Bioresources and Environment 2023, 1(3) 120-155.

Content list available at BioEnv

Bioresources and Environment

Journal homepage: www.bioenvuitm.com

Frog Metamorphosis: A Review of Metamorphic Stages, Developmental Progression, and Influential Factors

Khairunnisa Shahrum Nizam[1], Nor Azliza Ismail[1], Farah Ayuni Farinordin[1], Nur Amalina Mohd Izam[1*]

[1]*Faculty of Applied Sciences, Universiti Teknologi MARA Pahang Branch, Jengka Campus, 26400 Bandar Tun Abdul Razak Jengka, Pahang, Malaysia.*

Received August 30, 2022. Accepted in revised form October 25, 2023
Available online October 30, 2023

ABSTRACT. Frog (Order: Anura) is the most diverse, diversified, and ubiquitous of the three extant amphibian orders under the class Amphibia. They are distributed across the globe, with the exception of the polar regions, some marine islands, and very dry deserts. The life cycle of a frog is a fascinating event in which they go through an incredible transition known as 'metamorphosis' as they grow from frogspawn to adult frogs. Although extensive research has been done on the life cycle and metamorphosis of frogs, there is little comparative information on different variances in its unique transformation traits during evolution among the families and factors influencing these transformational processes. This review focuses on identifying the metamorphosis process in distinguished frog families by comparing stages of development, morphological and physiological changes, and the factors that influence their growth or metamorphosis and timing. The study was conducted by reviewing about 130 sources of previous scientific publications, primarily accessible through online journal and article publishing platforms or databases such as Google Scholar, Scopus, and Web of Science. Subsequently, significant differences within the frog families have been recorded. Hormones, environmental cues, and the availability of resources are all intrinsic and extrinsic variables that influence these developmental stages. Further studies are needed to undertake a comprehensive study that includes complete monitoring of frog metamorphosis and development at all phases. This would provide important insights into the genetic and molecular factors that control the timing and success of frog metamorphosis, which could also improve the understanding of the delicate interplay between environmental cues and developmental processes by doing such studies.

Keywords: Anura, Environmental effects, Frog development, Gosner stage, Life-cycle.

INTRODUCTION

Frog (Class: Amphibia, Order: Anura) is a diverse group with more than 5,450 species and live in most aquatic and terrestrial habitats from lowlands to mountaintops, although their inability to physiologically adapt to saltwater has largely excluded them from estuarine and marine habitats. The name of the order, Anura, refers to an obvious group characteristic: the absence of tails in adults (Vitt and Caldwell, 2008). The life cycle of a frog is a fascinating process in all of biology, full of striking transformations and developmental changes (Gilbert, 2000). The life cycle is divided into three stages: egg, larva, and adult, with each stage featuring major developmental changes. Most frog eggs hatch into tadpoles, which have a long, finned tail and both internal and external gills, no leg, specialised mouthparts for herbivore feeding and a highly specialised internal anatomy. Their appearance, morphology and behaviour are completely different from adult frogs. Anurans' (frogs and toads) metamorphosis is a complex process that involves major changes to practically almost every organ in their body. This process is induced by hormonal changes in the tadpole's thyroid gland (Fu et al., 2018) in order to prepare them from aquatic organisms to terrestrial existence (Vitt

*Corresponding author: amalinanurizam@uitm.edu.my
E-mail address: 609-4602000

and Caldwell, 2008).

Food supply, temperature, water level, and the presence of competition and predators all influence the timing of metamorphosis (Rose, 2005). Moreover, environmental variables experienced during the tadpole stage can change an amphibian's post-metamorphic glucocorticoid response to stress. For example, higher temperatures accelerate development more than the growth rate, resulting in smaller heads in post-metamorphic frogs (Tejedo et al., 2010). The growth and development of tadpoles into fully developed adult frogs during the metamorphosis is a fascinating biological occurrence which entails a series of complex physiological and morphological changes. Although much data regarding the life cycle and metamorphosis of frogs has been extensively studied, there is little comparative information about distinct differences in its unique alteration features during evolution within the families and the underlying variables or factors that influence this transformational process.

Despite extensive searches throughout databases, libraries, and scientific papers, little information about the species has been catalogued or thoroughly investigated. During the data collection, it became clear that information about certain Anura species is very limited and almost none to be found. For instance, in a previous study for *Bufo spinosus* (Spiny Toad), the development of the frog was not completely recorded since the study was only aimed at the locomotors and behavioural trait and its morphology changes during tadpole stages (Cheron et al., 2021). Moreover, in terms of the frog morphological changes, there was a small amount of information regarding their features throughout the observation. The duration of the metamorphosis also was not mentioned because it was not the main objective of that study.

Furthermore, a study of six Neotropical poison-dart frogs by Klein et al. (2021) also has an incomplete record of the frog development due to the main focus of the study was on larval development and morphology. Despite that, Klein et al. (2021) mentioned the complete development of two of the six species used as specimens in the research. Given the thorough information on the two species, it could be tempting to presume or extrapolate that the additional species experience similar egg and hatching stage morphological changes. This notion, however, can be misleading. The lack of data has already resulted in competing thoughts and discussions over the comparability of these developmental phases within the genus. Individual species within a genus may portray diverse developmental and morphological characteristics. The absence of specific information on four of the six species suggests an incomplete picture of their developmental trajectories. Hence, complete observation of their morphology and development during metamorphosis should be recorded, thus giving insight into their biological processes, evolutionary variations, and convergences within the family.

Therefore, the main objective of this review is to collect data on the unique morphological modifications that occur during the transition from embryo tadpole to adult in different frog species. The review tries to uncover common patterns and variances in the metamorphic process across different species by evaluating prior studies. Besides, we are also aiming to investigate environmental and physiological factors that influence the timing and progression of metamorphosis in frogs. The review tries to identify the important components that have been found and explored in relation to frog metamorphosis.

METHODOLOGY

Data collection

To review related published articles, a series of searches was conducted using the database platforms Scopus, Web of Science, Google Scholar, and ProQuest. The references cited in the articles and research papers are also considered, as these could provide additional sources. After two months of searching, we collected 130 papers that contained information on 32 species representing 14 anuran families.

Sampling method

The articles were selected based on uses of the Gosner staging system, a widely used anuran developmental staging method that allows for comparisons of development in different species with diverse morphologies and metamorphosis process durations. Moreover, in order to gather information sources, the main combination keywords used for searching related studies were “metamorphosis”, “larvae/tadpoles”, “anura”, “frog development”, “abiotic” and “biotic”. The biogeographic region of the selected articles was not a major consideration in the selection process. However, the findings of the studies on distinct anuran metamorphosis processes and factors were analysed in relation to the native habitats and biogeographic regions of the species studied. In terms of the methodology used in the research articles, both laboratory and naturalistic observations are accepted for this review.

FROG LIFE CYCLE AND DEVELOPMENT

The life cycle of frogs is typically divided into four stages, which are egg, tadpole, froglet and adult frog. Before the egg stage starts, the female and male will undergo courtship behaviour (Jr. et al., 2009). The objective of courtship in frog reproduction is to attract and look at potential mates', species identification, and genetic quality (Dreher and Pröhl, 2014; Stückler et al., 2019). Male frogs initiate contact by announcing their existence and readiness, typically calling from a potential breeding location such as a swamp, pond, or stream (Rowley, 2017).

Egg stage

The life cycle of a frog begins with the egg stage when females enter the water and are grasped by males in the process known as amplexus, during which eggs are externally fertilised. While the female lays eggs, the male releases seminal fluid containing sperm over the eggs to fertilise them. The jelly layers absorb water and enlarge once the eggs are fertilised (Jr. et al., 2009). These fertilised eggs, surrounded by transparent protective nutrient jelly, are referred to as frogspawns (Murakami, 2021). In some species, male paternal care can endure from oviposition to hatching and often for several days after hatching. Males are present during pre-hatching development and protect the eggs against predators, increasing offspring survival (Townsend et al., 1984). Meanwhile, for biphasic frogs with no parental care, the egg begins dividing repeatedly between a few minutes to a day after fertilisation, depending on the species and temperature. This process is known as cleavage (Harris, 1992). After several hours, cleavage results in the creation of a hollow mass of cells known as a blastula. The blastula will then gastrulate over the next few hours. For the next several days, the gastrula elongates and a tail bud forms. In general, frog eggs hatch five to ten days after fertilisation (Harris, 1992).

Tadpole stage

For the tadpole stage, the egg hatches into a tadpole, typically around three weeks after fertilisation (Teasdale and Hendry, n.d.). At first, the tadpole clings to vegetation with its sucker, obtaining nutrients from the remains of its yolk sac. Soon, however, the tadpole begins swimming with its tail fin feeding on algae and organic particles with its toothed mouth. The gills are external at first, and shortly after that, an operculum grows over the gill. On the left side, a spiracle forms as an exit for water drawn through the mouth and past the gills (Harris, 1992). The development of tadpoles into small frogs takes roughly 14 weeks. Transforming from toad tadpoles to toadlets takes around four months (Chapman, 2020).

Froglet stage

The next noticeable change in the tadpole is the development of the hind legs, which is usually complete after two or three weeks. Several days later, the forelimbs emerge from the gill chambers they have been developing (Harris, 1992). Harris (1992) also stated that the emergence of forelimbs is ostensibly triggered by a rise of thyroid hormones (thyroxine and triiodothyronine) levels and the decline of prolactin levels. This is when the tadpoles emerge to the next stage, which is froglet. This stage is also known as juvenile or young frog. The tadpole now has developed and resembles a tiny frog with a tadpole's tail. By this time, the froglet's lungs should have formed and can begin venturing out of the water. After that, the tadpole's body becomes rounder, the tail shortens, and the complete metamorphosis is reached. The tadpole has matured into a young frog. The juvenile frog will mature in around two to four years, depending on their sex and species (Sarasola-Puente et al., 2011; Schmidt et al., 2012; Upton et al., 2018). The froglet stage is essential for the juvenile frog as it transforms from an aquatic to a terrestrial lifestyle. The froglet becomes carnivorous and breathes through its moist, permeable skin and lungs (Chapman, 2020).

Adult frog stage

The adult frog stage is the ultimate stage of a frog's life cycle following complete metamorphosis and sexual maturity. The frog has developed adult features and reproductive capability at this stage and can begin the cycle again. Adult frogs have a corpulent body, projecting eyes, a tongue that is anteriorly attached, limbs that are folded beneath, and no tail (Vitt and Caldwell, 2008). Frogs have glandular skin and secretions that range from unpleasant to poisonous. In some species, frog skin colour varies from well-camouflaged mottled brown, grey, and green to vibrant patterns of bright red or yellow to warn and show their toxicity and fend off the predators (Rojas et al., 2014; Vitt and Caldwell, 2008).

