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Models of reproduction, development, and growth in invertebrates

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Abstract
Growing and producing offspring are inherent to all living organisms. The life cycle of an invertebrate species typically consists of four distinct stages: egg, larva, juvenile, and adult. In spite of this, there can be variations in this life cycle. Marine invertebrates are composed of microscopic, free-living dispersive stages, which may feed (planktotrophic) or not feed (lecithotrophic). This paper outlines a simple model to explain how reproductive patterns have evolved in marine benthic invertebrates.

Keywords: Invertebrate, reproduction, development, growth

1. Introduction

There is an enormous diversity in the life histories, morphologies, and reproduction strategies of invertebrates on earth due to their success in occupying most ecological niches on the planet (Subramoniam, 2018) [1]. The majority of benthic marine invertebrates pass through a complex life cycle involving a benthic juvenile-adult phase and an extended pelagic larval or embryonic phase (Pechenik, 1999; McEdward, 2000) [2, 3]. Generally, biphasic life histories are seen as the ancestral pattern, while linear life histories are seen as primitive. Abbreviated or entirely lacking pelagic phases are considered to be phylogenetically anomalous (Jägersten, 1972; Nielsen, 1998, Nielsen and Beaumont, 2009; Wowor *et al*., 2009; Pereira and García, 1995) [4, 8]. In the Dendrobranchiata group, only fertilized eggs are released into water column where all larval and embryonic development occurs (Anger *et al*., 2015) [9].

There are two main reproduction modes for invertebrates: As a result of the fusion of male and female gametes, an offspring may inherit a full set of genes from a single parent or a subset (asexual reproduction) (Bell, 1982) [10]. As compared to asexual reproduction, sexual reproduction is usually considered more advantageous (Bell, 1982; Schön and Van Dijk, 2009) [10, 11]. A developing organism, apart from being incompletely developed, may also appear to be more or less different from an adult organism. Without knowing the origin of the eggs or following the young through their entire development, it would be impossible to tell if the young and adult are the same species. Larvae transform into adults by undergoing a conspicuous metamorphosis (Giese and Pearse 1974, Hill, 1991, Mc Edward and Janies 1993, Nielsen 1998) [12 -14, 5]. Larvae growing in planktonic environments undergo sigmoid growth and metamorphosis at a certain size. It is assumed that the fecundity of adults is inversely proportional to the size of their eggs, and that the mortality of planktonic larvae is independent of density and dependent on size. Evolutionarily stable metamorphoses or smaller eggs may depend on larval growth rate and death rate. It is clear that there is a very high rate of larval mortality during the prolonged larval phase as a result of the exposure to mortality factors. In order for larvae to disperse efficiently and avoid mortality factors, their behavior is extremely important (Queiroga and Blanton, 2005) [15]. Here is a simple model of how invertebrates with marine benthic environments evolve their reproduction patterns.

2. Patterns of larval development

Sexes separate/ hermaphrodite/reversal of sex-cross fertilization are the rule. Eggs laid, free/attached/ in clusters- held in brood pouch- young hatch out at early stage-metamorphosis or may be similar to adult.

2.1 Porifera: No special organ, reproduce sexually by ova and spermatozoa and asexually by budding. Gemmaulation and formation of asexual larvae

2.2 Coelentrata
Dioecious or hermaphrodite, fertilized egg develops into a ciliated free swimming larva

2.2.1 Larval forms
The planula: Asexual reproduction by budding and fission, which may be transverse or longitudinal. And another method called pedal laceration which is common among sea anemones.

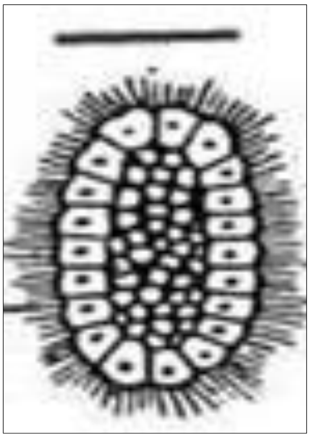

Fig 1: Planula. (Scale, 0.1μ)

2.3 Platyhelminthes
Hermaphrodite, complex reproductive organs. Self-fertilization, asexual reproduction by fragmentation, regeneration, fission and budding.

