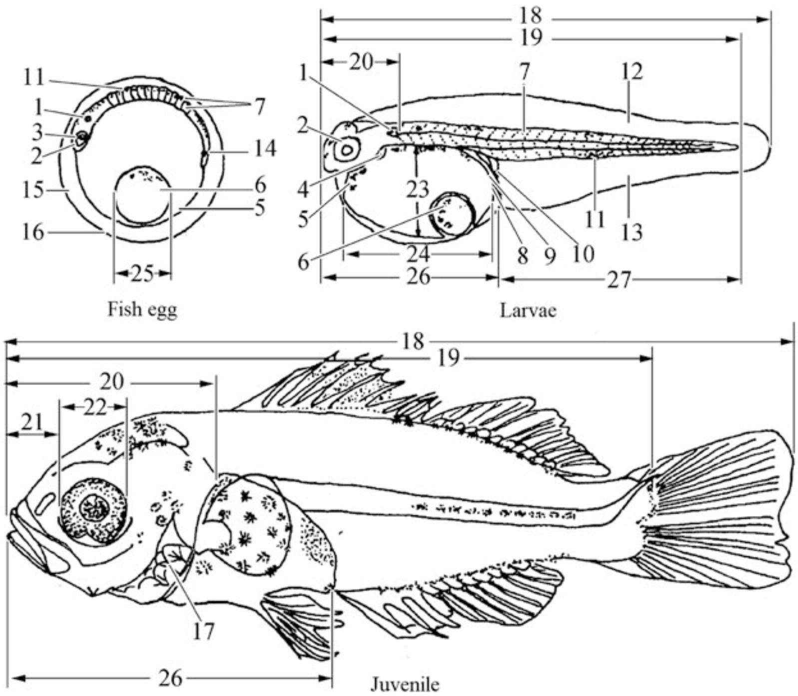

Fig. 3.4 Site and name of determination points for eggs, juveniles (Zhang et al. 1985)
1 auditory sac, *2* eye, *3* crystal, 4 Heart, *5* yolk (egg), yolk sac (litter), *6* oil bulb, *7* myotome, *8* anus, *9* digestive tract, *10* bladder, *11* melanopsin, *12* dorsal fin membrane (dorsal fin fold), *13* ventral fin membrane (ventral fin fold), *14* Gram's vesicle, *15* perivitelline space, *16* egg membrane, *17* anterior gill cover bone outer margin spine, *18* full length *19* body length, *20* head length, *21* muzzle length, *22* eye diameter, *23* yolk sac short diameter, *24* yolk sac long diameter, *25* olecranon diameter, *26* anterior anal distance, and *27* posterior anal distance

Embryos in live eggs, live young, and juvenile fish often exhibit bright colors, but soon after death, the colors fade; melanocytes are all that remain, and the time of appearance, number, size, shape, and location of melanocytes are the main basis for identification of the species. When live specimens are observed, all kinds of pigment cells are described, while for fixed specimens, melanocytes are mainly described.

3.4 Analysis of Environmental Factors Affecting the Survival of Juvenile Fish

Changes in the distribution and abundance of marine fish spawners and eggs in the pelagic zone and their correlation with changes in environmental factors are one of the main bases for predicting replenishment and its variability. Quantitative environmental factors, mainly water temperature, salinity, depth, current speed, wind, and waves, as well as water pollution and pH (pondus hydrogenii), have direct and indirect effects on the distribution and survival of fish eggs and juvenile fishes. Eggs and juvenile fishes are the youngest and most vulnerable stages of the fish life history process, and any unsuitable environmental conditions can cause significant mortality. For example, the development and growth of various species of eggs and juvenile fishes require a suitable temperature range, and unsuitable changes in water temperature will retard their development and even lead to mortality; their distribution is also necessarily limited by isotherms. If currents carry them to waters that are not suitable for development, then this will lead to their death. This idea has gained wide acceptance as an important factor in the mortality during egg and smolt stages and is also supported by many studies. Changes in environmental physicochemical factors are usually considered to have the most dramatic and pronounced effects on the number of offspring and the number of replenished populations of spawning fish in estuaries. For example, the Argentine shortfin squid *Illex argentinus*, which is distributed in the southwestern Atlantic, lives for 1 year, dies after spawning, and has no remaining population, and its resource recruitment varies drastically yearly. It was found that its stock recruitment is very closely related to the marine environment of the spawning grounds during the previous year. The higher the range of water temperatures suitable for spawning and its specific gravity during the spawning period, the higher the stock recruitment is the next year. This scenario has been confirmed during actual production.

Environmental physicochemical factors are of particular importance because they influence the distribution and density of prey organisms and thus the distribution and survival of juvenile fishes. It has been found that the survival of juvenile fishes is dependent on the presence of small dense areas of prey, or "patches." Once a school of juvenile fishes finds a prey "patch," it has the ability to stay in the "patch" to feed. The distribution of young fish and their prey organisms in the ocean is not random but rather unevenly distributed in dense areas. The results of many studies support this notion.

New methods and tools for investigating the distribution of eggs and juvenile fishes in the ocean, their population changes, and their correlation with environmental factors are constantly being developed, and it is now possible to use tools such as ocean satellites to infer the concentration areas of eggs and juvenile fishes in the ocean and to sample quantitatively at different water depths. Therefore, the study and determination of the effects of various environmental factors (e.g., water temperature, salinity, flow rate, and pH value) on juvenile development, survival in natural habitats, etc., in conjunction with actual field surveys, are of great significance and practical guidance for exploring the causes of early fish mortality, protecting natural resources and developing indoor factory nurseries.

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