STRUCTURAL DEVELOPMENT

According to Encyclopedia Britannica, structural development refers to the process by which the formation, arrangement, and modification of an organism's physical structures throughout its life cycle. It involves the development of complex body plans found in various species by considering the growth, differentiation, and arrangement of cells, tissues, and organs. During structural development, an organism develops from a single fertilised cell, known as a zygote, to a fully formed individual with specialised tissues and organs. Structural development is tightly controlled by genetic programs and environmental factors (Gilbert, 2000). Genes that regulate cellular functions and tissue connections are sequentially activated according to instructions provided by genetic factors (Padiath, 2023). Structural development can also be influenced by environmental factors like nutrition, temperature, interaction, and physical forces (Boulan et al., 2015).

Structural development in frogs includes body plan, organs, and tissue formation. The process may differ depending on the species and developmental style, such as direct or biphasic development (Zartman and Shvartsman, 2010). Body shape is predicted to differ among species for functional reasons and in relation to environmental niche and phylogenetic history (Vidal-García et al., 2014). Tadpoles have diverse morphology and ecological adaptation, ranging from small, fast-flowing streams, large rivers, puddles, ponds, and lakes to small, specialised niches such in the trunks of fallen trees, water-filled holes in standing trees, bamboo and in the axils of bromeliads and other plants (McDiarmid and Altig, 1999). For instance, a detailed description for four anuran species, *Duttaphrynus melanosticus* (Bufonidae), *Occidozyga lima* (Dicroglossidae), *Kaloula pulchra* (Microhylidae), and *Polypedates megacephalus* (Rhacophoridae) study has been reported and showed significant differences in their developmental stage for each of the species family (Köhler amd Thammachoti, 2023). Even though these studies were not based on environmental variables, the frogs (that represent different families) were collected in different areas to obtain a basic understanding of tadpole biology and conservation. The morphological changes throughout the metamorphosis of the studied frog families were compared and described by the duration of complete metamorphosis, tail length, colouration of the tadpole, mouth parts and limb growth (Köhler and Thammachoti, 2023). Therefore, environmental factors need to be considered and controlled to acquire the desired outcome because they can influence frogs' growth and development.

GOSNER STAGING SYSTEM

The Gosner stage is a staging system that describes the development stage in anuran (frogs and toads) (Gosner, 1960). The system was introduced by Kenneth Gosner in 1960 and includes 46 stages and is divided into four major phases, which is embryo (stage 1-20), hatchling (stages 21-24), tadpole (stages 25-41) and metamorph (stages 42-46) (Gosner, 1960). The Gosner stage system is useful for comparing the development of different species of anurans, which may have different development rates and sizes at different stages. For example, in a study by Traijitt et al. (2021), the somatic development stages of *Hoplobatrachus rugulosus* were identified using the Gosner stage, and the morphological characteristic changes were described according to each stage or phase. The Gosner stage system is useful in identifying and distinguishing physical characteristics and stages of development during the metamorphosis of anuran. However, this system may be unsuitable for demonstrating the development of some anuran species, especially for direct-developing frogs that hatch directly as froglets without being involved in the larval stage (McDiarmid and Altig, 1999).

METAMORPHOSIS

According to Encyclopedia Britannica, metamorphosis is biologically defined as “a striking change of form or structure in an individual after hatching or birth”. It also describes the physical changes, as well as development and differentiation, followed by changes in the organism's physiology, biochemistry, and behaviour. In an article by Bishop et al. (2006), the authors compiled several definitions of metamorphosis and provided an analysis that shows some of the key similarities. To sum up, the various conceptions of metamorphosis presented in the article, most of the authors agreed that the key elements of metamorphosis include a change in adaptive landscape, the presence of major morphological change and post-embryonic as pre-metamorphic stage (Bishop et al., 2006).

Metamorphosis commonly occurs after hatching or birth at various times, depending on the species and the surrounding environment. In that respect, the optimal duration of metamorphosis has significant variation, which ranges from hours to several months, even though the general time of the full growth cycle is around 16 weeks (Chapman, 2020). For instance, the American Bullfrog (*Lithobates catesbeianus*) can take up to one to two years to reach metamorphosis (Urbina et al., 2020). For anuran, as proposed by Gosner in his staging system, the longest phase in frog development is during the tadpole/larvae stage, where the larvae experience rapid growth and development. In comparison, in an insect such as Periodical Cicada (*Magicicada septendecim*), the longest phase of the metamorphosis is in the nymph stage, which can last for 13 to 17 years (Alger, 2013).

Metamorphosis plays a significant role in the development of an organism because it allows it to adapt to its environment, specialise in its adult stage, and create new traits and qualities that can improve its chances of survival (Britton, 2019). Furthermore, this process is also beneficial in resource utilisation efficiency and reducing the competition between juveniles and adults. This is due to the distinct ecological roles and feeding behaviour in different metamorphosis stages (Toft, 1985). For example, in anuran, tadpoles are generally thought of as microphagous herbivores that eat planktonic material, algae and small pieces of higher plants, although some species will consume available animal material (Alford et al., 2013) or when resources are scarce (Langley, 2023). Upon hatching, young tadpoles feed on the remaining yolk of their eggs for sustenance. Throughout development, they begin to able to ingest algae and phytoplankton. In contrast, adult frogs are principally carnivores which need to consume small invertebrates such as flies, moths, crickets, and worms due to their advanced gastrointestinal tract and to meet their energy expenditure for foraging activities (Brenes-Soto et al., 2018). Moreover, they also have distinct oral morphology as their feeding mechanism. Typically, an adult frog will propel its tongue out to its prey before pulling it back into its mouth along with the prey (Hou et al., 2013). In contrast, the tadpole has keratinized teeth in transverse rows on its oral discs, which it uses to scrape particles into suspension (Alford et al., 2013). Therefore, metamorphosis allows animals to have easier access to food without having to encounter intraspecific competition (juvenile and adult), which can be a huge advantage for survival (Toft, 1985).

Metamorphosis is usually attributed to a group of animals, especially insects and amphibians, some fish and numerous marine invertebrates (Bishop et al., 2006). The transition of a tadpole larva into an adult frog is one of biology's outstanding transformations. In amphibians, hormones from the tadpole's thyroid gland promote metamorphosis, and these changes prepare an aquatic organism for a terrestrial existence. The metamorphic alterations in anurans are most noticeable, and almost every organ is object to modification (Gilbert, 2000; Paul et al., 2022). The general tadpole body form has evolved into several shapes and sizes, each adaptable to a specific aquatic or semi-aquatic habitat and eating behaviour. The form alterations are quite apparent. The hindlimbs and forelimbs specialise for locomotion as the paddle tail recedes. The cartilaginous skull of the tadpole is replaced by the predominantly bony skull of the juvenile frog. The teeth used by the tadpole to tear up pond plants vanish as the mouth and jaw change shape, and the frog's fly-catching tongue muscle develops. Meanwhile, the large intestine of herbivores shortens to accommodate the adult frog's more carnivorous diet. The gills shrink, and the lungs enlarge (Gilbert, 2000).

COMPARISON OF METAMORPHOSIS AND DEVELOPMENT STAGES WITHIN FROGS’ FAMILIES AND SPECIES

Metamorphosis and development stages among frogs vary depending on their families or species. Table 1 provides an in-depth look at various metamorphosis stages observed in several frog species. The Gosner stage system is used in this table to differentiate and emphasise the significant variances and similarities in terms of time, physical traits, and ecological adaptations across different species, from the start development of eggs to the eventual emergence of adult frogs. However, some of the frog species in this table have an incomplete record of their metamorphic stage because the researchers only focused on specific stages of the frog. Therefore, it is expected that researchers will publish comprehensive papers covering all stages of frog metamorphosis and development in a future scientific journal. Such a publication would be extremely valuable to the scientific community, giving an immense amount of information on the complexities and nuances of this remarkable biological process.

Based on the table, the shortest time of frog until complete metamorphosis is in Ceratophryidae (*Chacophyrs pierotti* and *Ceratophrys cranwelli*), Leptodactylidae (*Physalaemus biligonigerus*), Bufonidae (*Duttaphrynus melanostictus*) and Microhylidae (*Dermatonotus muelleri* and *Kaloula pulchra*). This significant difference occurs because the species mentioned are usually distributed in warm and tropical regions. For instance, *Chacophyrs pierotti* and *Ceratophrys cranwelli*, two species of frogs found in the South American continent (Vitt and Caldwell, 2008), tend to reach complete metamorphosis earlier than other species of frogs. This is likely because South America is located on the equator, which means that this region receives more direct sunbeams, making the regions here hotter and warmer. Warmer temperatures have been shown to shorten the duration of frog metamorphosis. In contrast, *Bufo torrenticola*, a frog species found in Japan, has a longer metamorphosis due to the colder climate.

Furthermore, the appearance of colour patterns in larvae differs between developmental stages, demonstrating a variation in the onset of visibility. For example, most of the larvae from the Dendrobatidae, Megophryidae and Microhylidae family show the emergence of their distinguishing colour patterns or stripes during Gosner stage 35 to 42 development phases as their colouration changes until they reach complete metamorphosis. Conversely, compared to these species, other taxa only show the existence of pigmentation with no known occurrence of distinct colour patterns.

For their mouthparts, species in the Megophryidae family have very unique morphology of oral disc during the tadpole stage. Common anuran tadpoles have oval oral discs, while most of the Megophryidae family possess funnel-like or umbelliform oral discs, which are specialised to permit them to feed beneath the water surface or anchor to a substrate to stay safe during floods or other potential threats (Qian et al., 2023; Zheng, 2021).