2.4 Annelida
Hermaphrodite or sexes separate. Sexual reproduction, external fertilization. A special phenomenon called Epitoky Occurs in some polychaetes during breeding season, when they undergo considerable changes in structure and behavior. Sexually mature individuals are known as Epitoks and original non-sexual ones are as Atokes e.g. *Heteroneries*. Oligochaetes, copulation, cross fertilization or eggs in cocoon.

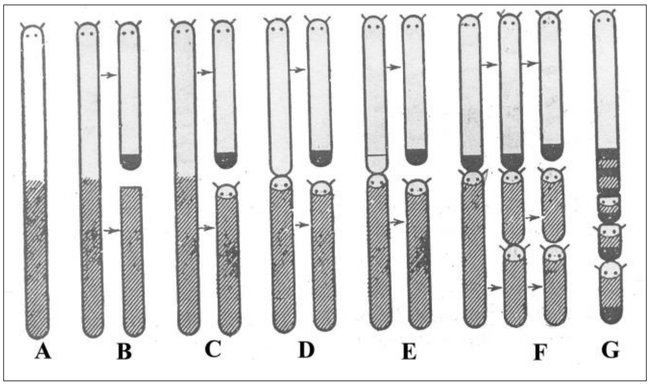

Fig 2: Budding and stolon formation in polychaetes.

Gamete bearing part striped, pygidial regeneration black (Modified after, Herlant- Meewis, 1964) [16]. A, heteronereid or heterosyllis (*Odonolosyllis*); B, epitokal region breaking off (Palolo worms); C, epitoke regenerating a head after liberation (*Syllis gracilis*); D, formation of head before liberation of epitoke (*Syllis amica*); E, formation of new head and pygidium of stock before liberation of epitoke (*Syllis vittata*); F, formation of a second stolon before liberation of the first; G, formation of multiple stolens (*Autolytus*).

Larval forms
2.4.1 Trochophore
Larval form of annelids is trochophore. This organism has a ring of cilia in the front of the mouth that gives it a spherical shape. Anterior apical plate (sensory area). Asexual reproduction by fragmentation (Fig.3).

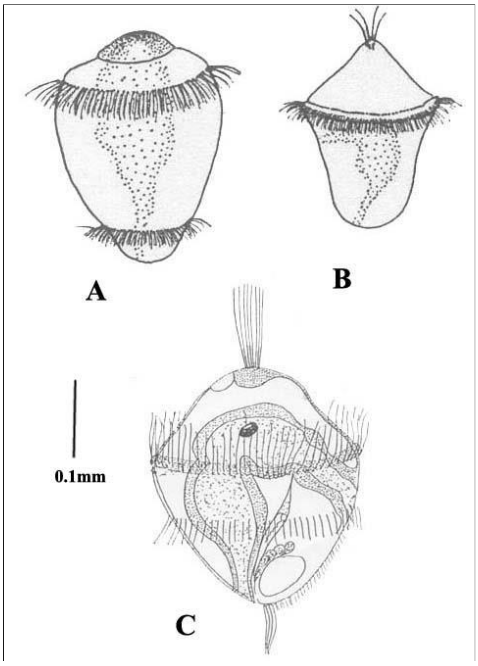

Fig 3: Trochophore larvae of annelids

2.5 Arthropoda

Sexes typically separate, few crustacean hermaphrodite, sexual dimorphism common. Appendages of male may modified during copulation.

Larval forms

2.5.1 Crustacea

Variety of larval form, often several per species.

2.5.1.1 Nauplius

Found in most marine crustaceans and a few malacostracans. Minute oval or pear shaped larva, three pair of appendages. Antennules, antennae and mandibles, a median eye (Nauplius eye), thorax unsegmented (Fig. 4A, B).

2.5.1.2 Metanauplius

Is the later nauplius instar, first stage of post embryonic growth and results by the process of moulting and growth? Cephalothorax oval. Its posterior portion is markedly segmented, with the rudiments of new appendages present. Abdomen ends in a caudal fork (Fig.4C).

2.5.1.3 Cyprid

Only in wikipedia, enclosed in a bivalve carapace, remarkable metamorphosis (Fig. 4D).