Table 1. Comparison of metamorphosis and development stages within frog families according to the Gosner stage system

Family / Species	Phases				Duration of metamorphosis	Source
	Embryo (Stage 1-20)	**Hatchling (Stage 21-24)**	**Tadpole (Stage 25-41)**	**Metamorph (Stage 42-46)**		
Bufonidae						
Bufo torrenticola	16: Gill bulges present; anterior kidney bulges visible; early tail bud development. 17-20: Fin primordium appears; heartbeat pulsation visible; gills transformation.	24: Formation of hind limb bud	25-26: Fin becomes transparent; gills disappear 27: Beginning of feeding 31: Knee junction appears 32-41: Toes appearance; hind limbs begin to move; cloacal tail disappear; forelimbs development; total length of larva reached	42-43: Forelimbs appear; eyeball protrudes. 44: Degeneration of tail 46: Tail disappears; Complete metamorphosis.	128 days	Tanaka and Nishikawa (2022)
Bufo spinosus			25: Free swimming; feeding behaviour 30: Hind limb bud fully shaped 37: Toe development 41: Cloacal tail disappear; fully grown hindlimbs	42: Forelimb formation; tail atrophy		Cheron et al. (2021)
Duttaphrynus melanostictus	17-18: Gill bulge appears, and tail bud develops. 20: External gills elongate and visible	23: The coiled guts can be seen; tail fin develops	28: Tail fin expands; external gills disappear 29: Cloacal tube visible 33: Hind limb bud formed 36: Dorsal and ventral fins rise at tail base; toes appearance; the total length of larva obtained 41: Forelimbs appear; eyeball protrudes	28: Tail fin expands; external gills disappear 29: Cloacal tube visible 33: Hind limb bud formed 36: Dorsal and ventral fins rise at tail base; toes appearance; the total length of larva obtained 41: Forelimbs appear; eyeball protrudes	21 days	Köhler and Thammachoti (2023)
Ceratophryidae						
Chacophyrs pierotti and *Ceratophrys cranwelli*			26-23: Proxima-distal differentiation of hind limb and autopodium 37-40: Appearance of tubercles and limb growth 41: Cloacal/vent tube disappears	42: Forelimb appearance 43-46: Tail shortens and disappears	21 days	Fabrezi and Cruz (2020)

Family / Species	Phases: Embryo (Stage 1-20)	Hatchling (Stage 21-24)	Tadpole (Stage 25-41)	Metamorph (Stage 42-46)	Duration of metamorphosis	Source
Dendrobatidae						
Colostethus machalilla	17: Tail bud protrude on the yolk endoderm 18-20: Heart began to beat; external gills develop	22: External gills enlarge 23: External gills full development	25: Tail elongated and has the appearance of a tadpole with the dark pigmented body, intestine coils; and tail fin visible		19-20 days (From fertilization to hatching only)	Del Pino et al. (2004)
Ranitomeya amazonica	19: Embryonic body in larval shape; head and tail region visible; gills buds present 20: Tail elongates; gills present; vent tube bud and tail fin slightly visible	21-22: Tail and gills elongate; body size increases; ventral and dorsal fins become more transparent; denser pigmentation of body and tail; eyes visible 24: Gills reduction	25: Free-swimming and mobile tadpoles; gills absent 25-27: Hindlimb bud slightly develop 29-40: Full hindlimb development with pigmentation 41: Appearance and enlargement of forelimb buds; lateral stripes present	42: Forelimbs appear 43-46: Tail reduction and complete metamorphosis	96 days	Klein et al. (2021)
Ranitomeya benedicta			25-27: Hindlimb bud slightly visible 28-40: Toes appear; completion of hindlimbs development with pigmentation 41: Forelimbs bud and hindlimbs colour pattern visible	42: Fully forelimbs developed 43-46: Tail reduction and complete metamorphosis	114 days	Klein et al. (2021)
Ranitomeya imitator	19: Head and tail region visible; gills bud present, embryonic body in larval shape 20: Tail elongates; gill present; tail fins and vent tube visible	21-22: Tail and gills elongate; Body size increases; ventral and dorsal fin becomes transparent; denser pigmentation of body and tail region 24: External gills disappear; body and	25-27: Larva hatched; oral apparatus visible; hindlimb bud develop 28-40: Hindlimbs complete development with pigmentation and toes appearance 41: Forelimb buds present	42: Complete development and appearance of forelimbs 43-46: Tail reduction and complete metamorphosis		Klein et al. (2021)

Family / Species	Phases Embryo (Stage 1-20)	Hatchling (Stage 21-24)	Tadpole (Stage 25-41)	Metamorph (Stage 42-46)	Duration of metamorphosis	Source
		tail pigmentation and spots denser				
Ranitomeya reticulata			25-27: Hindlimb buds slightly visible, 28-40: Toes appear; completion of hindlimbs development with pigmentation. 41: Forelimbs bud and hindlimbs colour pattern visible	42: Complete development and appearance of forelimbs 43-46: Tail reduction and complete metamorphosis		Klein et al. (2021)
Ranitomeya vanzolinii			25-27: Hindlimb buds are slightly visible. 28-40: Toes appear; completion of hindlimbs development with pigmentation 41: Forelimbs bud and hindlimbs colour pattern visible; lateral stripes present	42: Complete development and appearance of forelimbs 43-46: tail resorption and reduction; complete metamorphosis		Klein et al. (2021)
Ranitomeya sirensis			25-27: Hindlimb bud visible; oral apparatus visible; sinistral spiracle present 28-40: Toes appear; completion of hindlimbs development with pigmentation 41: Forelimb buds present and hindlimbs colour pattern visible; lateral stripes present	42: Complete development and appearance of forelimbs 43-46: tail resorption and reduction; complete metamorphosis	77 days	Klein et al. (2021)
Dicroglossidae						
Limnonectes leytensis		23-25: Operculum and gills gradually disappear; initial pattern at tail appears;	26: Development of tooth rows; oral papillae forms change; limb bud develops 31: Paddle-shaped foot formed			Flores et al. (2023)

Family / Species	Phases Embryo (Stage 1-20)	Hatchling (Stage 21-24)	Tadpole (Stage 25-41)	Metamorph (Stage 42-46)	Duration of metamorphosis	Source
		differentiation of labial tooth formula; total length larvae grow	37: Individual toes started to emerge 38-40: Differential changes in individual toe length; bright patches emerge			
Heliophrynidae						
Heleophryne orientalis			28: Transparent venter, dorsal and ventral fins and equally developed; rounded tail tip; large and muscular tail; lack of jaw sheath; unpigmented oral disc with several tooth rows			Lukas (2021)
Hylidae						
Boana riojana			26: Forelimb and hindlimb buds present 34: Fins become translucent 38: Pigmentation occurs 40: Vent tube disappear 41: Forelimb bud protrude; tail shorten	42: Tail and fins begin to decrease in size; forelimbs appear 43-46: Tail reduction continues; complete metamorphosis	125-234 days	Goldberg et al. (2019)
Leptodactylidae						
Physalaemus biligonigerus	1-6: Cell division; four hours after fertilisation, the 32 cell-stage reached 7-8: Externally compact appearance acquired. Complete cleavage 15: Semicircular shape with ventral yolk mass acquired 16: Tail bud appear 17: External gill bulges appear	21-24: Development of gill, tail bud elongates; dorsal and ventral fins grow; pigment formation begins, the eyeball structure defined (Stage 24)	25: Oval stomodeum (mouth opening) with sharp edges and lower and upper lips outline; gill filaments maximum number reached 26: Operculum develop and cover the gills; coiled intestine visible 27: Hind limb buds appear 34: Appearance of pigment on the limb 37: Individual toes visible	42: Forelimbs emerge 43-45: Tail reduction 46: Complete metamorphosis; tail fully resorbed	20-24 days	Chuliver and Fabrezi (2019)
Megophryidae						

Family / Species	Phases				Duration of metamorphosis	Source
	Embryo (Stage 1-20)	**Hatchling (Stage 21-24)**	**Tadpole (Stage 25-41)**	**Metamorph (Stage 42-46)**		
Brachytsrsophrys popei			25-27,36-37: Oval and robust body; semi-transparent hindlimbs; has golden pigmented, funnel-like oral disc and terminal mouth; massive tail muscle; the body has dark brown pigment with dense white spots			Qian et al. (2023)
Boulenophrys shimentaina			25-28: Oval and flattened above body; has translucent milky white, funnel-like oral disc and terminal mouth; massive tail muscle, the body has dark brown pigment with minimal pale golden spots			Qian et al. (2023)
Boulenophyrs cf. *ombrophila*			25-27, 36: Oval and flattened body; massive tail muscle; has translucent beige, funnel-like oral disc and terminal mouth; the body and tail have semi-transparent beige and brown pattern with whitish and golden pigmented spots at lower body			Qian et al. (2023)
Boulenophrys nanlingensis			25-29, 34-35: Elongated, oval, and flattened above the body, a massive tail muscle that is deeper than tail fins; has translucent beige, funnel-like oral disc; the body is semi-transparent grey that has a pale brown pattern and pale golden spots			Qian et al. (2023)
Leptobrachium hasseltii		23: Formation of oral apparatus	25: Complete formation of oral apparatus 40: Hindlimbs formed			Eprilurahman and Maghfiroh (2020)
Microhylidae						
Dermatonotus muelleri			26-30: Limb bud present; complete oral apparatus (mouth) 31-34: Pointed foot elongate	42: Forelimbs appear 43: Dorsal fin reduction 44: Eyelids protrude and visible	25-30 days	Fabrezi et al. (2012)

Family / Species	Phases: Embryo (Stage 1-20)	Hatchling (Stage 21-24)	Tadpole (Stage 25-41)	Metamorph (Stage 42-46)	Duration of metamorphosis	Source
			35-37: Maximum larval size; toe development 38-39: Pigmentation occurs 40: Vent tube disappear 41: Nostril and forelimbs protrude	45: Tail shortens; spiracle disappears 46: Tail absents; disappearance of larval structure; complete metamorphosis		
Kalophrynus cryptophonus			26-31: The body is almost unpigmented with pinkish colour 35-39: Semitransparent skin with tail and body greyish-brown with orange speckles; tail fins slightly pigmented; spiracle unpigmented; keratinised mouthparts absent; long body pyriform with a broad and even or slightly concave snout; has long tail almost three and half times longer than the body; low tail fins		-3 days (Embryonal period) -23-24 days during hatching stage -11 days (From stage 37 to stage 46)	Vassilieva and Nguyen (2023)
Kalophrynus honbaensis			35-41: Uniformly dark brown with scarce pinkish or orange speckles on body and tail; pale underside of tail and belly; body slightly elongated; broad concave snout; long tail, almost two and a half longer than the body; tail fins moderately tall and the tip broadly acuminate		-2.5 days (Embryonal period) - 20-22 days (During hatching stage) - 13 days (From stage 38 to stage 46)	Vassilieva and Nguyen (2023)
Kalophrynus interlineatus			36-37: The body is broadly elliptical; the snout is bluntly rounded; moderate tail length, slightly longer than one and a half of the body; tail muscle weakly developed; tall tail fins and densely pigmented, greyish-brown with irregular pink or orange spots and yellow or orange speckling; body colour is dull brown with a pink or		- <1 days (Embryonal period) - 20-21 days (During hatching stage) - 13-15 days (Larval period)	Vassilieva and Nguyen (2023)

Family / Species	Phases: Embryo (Stage 1-20)	Hatchling (Stage 21-24)	Tadpole (Stage 25-41)	Metamorph (Stage 42-46)	Duration of metamorphosis	Source
			reddish marbled pattern; tail's tapering parts is unpigmented			
Kaloula pulchra	18: Gill bud appears; tail bud begins to develop. 19: Tail elongates; Fin slightly develops 20: External gills elongate and visible; tail fin visible	23: Eyes visible	25: External gills disappear; vent tube visible 27: Dorsal and ventral tail fins become transparent; coiled gut visible 30: Hindlimb bud begins to develop 39: Complete hindlimb development 41: Forelimb bud development visible under the larval skin, eyes protrude	42: Forelimb and hindlimb fully developed; pigmentation occurs and colour pattern visible 43-46: Tail shortens; complete metamorphosis	40 days	Köhler and Thammachoti (2023)
Microhyla mukhlesuri			25: Eyes is well developed; nearly transparent body; obvious mouthparts with a wide mouth; gills covered by closed operculum; single pigment cells on the body 26-30: Development of hind limb buds 31-36: Development of foot paddle 37: All toes are completely separated 40: Complete toe pads development 41: Forelimb visible under the transparent skin; mouthparts atrophy begins	42: Forelimbs emerge 43: Tail atrophy 44: Tail strongly reduced 45: Coloration and pattern develop; only a tail stub is left 46: Tail resorbed completely absent, development of colouration and pattern completed; complete metamorphosis	37 days (recorded after hatching)	Rödder and Behr (2014)
Nasikabatrachidae						
Nasikabatrachus sahyadrensis	17-18: Embryos develop on top of the yolk 20: External gills appear	22: Appearance of pigmentation visible on the dorsal surfaces 23: Tadpole can use the oral disc to stick to the substrate; has a	25: Dense pigmentation formed on the body; large white yolk remains within the body 27: Hind limb bud under triangular flap 30: Body elongates	42: Tail resorbed; flat ventral body; both forelimbs emerge, and hindlimbs muscle develop 43: Oral disc atrophy started; tail shorten; purple pigment visible	About 100 days	Zachariah et al. (2012)

Family / Species	Phases Embryo (Stage 1-20)	Hatchling (Stage 21-24)	Tadpole (Stage 25-41)	Metamorph (Stage 42-46)	Duration of metamorphosis	Source
		downward-oriented mouth	39: Reach maximum growth with hind limbs 41: Left forelimb emerges	45: Pointed snout visible 46: Tail absents; fully dark purple body; complete metamorphosis		
Odontophrynidae						
Macrogenioglottus alipioi			25: Fully formed of mouthparts; yolk sac absent; translucent body 26: Hind limb bud appears; pigment spots formed on tail and body; fully formed jaw sheath 27: Hind limb bud elongates 31: Dense dark brown colouration visible; paddle-shaped hind limb bud 32-35: Toes start to differentiate 36: Visualization of forelimbs; toes separation 37-39: Toes fully separated; hind limb covered by spots 40: Forelimb visible within the branchial chamber 41: Upper and lower eyelids appearance; vent tube absent; skin tubercles appear; mouthparts advanced degeneration; oval shaped body	42: Head differentiation; forelimbs emerge; skin thicker; lateral line and spiracle disappear 43: Tail and fins atrophy; darker and thicker skin; prominent skin tubercles 44: Adult body appearance; tail reduced to a stub 45: Skin darker		Nascimento et al. (2022)
Ranidae						
Rana leptoglossa	8: Morula achieved 13: Neural plate formation; embryo slightly elongate 15: Embryo elongation and rotation	21: Branched gills well developed; tail fins become transparent 23: Tail pigmentation begin; prominent	25: External gills disappear; start to feed; tail slightly pigmented 26: Tail length increases; appearance of hind limb bud; pigmentation becomes dense 31: Hind limb starts to appear with toes differentiation	42: Forelimbs emerge; maximum length achieved; mouth restructure 43: Angle of mouth widens; tail shorten; dorsal and ventral fins shrink	68-72 days	Saha and Gupta (2011)

Family / Species	Phases Embryo (Stage 1-20)	Hatchling (Stage 21-24)	Tadpole (Stage 25-41)	Metamorph (Stage 42-46)	Duration of metamorphosis	Source
	17: Tail bud appears at the end of embryo posterior 19: Gill buds appear and become prominent; start of head, abdomen, and tail differentiation 20: Tail elongation	external branched gills visible 24: Oral disc development	35: Five toes separated 40: Forelimb buds visible, complete hindlimbs and toes development; mouthparts atrophied 41: Cloacal tail reduced; tail reabsorption begins	44: Tadpoles start to jump; tail absent 45: Tadpoles come out from the water; body colour changes from black to brown; tail reduced to a stub 46: Tail stub disappears; well develop limbs; complete metamorphosis		
Ranixalidae						
Indirana leithii	11: Grey in colour with white yolk	22-23: No tail fins visible; cornea visible	25: Oral apparatus develops 26-39: Hind limbs develop			Modak et al. (2018)
Rhacophoridae						
Buergeria japonica	1-8: Fertilization, cleavage, and blastula formation 9-11: Gastrula formation 12-15: Neural embryos differentiate 16: Tail bud starts to elongate 17: Nostril opened 19: Gill buds appear 20: Gill elongation; tail length greater than head-body	21: Mouth starts to open; cornea becomes transparent 22: Early development of opercular; opercular fold covers the right gills 23: Tadpoles start to feed; left gill cover with opercular fold 24: Limb bud develop	27: Labial teeth complete 28: Appearance of knee joint visible; hindlimb bud reaches maximum length and slightly bends at the knee junction base 29: The limb bud becomes paddle-shaped 30-34: Toes formation 35-38: Hindlimb development and the five toes completely separated; tubercles emerge; phalanges develop; hindlimb begins to function 39-41: Cloacal tube degenerate; larval mouth degenerate; forelimbs appear and banded pattern visible on hindlimbs; tail starts to resorb; tongue formed	42: Tail shortens; mouth angle reaches the level beneath the posterior and centre of eyes 44: Complete metamorphosis		Kuroshima and Tominaga (2021)
Polypedates teraiensis	1: Fertilized egg uniformly white in colour	21: Tail fins visible; eyes distinct, gills	25: Gills disappear	42: Forelimb emerge; vent tube completely disappear; tail shortens and becomes	58 days	Chakravarty et al. (2011)

Family / Species	Phases: Embryo (Stage 1-20)	Hatchling (Stage 21-24)	Tadpole (Stage 25-41)	Metamorph (Stage 42-46)	Duration of metamorphosis	Source
	3: Two cell stage 10: Blastula stage 12: Gastrula stage 14: Neural fold appears 17: Tail bud appear 18: Body and tail buds elongate 20: Gill visible; Yolk sac reserve; tail prominent; larvae remain in the nest	develop; transparent eyes 22: Transparent tail fins; gills well developed 23: Operculum develops; dark pigmentation appears on the dorsal side and extends to tail 24: Operculum slowly close over the gills; mouthparts development; tail tip pointed	26: Hind limb bud appears; pigmentation denser at the dorsal side except for the eyes 28-30: Gill buds elongate; tail muscle develop 31: Hind limb becomes paddle shape 32-34: Toes development 35: All five toes separated; pigment denser on the dorsal side uniformly with a longitudinal dark line in the middle 36: Knee joint formation 38: Feet web visible 39: Forelimbs develop under skin; pigment at fins visible; rounded toe tips with pigmentation 40: All keratodont present 41: Vent tube reduced; pigmentation on the hind limb with tubercles; keratodont become faint	darker; mouth start to widening 43: Eyes slightly protrude; the dorsal and ventral fins disappear; tail shortens 45: Tail reduced until it becomes stub 46: Tail stub completely disappears; complete metamorphosis		

FACTORS AFFECTING METAMORPHOSIS

In amphibians, the process of metamorphosis begins when hormones released by the tadpole's thyroid gland trigger a series of transformations (Gilbert, 2000; Sachs and Buchholz, 2019; Paul et al., 2022). These changes are essential in adapting an aquatic creature to live on land (Gilbert, 2000). The physical and chemical changes in the environment can affect the growth rate and metamorphosis of many aquatic creatures (Bekhet et al., 2014). Amphibian adult and tadpole assemblages may be influenced by various environmental conditions. These variables include predation, competition, temperature, salinity, water chemistry, water quantity or level, and water pH. However, not only limited to that, the factors that influence the adult assemblage may also affect the tadpole assemblage. Besides, the relationship between amphibian adult density and larval survival in some species could be a factor that influences metamorphosis (Simpkins, 2013).

Anurans possess an amazing capacity to adapt their physical traits (phenotypes) in response to environmental changes. Phenotypic plasticity gives them the ability to not only adapt to various environments but also has substantial ecological effects throughout their lifetime (Fox et al., 2019). Phenotypic plasticity is referred to as the ability of an organism to modify or adjust its physical traits in response to the various environmental conditions that they encounter (Pigliucci et al., 2006; Garland and Kelly, 2006). The survival and reproductive success of a species are greatly influenced by this adaptive response (Wake and Koo, 2018). Among the various animal species, anurans exhibit exceptional adaptive plasticity to a variety of habitats and complex life cycles (Wake & Koo, 2018). Additionally, some variables could influence not only their structural development but also the duration of their metamorphosis process. Table 2 shows abiotic and biotic factors influencing frog metamorphosis.

Water pH

Aquatic amphibians have been proven to have higher mortality (Gosner and Black, 1957), lower hatching success (Pough, 1976), and lower growth rates in acidic environments (Farquharson et al., 2016). The pond environment usually inhabited by most tadpoles has low levels of certain critical ions, such as Na+ and Cl- (Moore and Klerks, 1998). Anurans have systems enabling them to transport these ions into the body against the prevailing ionic gradient in order to maintain the required amounts of these ions (Kirschner, 1983). Low pH has been found to affect the process of ion transport across the epithelia of various anuran species. In general, acidic environments diminish active sodium transport into the body while at the same time increasing the passive losses of ions (Freda, 1986). Low pH may interfere with an array of activities, including osmoregulation, regulation, and excretion (Moore and Klerks, 1998). This implies that pH levels can affect the frog metamorphosis process and influence tadpole physiology, especially in ion regulation (Wijethunga et al., 2015). Pad et al. (1988) proposed that during the late gastrula stage, the embryo's development was immediately halted at below pH 3 and was dead within a few hours, while the embryos that were exposed to pH between 4 and 10.5 showed normal development and hatching afterwards. Shu et al. (2015) suggested that the uptake of Ca^{2+} for embryos is essential for survival and ionic balance to counter the negative effect of acid stress, indicating that the acid tolerance for frog development is correlated with Ca^{2+} ion flux. However, the survival and acid tolerance of frogs could also be dependent on their native population breeding, which may cause them to evolve in response to environmental acidification under strong selection. This implies adaptive plasticity occurrence, which causes genetic differentiation among the anuran species such as *Rana arvalis* (Ra¨sa¨nen et al., 2003).