2.5.1.4 Protozoea

Postnupliar stages in penaeidae. Distinct cephlothorax and abdomen, undeveloped eyes, seven pairs of appendages. Later stages have stalked eyes, rostrum and separate uropod (Fig. 4E).

2.5.1.5 Mysis or schizopod stage

Found in penaeid. Pereiopods are biramous and setose, abdomen and uropods well developed (Fig. 4F).

2.5.1.6 Zoea

First motile stage in brachyuran development, characterized (in most species) by the presence of a long dorsal spine and the spine like rostrum, some also have lateral spines. Carapace developed, mandible become functional. Abdomen has six segments and terminates in a caudal furca (Fig. 4G).

2.5.1.7 Megalopa

Found in brachyuran. Cephalothorax is broad, unsegmented and crab like. Large stalked eyes well developed appendages (Fig.4H).

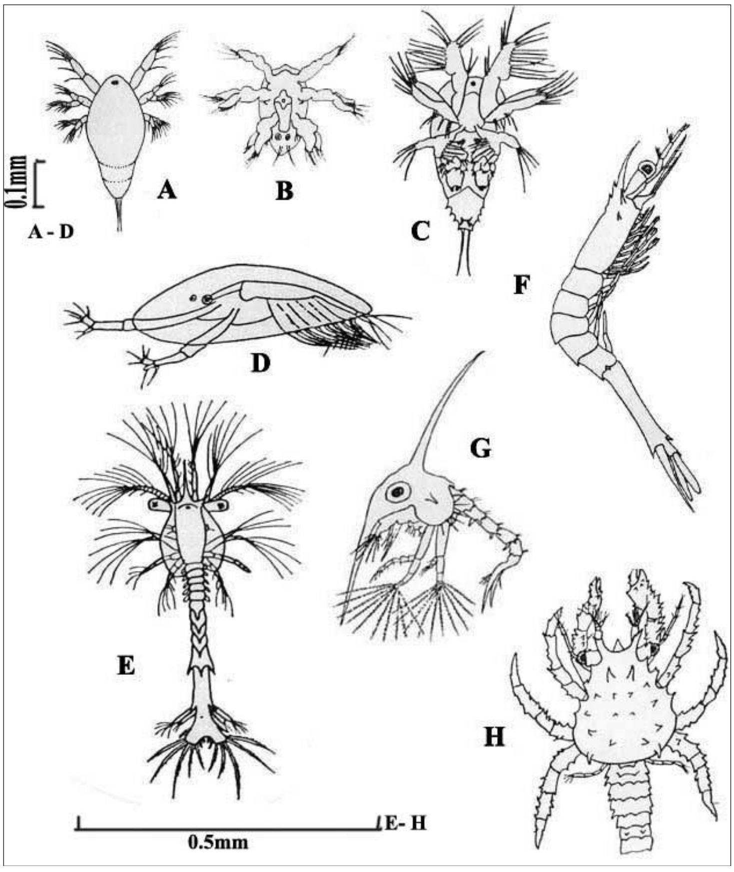

Fig 4: Arthropods larvae: A & B, Nauplius stage; C, Metanauplius stage; D, Cyprid stage; E, Protozoeal stage; F, Mysis stage; G, Zoea; H, Megalopa.

2.5.1.8 Phyllosoma

Larvae of lobster. Unique larva, only in spiny lobsters. Transparent, thin, very broad leaf like body, demarcated into head, thorax and abdomen. Carapace oval, abdomen unsegmented (Fig.5A).

2.5.1.9 Glaucothoe

Only in hermit crab, structure like megalopa. Miniature adult except straight (Fig.5B).

2.5.1.10 Erichthus

(Stomatopod) Carapace covers greater part of body, median and paired eyes, and five pairs of cephalic appendages. Segmented thorax bear five pairs of biramous appendages (Fig.5C).

2.5.1.11 Alimaa

Special of squilla. Transparent elongated body, short and broad carapace, head appendages present. Abdomen six segmented with four or five pairs of appendages (Fig.5D).

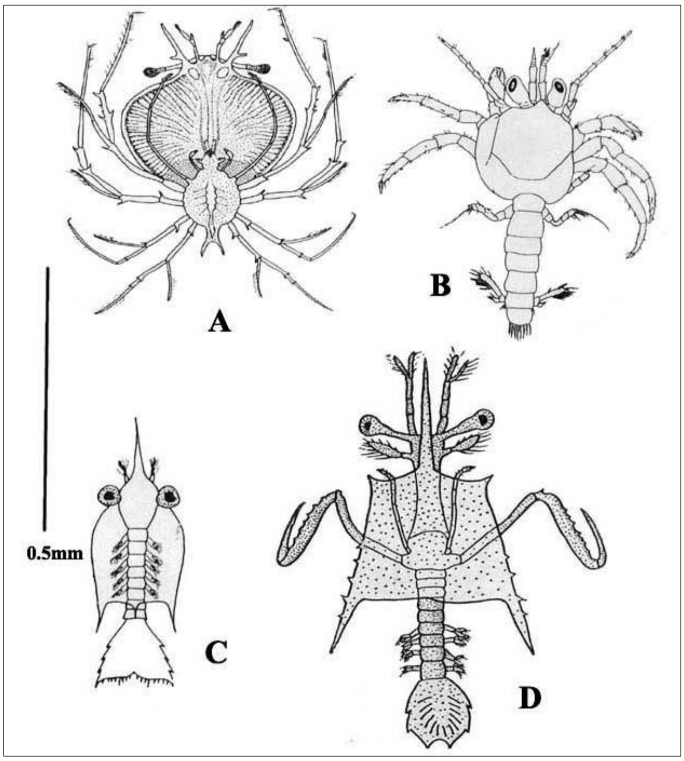

Fig. 5. Arthropods larvae: A, Phyllosoma larva; B, Glaucothoe larva; C, Erichthus larva; D, Alima larva.

2.6 Mollusca

Sexes may be separate, hermaphrodite. Some species start as male then hermaphrodite later female. Development may be direct as in cephalopods, the young ones hatches out from egg. Indirect development has different larval stages.

Larval forms

2.6.1 Trochophore

Found in annelids and most groups of mollusks. Pear shaped larvae measured about 0.5 mm in length. Body is divided into two unequal parts by a circelet of preoral cilia, the protofreh or velum. Upper part is prostomimum and lower part bearing mouth and anus. The Preoral part large and Convex with an apical plate bearing long cilia, the apical cilia (Fig. 6A).

6.2 Veliger

Planktonic, free swimming. Tupical gastropod larvae. Preoral ciliated velum consists of two large semicircular lobes bearing long cilia for locomotion. A small shell and foot is also present (Fig. 6B, C).

2.6.3 Glochidium

Bivalve's larvae small version of adult. Shell two triangular, porous valves, united dorsally. The valves clap by the action of adductor muscle. A glandular pouch in the mid ventral body secretes a long stick thread, the provisional byssus. Foot is not developed (Fig. 6D).

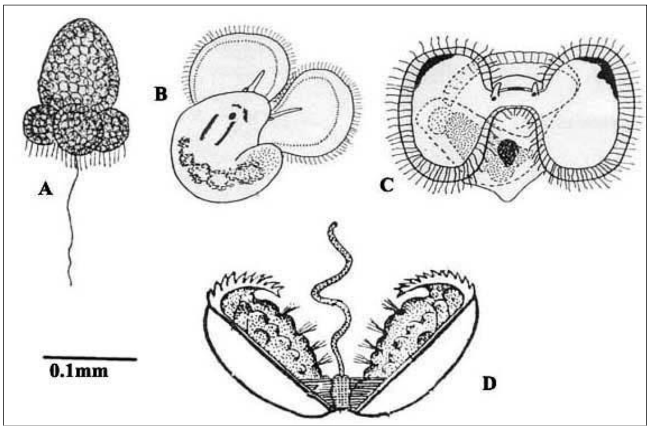

Fig 6: Molluscan larvae: A, Trochophore larva; B, Veliger larva; C, Glochidium larva.

2.7 Echinoderm
Sexes separate, free swimming bilaterally symmetrical larval stages, remarkable metamorphosis, radially symmetrical adult. Some species viviparous, and few reproduce asexually by transverse fission.

Larval forms
2.7.1 Bipinnaria
(Asteroid larvae) three lateral lobes or projections on each side of the body bordered by ciliary bands, free swimming (Fig. 7A).