Salinity

Amphibians are particularly sensitive to freshwater salinisation due to a general lack of ability to regulate their osmolarity (Gómez-Mestre et al., 2004), low dispersion rates (Schivo et al., 2019), and a significant reliance on freshwater habitats (Montaña et al., 2019). Elevated salinity can raise osmoregulation demands in freshwater creatures, and frogs are especially vulnerable due to their permeable skin and, among other species, semi-aquatic life cycle (Welch et al., 2019). Early life stages, such as eggs, embryos, and tadpoles, are assumed to be more vulnerable to changes in ambient salinity than adults because they are constrained to the aquatic habitat where they hatch (Viertel, 1999). This happens because osmoregulatory organs are still developing during their early stages of development, where they are more vulnerable to adapting to salinity, thus reducing an individual's ability to maintain homeostasis (Uchiyama and Yoshizawa, 1992). Studies of various anuran species have shown that exposure to elevated salinity typically retards tadpole growth and ultimately reduces animal body size. Results from the three experiments conducted by Welch et al. (2019) have shown that prolonged exposure to salinity can affect tadpoles' growth and survival. In one of the experiments, the tadpoles exposed to elevated salinity at the early development stage have low salinity tolerance and reduced growth with some signs of accelerated growth due to salinity stress. Only 3 out of 30 tadpoles survived successfully for the first 8 days; however, they died within 16 days later compared to those in the control treatment. Research by Alexander et al. (2012) and Kearney et al. (2016) has shown similar developmental responses in Gulf Coast Toad (*Incilius nebulifer*) and two native Australian frog species (*Litoria ewingii* and *Limnodynates peronii*), respectively. Gomez-Mestre et al. (2004) suggested that the slower growth and decreased body size at metamorphosis may be the result of energy ordinarily distributed to growth being shifted into salt excretion and osmo- and ion-regulations, lowering the maximum body size obtained during the developmental phase (Mueller et al., 2012; Newman, 1992).

Temperature

Temperature has a major influence on amphibian growth and metamorphosis, especially frogs. Frogs are ectothermic, meaning they rely on external environmental conditions to keep their body temperature stable, making them vulnerable to temperature variations. The physiology and development of an individual can be significantly impacted by temperature during a particular stage of the life cycle in ectotherms with complex life cycles, and this can have a significant impact on performance in the future (Altwegg and Reyer, 2003; Chakir et al., 2002; Giménez, 2006; Nicieza et al., 2006; Semlitsch et al., 1988; Stevens, 2004). Changes in temperature during the metamorphic period may affect the process's duration and the body shape of later stages. Individuals that are raised at low temperatures typically grow slower than those exposed to higher temperatures (Angilletta et al., 2004; Atkinson, 1994). A study by Orizaola and Laurila, (n.d.) found that tadpoles held at 26°C developed more slowly than larvae subjected to a temperature of 30°C. This concludes that the high temperature could influence the larvae development by shortening their time of metamorphosis. In species such as Relict leopard frog (*Rana onca*), the tadpoles could not undergo metamorphosis at 15°C, but those that survived did so when the temperature was raised to 25°C. Despite the constant availability of food, the tadpoles in the 35°C group observed were skinny and listless. Even though the temperature was reduced, none of the tadpoles initially exposed to 35°C completed the metamorphosis (Goldstein et al., 2017). Frogs' development, growth, and size at metamorphosis can be affected by temperature via their endocrine system. In tadpoles of the Indian skipper frog (*Euphlyctis cyanophlyctis*), exposure to high temperatures promoted testis growth and disrupted ovary development, leading to an early metamorphosis with a smaller body size (Phuge, 2017). Based on the available studies, the optimal temperature range that seems best for egg or larvae development is between 20-25°C (Goldstein et al., 2017; Harkey and Semlitsch, 1988).

Water level and space availability

The water restriction for tadpoles reduces their locomotion space, which inhibits their foraging behaviour and reduces their body size. This has been identified as the main cause of the tadpoles' reduced growth time and subsequent reduction in body size (Denver, 1997; Merilä et al., 2016). The water level and space availability in the habitat of eggs and larvae are typically associated with temperature since water loss may raise the mean temperature and increase the daily thermal fluctuation of bodies of water (Wilbur, 1990). Space availability is also associated with the crowding effect caused by larvae population size in the pond or environment where they cohabitate or in confined space (John and Fusaro, 1981). Desiccation on a pond where larvae inhabit will alter the volume and surface area of the water. John and Fusaro, (1981) emphasised that these alterations will result in a congested situation with two major changes: less physical wall space (surface area) and higher density with other tadpoles. Larvae exposed to declining water treatments underwent much more rapid metamorphosis than controlled water treatments (Gómez-Mestre et al., 2013; Merilä et al., 2016). However, the shorter metamorphosis time of the larvae results in a smaller body size, which may also be associated with reduced fitness. (Merilä et al., 2016).

Elevation gradient

Elevation differences can influence frog development and metamorphosis significantly. Elevation changes are frequently related to changes in temperature, humidity, oxygen levels, and other environmental conditions, all of which can have a direct impact on the physiological processes and developmental stages of frogs. A review article by Morrison and Hero, (2003) summarised that amphibians cohabit at higher altitudes and latitudes prone to have longer larval periods, have large body sizes at all larval stages, including metamorphosis and in the adult stage; reproductive maturity reaches older ages; produce fewer clutches per year but have larger clutches and smaller clutches that depends on the female body size. Amphibian development rates in higher elevations and latitudes tend to be reduced during the winter months; nevertheless, they can have higher stage-specific growth throughout the warmer months than those in lower elevations and latitudes (Berven et al., 1979). Reduced growth caused by extended periods of colder temperatures and shorter seasons of growth at higher elevations might force organisms to overwinter as tadpoles, resulting in prolonged larval phases and delayed sexual maturation (Macedo and Garwood, 2023). These developmental constraints and longer larval periods have an impact on the size of the body at metamorphosis, metamorphic timing, and post-metamorphic life history (Ruthsatz et al., 2020; Thompson and Popescu, 2021). Berven (1982) suggested that larval populations growing at high-elevation ponds grew at a slower pace, low developmental rates, and were larger in size at all stages which is including metamorphic climax, than larval populations growing at low-elevation ponds. Due to that, it is explained that high elevation has low temperature compared to lowland.

Pollution

Pollution can have adverse effects on frog development and metamorphosis. Frogs are extremely sensitive to environmental changes, and numerous types of pollutants can impact their developmental phases both directly and indirectly. According to the IUCN SSC Amphibian Specialist Group, pollution is the second major cause of amphibian decline worldwide, as reported in their first Global Amphibian Assessment (GAA1) (Stuart et al., 2004). Agriculture has been demonstrated to have a negative impact on anuran density and variety (Bishop et al., 1999), and pesticides have been proven to disrupt its community structure, resulting in lower growth (Relyea and Diecks, 2008). Heavy metals, pesticides, herbicides, industrial chemicals, and pharmaceuticals are examples of chemical pollutants that can contaminate water bodies where frogs breed and develop (Gonçalves et al., 2017). These pollutants can enter the frogs' system via their permeable skin or ingestion (Broomhall, 2004). Tadpoles' hormonal balance and physiological processes can be disrupted by water pollution, resulting in abnormalities in development and disrupted metamorphosis (Egea-Serrano et al., 2012; Thambirajah et al., 2019). Herbicides such as atrazine, which is known to be directly hazardous only to plants, have been shown to damage animals in complex communities when any additional stress factor is introduced into the system. There is evidence reported that larvae treated with a high concentration of atrazine underwent development disruption, which resulted in small body size and lower body mass (Diana et al., 2000; Trachantong et al., 2013; Zaya et al., 2011). Furthermore, Hayes et al., (2002) reported that atrazine could cause steroidogenesis disruption, which is associated with demasculinisation of the male and hermaphrodite production. Besides, insecticide such as malathion has been proven to cause delayed metamorphosis even at low concentration in anuran (Smith et al., 2011). In addition, pollution has the potential to harm or destroy frog habitats, making them more liable to disease and diminishing their overall survival and fitness (Blaustein and Johnson, 2003; Allentoft and O’Brien, 2010).

Predation

Predators have an important influence in altering frog populations and behaviours throughout their life stages. Predators have considerable effects on both prey survival and growth, emphasising the potential relevance of predators in altering prey populations and tropical aquatic food web interactions (Gonzalez et al., 2011). Predation is a primary cause of tadpole mortality, occurring at all phases of development and metamorphosis, which could influence their size at metamorphosis, behaviour, morphology, and age. Vodrážková et al. (2022) discovered that when the predator was present in early development, the tadpoles had a longer larval stage, were smaller in size at metamorphosis, and had lower body mass. In the presence of a predator, larvae develop slowly and have an elongated larval period (Laurila and Kujasalo, 1999). Tadpoles frequently demonstrate anti-predator behaviours when predators are present, which include reduced activity, hiding and resting (Qiang et al., 2004). Metamorphs that emerged from larval predator settings had comparatively big hind and forelimbs and narrowed bodies (Relyea, 2001). However, Walsh et al. (2008) had different findings where the metamorphosis accelerated; larvae have a long functional tail and reduced mass bodies with rapid development in the presence of predators. It also mentioned that tail retention is beneficial for locomotor performance under predation risk to increase survivorship. In addition, parental care can protect tadpole growth from predation by affecting aspects such as nutrition, protection, and behaviour. For instance, females of *Leptodactylus insularum* guard their nests and tadpole schools, communicate with them through body-pumping movements, lead them around the wetlands, and aggressively protect their offspring against predators (Carrillo et al., 2023; Hurme, 2011). In species such as *Oophaga sylvatica* (Dendrobatidae) and *Mantella laevigata* (Mantellidae), whose parental care includes feeding the tadpoles, such as providing unfertilised eggs (oophagy) or nutritive secretions, increased nutritional availability can encourage faster growth and development (Weygoldt, 2009; Fischer et al., 2019). Tadpoles that get proper nourishment are more likely to undergo metamorphosis fast, minimising time spent in the water and the related predation risk.

Competition

Competition between species can play an important role in the development of anuran tadpole assemblages. Competition can be either intraspecific or interspecific. Intraspecific competition occurs when individuals from the same species compete against one another, whereas interspecific competition occurs when individuals from different species compete with one another. Tadpoles from the same or distinct species may struggle for scarce resources like food, space, and shelter. Tadpoles in high-competition circumstances may grow more slowly because of limited access to food supplies (Steinwascher, 1978). High resource competition might result in lower food availability or increased crowding, impairing tadpole growth rates and development (Bekhet et al., 2014). Intense competition may result in reduced body sizes (Haramura et al., 2022), shallow muscles (Relyea, 2002), delayed metamorphosis (Smith, 2005), or more time spent as an aquatic larva (Girish and Saidapur, 2003; Haramura et al., 2022). Slower growth rates can postpone the attainment of the essential size and developmental stage for transformation. Furthermore, competition-induced stress can modify the hormonal regulation of metamorphosis, which can result in changes in developmental time (Denver, 2021). In resource-limited situations, tadpoles may engage in aggressive interactions such as cannibalism or interference competition (Faragher and Jaeger, 2011). Relyea (2002) proposed that larvae can discriminate between rivalry caused by a lack of food and competition caused by increased density. These encounters can cause increased stress, injury, or mortality, which can have an impact on tadpole development and survival. The author also stated that competition may lead to phenotypic plasticity in tadpoles, where the presence and degree of competition could influence their development. Tadpoles may undergo morphological and behavioural changes to improve their competing ability (Relyea, 2002). To compete for resources, they may acquire greater body sizes, deeper bodies, or specialised feeding mechanisms (Steinwascher, 1978). These phenotypic alterations can potentially influence the timing and success of transformation.

Food / Diet

Adequate nutrition is crucial for tadpole growth. Tadpoles require a well-balanced diet rich in nutrients. Tadpoles benefit from nutrient-rich food sources for appropriate organ development, muscle growth, and skeletal development. Tadpoles with access to high-quality food and various diets grow faster and reach the size necessary for successful metamorphosis at a greater rate. Tadpoles consume extensively prior to metamorphosis, and a plant-based diet may provide all the nutrients they require. Besides, tadpoles can feed on vascular plants, a broad variety of algal forms, precipitates of dissolved organic materials, detritus, and live or dead animals, including conspecifics or heterospecific tadpoles, depending on taxon and environment (Kupferberg, 1997). The nutritional quality variations between these food categories are significant; for example, plant tissue is often richer in carbohydrates and lower in lipids and proteins. Dietary composition, particularly the relative amounts of protein, carbohydrate, and lipid, can alter thyroid hormone activity, which in turn affects development and differentiation and, ultimately, metamorphosis (Jacobson et al., 2019). Higher food availability and improved nutritional conditions may speed up metamorphosis (Bekhet et al., 2014) and produce larger body sizes (Leips and Travis, 1994) by providing tadpoles with the resources they need to cross this threshold sooner. Minimising time to metamorphosis while increasing bulk at metamorphosis will minimise the likelihood of juvenile predation and reaching maturity quickly, which has a favourable influence on adult reproduction (Rose, 2005). Jacobson et al. (2019) reported that high-protein commercial fish meal reduced variability and mortality throughout the larval period while increasing growth rates. As a result, individuals can metamorphosis at large sizes earlier than tadpoles that had been fed with low protein food. Furthermore, the tadpole will practice cannibalism mostly triggered by starvation, extreme competition for limited food resources and when their meals fail to match their nutritional needs (Jefferson et al., 2014a; Jefferson et al., 2014b). Jefferson et al., (2014b) discovered that cannibalism improved the likelihood of metamorphosis development, even though an exclusively conspecific diet extended the larval phase for tadpoles.

Diseases, pathogens, and parasites

Diseases, pathogens, and parasites are capable of having serious effects on anuran development and metamorphosis. These frogs and toads undergo an astonishing transition from aquatic larvae to terrestrial adults. Their growth journey, however, is not immune to the influence of numerous disease-causing agents. Pathogens and parasites can have an impact on anuran development via a variety of mechanisms, including slowed growth, organ damage, changed metabolic processes, and higher mortality. Repeated early-life exposure to additional environmental stressors, including pollutants, predator cues, and pathogens, can be harmful to amphibians and can induce delayed effects in amphibians, both juvenile and adult (Richter-Boix et al., 2014; Garcia et al., 2017). For example, tadpoles or larvae that are infected by parasitic trematode, *Ribeiroia ondatrae* would develop deformities such as extra and missing limbs. This parasite is usually found in a pond with a population of aquatic snails *Planorbella tenuis,* which become the first intermediate host for the parasite. After the parasite develops into free-swimming cercariae form, it will swim through the water and embed itself in the tadpole’s limb bud (second intermediate host). The cercariae then developed into metacercaria, which is in an encysted stage or resting within the tadpole’s tissues. The cyst will disrupt limb development and exhibit severe malformations, such as sprouting extra legs upon metamorphosis. This will cause the frog to be vulnerable to predation by the parasite’s definitive host. The cycle begins again when the definitive host releases the parasite eggs through the water via its faeces. Additionally, excessive radiation exposure and pollutant exposure, such as pesticides, may aid the cycle by weakening the tadpoles' immune systems and making them more susceptible to parasite infections and pathogens (Blaustein and Johnson, 2003).

Thyroid hormone level

Thyroid hormones (TH) are essential for the metamorphosis and development of anuran. These hormones, basically thyroxine (T4) and triiodothyronine (T3), control a variety of physiological processes that propel aquatic tadpoles into terrestrial adults (Campinho, 2019). Thyroid hormone levels fluctuate throughout anuran development, with peak concentrations occurring at the climax of metamorphosis. Thyroid hormone levels can have a big impact on the timing, rate, and success of metamorphosis, as well as the overall development of anuran individuals. Since thyroid hormones regulate frog metamorphosis, which promotes the transformation of aquatic larvae into adult tetrapods, the significant morphological and functional changes of larval tissues can be easily utilised as parameters reflecting endocrine disturbance (Miyata and Ose, 2012). Thyroid hormone deficiency can cause incomplete metamorphosis, which can lead to impairments in development and decreased fitness (Sachs and Buchholz, 2019). Additionally, TH receptor (TR) inhibition by transgenic overexpression of a dominant negative TR slows metamorphosis when expressed across the body and inhibits the growth of specific tissues when overexpressed in those tissues (Buchholz et al., 2003).

Table 2. Factors influencing frog metamorphosis.

Factors	Sources	Description
Abiotic		
Water pH	Rasanen et al., (2002); Freda and Dunson (1984); Hangartner et al. (2012); Farquharson et al. (2016); Wijethunga et al. (2015)	Embryonic survival is high at low pH but severely reduced larval growth, survival, and development over time due to disruption of ionic regulation; Increased deformities and delayed metamorphosis of tadpoles in acidity conditions; High pH enabled earlier metamorphosis and larger body size.
Salinity	Sanzo and Hecnar (2006); Welch et al. (2019); Kearney et al. (2016); Welch et al. (2019)	Exposure to a high salinity environment will retard larval growth rates, physical abnormalities, and decreased time of metamorphosis; High salinity causes a small body size of tadpoles.
Temperature	Atkinson (1994); Maciel and Juncá (2009); Goldstein et al. (2017); Phuge (2017)	High temperature will reduce the larval development, which accelerates their metamorphosis process. The development of embryos and tadpoles arrested in the low temperature exposure (lower than 20°C)
Water level	Richter-Boix et al. (2006); Tejedo et al. (2010); Bekhet et al. (2014)	Pond desiccation will accelerate larval metamorphosis with a lower body mass and low growth rates after completing the process. Larvae that are raised in deep water pens show longer fore and hind limbs due to the extension of the larval period.
Space availability	John and Fusaro (1981)	Confined space causes low growth rates on larvae, smaller size body.
Elevation gradient	Macedo and Garwood (2023); Morrison and Hero (2003)	Larvae raised in higher elevations and latitudes have longer larval periods, slower growth rates and delayed development.
Pollution	Diana et al. (2000); Zaya et al. (2011); Hayes et al. (2002)	The presence of atrazine in water can cause development disruption in larvae (small body size and lower body mass); Atrazine also can cause

		gonad development alteration, morphology, and function alteration.
Biotic		
Predation	Laurila and Kujasalo (1999); Vodrážková et al. (2022)	The increase in predator risk will reduce both development and growth rates
Competition	Bekhet et al. (2014); Girish and Saidapur (2003); Haramura et al. (2022)	The increase in crowding will regress the larval size at metamorphosis; Prolonged larval period
Food/ Diet	Bekhet et al. (2014); Jefferson et al. (2014a); Jefferson et al. (2014b)	Larval grew faster in high food resources; Practise cannibalism in limited food resources
Disease, pathogen, and parasites	Blaustein and Johnson (2003)	Risk of death or impaired survival and deformity (extra limbs, missing limbs, and misshapen limbs) increase if the larvae are exposed to large or persistent numbers of infectious parasites such as *Ribeiroia ondatrae*
Thyroid hormone level	Sachs and Buchholz (2019)	The absence of thyroid hormone reduces the tadpole developmental process unless it is induced prematurely by exogenous thyroid hormone.

CONCLUSION

In reviewing the literature on the stages, development, and factors affecting the metamorphosis of frogs, metamorphic processes exhibit significant variations across different families by showing the distinct transformation of oral apparatus, coloration, and metamorphosis period. These differences can be linked to a variety of causes, including abiotic and biotic variables. Understanding the subtleties of frog metamorphosis is vital not just for biological and evolutionary reasons, but also for understanding how amphibians respond to changes in their habitats, which is critical given current global challenges such as habitat destruction and climate change. However, there are still gaps in understanding many Anura species' whole metamorphic cycle. Much research has concentrated on the mid-metamorphic stages (hatchling and tadpole), leaving the early and later stages unexplored. Given these findings, future Anura metamorphosis studies should aim to present a full picture by examining the entire metamorphic trajectory of a certain species, from egg to adult.

ACKNOWLEDGMENTS

The authors would like to acknowledge Universiti Teknologi MARA (UiTM) Pahang Branch, Malaysia for academic and technical support.

AUTHOR CONTRIBUTIONS

Original draft preparation – Khairunnisa Shahrum Nizam; Literature Review, Writing – Khairunnisa Shahrum Nizam, Farah Ayuni Farinordin; Review and Editing – Nur Amalina Mohd Izam, Nor Azliza Ismail.

COMPETING INTEREST

The authors declare that there are no competing interests.

COMPLIANCE WITH ETHICAL STANDARDS

Not applicable.

REFERENCES

Simpkins, C. (2013). Abiotic and biotic factors influencing the assemblage of tadpoles and adult anurans in coastal wallum habitats of eastern Australia. Master's dissertation. Griffith University. https://doi.org/10.25904/1912/122.