2.7.2 Brachiaria
Is the second stage of larval development in many starfishes? Bipinnaria develops into Brachiolaria, three short arms are added to preoral lobe, one median and two lateral (Fig. 7B).

2.7.3 Ophiopluteus
(Ophiuroidea) four pairs of armes posterolateral arms are longest and directed forward (Fig. 7C).

2.7.4 Echinopluteus
(Echionidea) six pairs of arms some may have four or five pairs, posterolateral arms very short (Fig. 7D).

2.7.5 Aurieularia
(Holothuroidea) small transparent larvae. Preoral ciliated loop help in swimming (Fig. 7E).

2.7.6 Doliolaria
It is the second larval form of holothuroidea. Auricalaria transform into a barrel shaped doliolaria. Ciliated band broken into three to five flagellated rings (Fig. 7F).

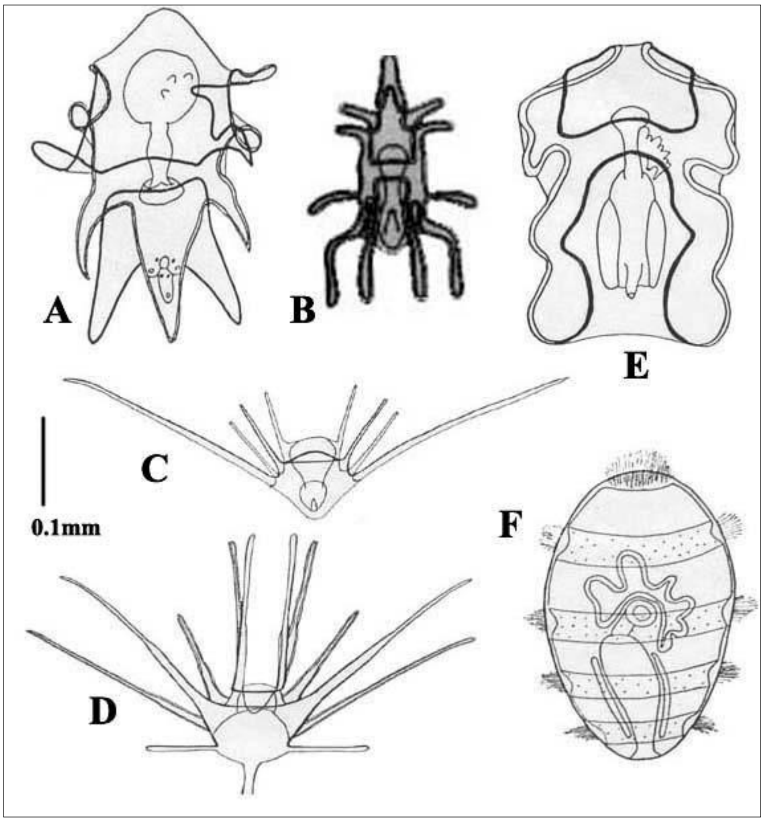

Fig 7: Echinoderm larvae: A, Bipinnaria larva; B, Brachiolaria larva; C, Ophiopluteus larva; D, Echinopluteus larva; E, Aurieularia larva; F, Doliolaria larva.

3. Concluding Remarks
It is crucial for the conservation and management of species to understand their life cycles in light of the impacts of global climate change and other human activities. Many species of larvae are capable of delaying their metamorphosis unless specific environmental cues are present, which increases the likelihood that larvae will eventually metamorphose into suitable habitats (Pechenik 1990, Morgan 1995) [17,18]. Despite dispersal away from favorable habitat, larvae may partially compensate for the negative effects of diffusion via selective metamorphosis and postponing metamorphosis without appropriate triggering indications (Thorson 1950, 1966) [19, 20]. In spite of this, not all larvae will survive to metamorphose competently, and not all who do survive will eventually find suitable cues or metamorphose into habitats that are appropriate for them. Free-living larvae might therefore be eliminated from life cycles by minimizing dispersal from the natal population. In order to avoid the disadvantages of long-distance diffusion, larvae are either not produced or they metamorphose approximately immediately after release into the plankton (Christiansen and Fenchel 1979, Jackson 1986, Olson and McPherson 1987, Young *et al.* 1988, Davis and Butler 1989, Stoner 1990, Bhaud and Duchêne 1996, Turon and Vazquez 1996) [21, 28].

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