Alexander, L. G., Lailvaux, S. P., Pechmann, J. H. K., & DeVries, P. J. (2012). Effects of salinity on early life stages of the Gulf Coast Toad, *Incilius nebulifer* (Anura: Bufonidae). Copeia, 2012(1), 106–114. https://doi.org/10.1643/CP-09-206.

Alford, R. A., Richards, S. J., & McDonald, K. R. (2013). Amphibians, biodiversity of. Encyclopedia of Biodiversity: Second Edition, 169–178. https://doi.org/10.1016/B978-0-12-384719-5.00254-9.

Alger, S. J. (2013). Cicadian Rhythms: Why Does the 17-Year Cicada Emerge Like Clockwork?. Scitable by Nature Education. https://www.nature.com/scitable/blog/accumulating-glitches/cicadian_rhythms_why_does_the/ Accessed 19 October 2023.

Allentoft, M., & O'Brien, J. (2010). Global amphibian declines, loss of genetic diversity and fitness: A review. diversity, 2(1), 47–71. http://dx.doi.org/10.3390/d201004.

Altwegg, R., & Reyer, H.U. (2003). Patterns of natural selection on size at metamorphosis in water frogs. Evolution, 57(4), 872–882. https://doi.org/10.1554/0014-3820(2003)057.

Angilletta, M. J., Steury, T. D., & Sears, M. W. (2004). Temperature, growth rate, and body size in ectotherms: fitting pieces of a life-history puzzle. Integrative and Comparative Biology, 44(6), 498–509. https://doi.org/10.1093/ICB/44.6.498.

Atkinson, D. (1994). Temperature and organism size—A biological law for ectotherms? Advances in Ecological Research, 25(C), 1–58. https://doi.org/10.1016/S0065-2504(08)60212-3.

Bekhet, G. A., Abdou, H. A., Dekinesh, S. A., Hussein, H. A., & Sebiae, S. S. (2014). Biological factors controlling developmental duration, growth and metamorphosis of the larval green toad, *Bufo viridis viridis*. The Journal of Basic & Applied Zoology, 67(3), 67–82. https://doi.org/10.1016/J.JOBAZ.2014.09.005.

Berven, K. A. (1982). The genetic basis of altitudinal variation in the wood frog *Rana sylvatica* II. An experimental analysis of larval development. Oecologia, 52(3), 360–369. https://doi.org/10.1007/BF00367960/METRICS.

Berven, K. A., Gill, D. E., & Smith-Gill, S. J. (1979). Countergradient selection in the Green Frog, *Rana clamitans*. Evolution, 33(2), 609. https://doi.org/10.2307/2407784.

Bishop, C. A., Mahony, N. A., Struger, J., Ng, P., & Pettit, K. E. (1999). Anuran development, density and diversity in relation to agricultural activity in the Holland River watershed, Ontario, Canada (1990-1992). Environmental Monitoring and Assessment, 57(1), 21–43. https://doi.org/10.1023/A:1005988611661.

Bishop, C. D., Erezyilmaz, D. F., Flatt, T., Georgiou, C. D., Hadfield, M. G., Heyland, A., Hodin, J., Jacobs, M. W., Maslakova, S. A., Pires, A., Reitzel, A. M., Santagata, S., Tanaka, K., & Youson, J. H. (2006). What is metamorphosis? Integrative and Comparative Biology, 46(6), 655–661. https://doi.org/10.1093/icb/icl004.

Blaustein, A. R., & Johnson, P. T. J. (2003). Explaining frog deformities. Scientific American, 288(2), 60–65. https://doi.org/10.1038/scientificamerican0203-60.

Boulan, L., Milán, M., & Léopold, P. (2015). The systemic control of growth. Cold Spring Harbor Perspectives in Biology, 7(12). https://doi.org/10.1101/CSHPERSPECT.A019117.

Brenes-Soto, A., Dierenfeld, E. S., & Janssens, G. (2018). The interplay between voluntary food intake, dietary carbohydrate-lipid ratio and nutrient metabolism in an amphibian, (Xenopus laevis). PLOS ONE, 13(12). https://doi.org/10.1371/journal.pone.0208445.

Britannica. (n.d.). Metamorphosis. Encyclopedia Britannica. Accessed 19 October 2023. https://www.britannica.com/science/metamorphosis

Britton, D. (2019). Metamorphosis: a remarkable change. The Australian Museum. https://australian.museum/learn/animals/insects/metamorphosis-a-remarkable-change/ Accessed 19 October 2023.

Broomhall, S. (2004). Frogs in an effluent society: Risks, remedies and responsibilities. WWF Australia.

Buchholz, D. R., Hsia, S.-C. V., Fu, L., & Shi, Y.-B. (2003). A dominant-negative thyroid hormone receptor blocks amphibian metamorphosis by retaining corepressors at target genes. Molecular And Cellular Biology, 23(19), 6750–6758. https://doi.org/10.1128/MCB.23.19.6750-6758.2003.

Campinho, M. A. (2019). Teleost Metamorphosis: The role of thyroid hormone. Frontiers in Endocrinology, 10. https://doi.org/10.3389/fendo.2019.00383.

Carrillo, J. F. C., Santana, D. J., & Prado, C. P. A. (2023). An overview of parental care in the foam-nesting frogs of the genus *Leptodactylus* (Anura: Leptodactylidae): current knowledge and future directions. Amphibia-Reptilia, 1, 1–11. https://doi.org/10.1163/15685381-BJA10140.

Chakir, M., Chafik, A., Gibert, P., & David, J. R. (2002). Phenotypic plasticity of adult size and pigmentation in Drosophila: thermosensitive periods during development in two sibling species. Journal of Thermal Biology, 27(1), 61–70. https://doi.org/10.1016/S0306-4565(01)00016-X.

Chakravarty, P., Bordoloi, S., Grosjean, S., Ohler, A., & Borkotoki, A. (2011). Tadpole morphology and table of developmental stages of *Polypedates teraiensis* (Dubois, 1987). Alytes, 27(3), 85–115.

Chapman, D. (2020). Tadpole to frog: development stages & metamorphosis. SAGA. https://www.saga.co.uk/magazine/home-garden/gardening/wildlife/amphibians/the-tadpole Accessed 19 October 2023.

Cheron, M., Raoelison, L., Kato, A., Ropert-Coudert, Y., Meyer, X., Macintosh, A. J. J., & Brischoux, F. (2021). Ontogenetic changes in activity, locomotion, and behavioural complexity in tadpoles. Biological Journal of the Linnean Society, 134(1), 165-176.

Chuliver, M., & Fabrezi, M. (2019). A developmental staging table for *Physalaemus biligonigerus* (Cope, 1861) (Anura: Leptodactylidae). South American Journal of Herpetology, 14(2), 150. https://doi.org/10.2994/SAJH-D-18-00005.1.

Del Pino, E. M., Ávila, M. E., Pérez, O. D., Benítez, M. S., Alarcón, I., Noboa, V., & Moya, I. M. (2004). Development of the dendrobatid frog *Colostethus machalilla*. International Journal of Developmental Biology, 48(7), 663–670. https://doi.org/10.1387/ijdb.041861ed.

Denver, R. J. (1997). Proximate mechanisms of phenotypic plasticity in amphibian metamorphosis. Integrative and Comparative Biology, 37(2), 172–184. https://doi.org/10.1093/ICB/37.2.172.

Denver, R. J. (2015). Stress hormones mediate developmental plasticity in vertebrates with complex life cycles. Neurobiology of Stress, 14. https://doi.org/10.1016/j.ynstr.2021.100301.

Diana, S. G., Resetarits, W. J., Schaeffer, D. J., Beckmen, K. B., & Beasley, V. R. (2000). Effects of atrazine on amphibian growth and survival in artificial aquatic communities. Environmental Toxicology and Chemistry, 19(12), 2961-2967. http://dx.doi.org/10.1002/etc.5620191217.

Dreher, C. E., & Pröhl, H. (2014). Multiple sexual signals: Calls over colors for mate attraction in an aposematic, color-diverse poison frog. Frontiers in Ecology and Evolution, 2. https://doi.org/10.3389/FEVO.2014.00022/ABSTRACT.

Egea-Serrano, A., Relyea, R. A., Tejedo, M., & Torralva, M. (2012). Understanding of the impact of chemicals on amphibians: a meta-analytic review. Ecology and Evolution, 2(7), 1382–1397. https://doi.org/10.1002/ece3.249.

Eprilurahman, R., & Maghfiroh, N. L. (2020). The tadpole of *Leptobrachium hasseltii* Tschudi. 1838 (Amphibia: Anura: Megophryidae): Morphometry and larval developmental stage as identification character of species. 020023. https://doi.org/10.1063/5.0015681.

Fabrezi, M., & Cruz, J. C. (2020). Evolutionary and developmental considerations of the diet and gut morphology in ceratophryid tadpoles (Anura). BMC Developmental Biology, 20(1). https://doi.org/10.1186/s12861-020-00221-5.

Fabrezi, M., Quinzio, S., Goldberg, J., & De S, R. O. (2012). The development of *Dermatonotus muelleri* (Anura: Microhylidae: Gastrophryninae). Journal of Herpetology, 46(3), 363–380. https://doi.org/10.1670/11-194.

Faragher, S. G., & Jaeger, R. G. (2011). Tadpole bullies: examining mechanisms of competition in a community of larval anurans, 76(1), 144–153. https://doi.org/10.1139/Z97-177.

Farquharson, C., Wepener, V., & Smit, N. J. (2016). Acute and chronic effects of acidic pH on four subtropical frog species. Water SA, 42(1), 52. https://doi.org/10.4314/wsa.v42i1.07.

Fischer, E. K., Roland, A. B., Moskowitz, N. A., Vidoudez, C., Ranaivorazo, N., Tapia, E., Trauger, S. A., Vences, M., Coloma, L. A., & O'Connell, L. A. (2019). Mechanisms of convergent egg provisioning in poison frogs. Current Biology, 29(23), 4145-4151. https://doi.org/10.1016/j.cub.2019.10.032.

Flores, A. B. A., Diesmos, A. C., & Nuňeza, O. M. (2023). Morphological description and life history of the Philippine Swamp Frog *Limnonectes leytensis* (Boettger, 1893). Biodiversitas, 24(1), 133–139. https://doi.org/10.13057/biodiv/d240117.

Fox, R. J., Donelson, J. M., Schunter, C., Ravasi, T., & Gaita ́n-Espitia, J. D. (2019). Beyond buying time: the role of plasticityin phenotypic adaptation to rapidenvironmental change. Philosophical Transactions of the Royal Society B, 374(1768).

Freda, J. (1986). The influence of acidic pond water on amphibians: A review. Water, Air, and Soil Pollution, 30(1–2), 439–450. https://doi.org/10.1007/BF00305213/METRICS.

Fu, L., Wen, L., & Shi, Y. B. (2018). Role of thyroid hormone receptor in amphibian development. Methods in Molecular Biology (Clifton, N.J.), 1801, 247. https://doi.org/10.1007/978-1-4939-7902-8_20.

Garcia, T. S., Urbina, J., Bredeweg, E. M., & Ferrari, M. C. O. (2017). Embryonic learning and developmental carry-over effects in an invasive anuran. Oecologia, 184(3), 623–631. https://doi.org/10.1007/s00442-017-3905-5.

Garland, T., & Kelly, S. A. (2006). Phenotypic plasticity and experimental evolution. The Journal of Experimental Biology, 209(12), 2344–2361. https://doi.org/10.1242/jeb.02244.

Gilbert, S. F. (2000). Ecological developmental biology. (6th ed.). Sinauer Associates.

Gillis, G. B. (2013). Feeding frogs, tongues and temperature. The Journal of Experimental Biology, 216(5). https://doi.org/10.1242/jeb.077776.

Giménez, L. (2006). Phenotypic links in complex life cycles: conclusions from studies with decapod crustaceans. Integrative and Comparative Biology, 46(5), 615–622. https://doi.org/10.1093/ICB/ICL010.

Girish, S., & Saidapur, S. K. (2003). Density-dependent growth and metamorphosis in the larval bronze frog *Rana temporalis* is influenced by genetic relatedness of the cohort. Journal of Biosciences, 28(4), 489–496. https://doi.org/10.1007/BF02705123/METRICS.

Goldberg, J., Quinzio, S. I., Cruz, J. C., & Fabrezi, M. (2019). Intraspecific developmental variation in the life cycle of the Andean Treefrog (*Boana riojana*): A temporal analysis. Journal of Morphology, 280(4), 480–493. https://doi.org/10.1002/jmor.20958.

Goldstein, J. A., von Seckendorr Hoff, K., & Hillyard, S. D. (2017). The effect of temperature on development and behaviour of relict leopard frog tadpoles. Conservation Physiology, 5(1). https://doi.org/10.1093/CONPHYS/COW075.

Gomez-Mestre, I., Tejedo, M., Ramayo, E., & Estepa, J. (2004). Developmental alterations and osmoregulatory physiology of a larval Anuran under osmotic stress. Physiological and Biochemical Zoology, 77(2), 267–274. https://doi.org/10.1086/378143.

Gómez-Mestre, I., Kulkarni, S. S., & Buchholz, D. R. (2013). Mechanisms and consequences of developmental acceleration in tadpoles responding to pond drying. PLOS ONE, 8(12). https://doi.org/10.1371/journal.pone.0084266.

Gonçalves, M. W., Gambale, P. G., Godoy, F. R., Alves, A. A., De Almeida Rezende, P. H., Da Cruz, A. D., Maciel, N. M., Nomura, F., Bastos, R. P., De Marco, P., & De Melo E Silva, D. (2017). The agricultural impact of pesticides on Physalaemus cuvieri tadpoles (Amphibia: Anura) ascertained by comet assay. Zoologia, 34, 1–8. https://doi.org/10.3897/zoologia.34.e19865.

Gonzalez, S. C., Touchon, J. C., & Vonesh, J. R. (2011). Interactions between competition and predation shape early growth and survival of two Neotropical Hylid tadpoles. Biotropica, 43(5), 633–639. https://doi.org/10.1111/J.1744-7429.2010.00748.X.

Gosner, K. L. (1960). A simplified table for staging anuran embryos and larvae with notes on identification. Herpetologica, 16(23), 183–190. https://doi.org/10.2307/3890061.

Gosner, K. L., & Black, I. H. (1957). The effects of acidity on the development and hatching of New Jersey Frogs. Ecology, 38(2), 256. https://doi.org/10.2307/1931684.

Haramura, T., Eto, K., Crossland, M. R., Nishikawa, K., & Shine, R. (2022). Competition between the tadpoles of Japanese toads versus frogs. Scientific Reports 2022 12:1, 12(1), 1–6. https://doi.org/10.1038/s41598-022-05525-z.

Harkey, G. A., & Semlitsch, R. D. (1988). Effects of temperature on growth, development, and color polymorphism in the Ornate Chorus Frog *Pseudacris ornata*. Copeia, 1988(4), 1001. https://doi.org/10.2307/1445724.

Harris, C. L. (1992). Concepts In Zoology. HarperCollins Publishers Inc.

Hayes, T. B., Collins, A., Lee, M., Mendoza, M., Noriega, N., Stuart, A. A., & Vonk, A. (2002). Hermaphroditic, demasculinized frogs after exposure to the herbicide atrazine at low ecologically relevant doses. Proceedings of the National Academy of Sciences of the United States of America, 99(8), 5476–5480. https://doi.org/10.1073/PNAS.082121499/ASSET/32EA9B5E-B4F9-4857-8D5B-1A9166729B0C/ASSETS/GRAPHIC/PQ0821214004.JPEG.

Hurme, K. J. (2011). Parental care and tadpole schooling in the Neotropical Frog, *Leptodactylus insularum*. [Doctoral dissertation, University of Connecticut]. ProQuest Dissertations Publishing.

Jacobson, B., Rogelio Cedeño-Vázquez, J., Espinoza-Avalos, J., & González-Solís, D. (2019). The effect of diet on growth and metamorphosis of *Triprion Petasatus* (Anura: Hylidae) Tadpoles. Herpetological Conservation and Biology, 14(2), 308–324.

Jefferson, D. M., Hobson, K. A., & Chivers, D. P. (2014a). Time to feed: How diet, competition, and experience may influence feeding behaviour and cannibalism in wood frog tadpoles *Lithobates sylvaticus*. Current Zoology, 60(5), 571–580.

Jefferson, D. M., Hobson, K. A., Demuth, B. S., Ferrari, M. C. O., & Chivers, D. P. (2014b). Frugal cannibals: How consuming conspecific tissues can provide conditional benefits to wood frog tadpoles (*Lithobates sylvaticus*). Naturwissenschaften, 101(4), 291–303. https://doi.org/10.1007/S00114-014-1156-4/METRICS.

John, K. R., & Fusaro, J. M. (1981). Growth and metamorphosis of solitary *Rana pipiens* tadpoles in confined space. Copeia, 1981(3), 737. https://doi.org/10.2307/1444591.

Jr., C. H., Roberts, L., Keen, S., Larson, A., & Eisenhour, D. (2009). Animal diversity (5th Edition). McGraw-Hill Higher Education.

Kearney, B. D., Byrne, P. G., & Reina, R. D. (2016). Short-and long-term consequences of developmental saline stress: impacts on anuran respiration and behaviour. The Royal Society Open Science. https://doi.org/10.1098/rsos.150640.

Kirschner L. B. (1983). Sodium chloride absorption across the body surface: frog skins and other epithelia. The American journal of physiology, 244(4), R429–R443. https://doi.org/10.1152/ajpregu.1983.244.4.R429.

Klein, B., Regnet, R. A., Krings, M., & Rödder, D. (2021). Larval development and morphology of six Neotropical poison-dart frogs of the genus *Ranitomeya* (Anura: Dendrobatidae) based on captive-raised specimens. Bonn Zoological Bulletin, 69(2), 191–223. https://doi.org/10.20363/BZB-2020.69.2.191.

Köhler, G., & Thammachoti, P. (2023). Comparative study of the larval development of four anuran species from the Khorat Plateau, Thailand. Raffles Bulletin of Zoology, 71, 26–50. https://doi.org/10.26107/RBZ-2023-0003.

Kupferberg, S. J. (1997). The role of larval diet in anuran metamorphosis. American Zoologist, 37(2),146–159. https://doi.org/10.1093/icb/37.2.146.

Kuroshima, S., & Tominaga, A. (2021). Normal development of an aquatic spawning Tree Frog, *Buergeria japonica* (Amphibia: Rhacophoridae). Current Herpetology, 40(2). https://doi.org/10.5358/hsj.40.169.

Langley, L. (2023). Cannibalism in animals is more common than you think. National Geographic. https://www.nationalgeographic.com/animals/article/cannibalism-common-leopards-fish-invertebrates Accessed 19 October 2023.

Laurila, A., & Kujasalo, J. (1999). Habitat duration, predation risk and phenotypic plasticity in common frog (*Rana temporaria*) tadpoles. Journal of Animal Ecology, 68(6), 1123–1132. https://doi.org/10.1046/J.1365-2656.1999.00354.X.

Leips, J., & Travis, J. (1994). Metamorphic responses to changing food levels in two species of Hylid Frogs. Ecology, 75(5), 1345–1356. https://doi.org/10.2307/1937459.

Lukas, P. (2021). Larval cranial anatomy of the Eastern Ghost Frog (*Heleophryne orientalis*). Acta Zoologica, 102(4), 452–466. https://doi.org/10.1111/azo.12352.

Macedo, A. D., & Garwood, J. (2023). Larval life history of Coastal Tailed Frogs (*Ascaphus truei*) across an elevational gradient in Northern California: Implications for a Changing Climate. Article in Journal of Herpetology. https://doi.org/10.1607/21-073.

Maciel, T. A., & Juncá, F. A. (2009). Effects of temperature and volume of water on the growth and development of tadpoles of *Pleurodema diplolister* and *Rhinella granulosa* (Amphibia: Anura). Zoologia (Curitiba), 26(3), 413–418. https://doi.org/10.1590/S1984-46702009000300005.

McDiarmid, R., & Altig, R. (1999). Tadpoles: The biology of anuran larvae. The University Of Chicago Press.

Merilä, J., Laurila, A., Pahkala, M., Räsänen, K., & Timenes Laugen, A. (2016). Adaptive phenotypic plasticity in timing of metamorphosis in the common frog *Rana temporaria*. Ecoscience, 7(1), 18–24. https://doi.org/10.1080/11956860.2000.11682566.

Miyata, K., & Ose, K. (2012). Thyroid Hormone-disrupting effects and the amphibian metamorphosis assay. Journal of Toxicologic Pathology, 25(1), 1–9. https://doi.org/10.1293/TOX.25.1.

Modak, N., Chunekar, H., & Padhye, A. (2018). Life history of Western Ghats endemic and threatened anuran – Matheran leaping frog, (*Indirana leithii*) with notes on its feeding preferences. Journal of Natural History, 52(27–28), 1745–1761. https://doi.org/10.1080/00222933.2018.1488008.

Montaña, C. G., Silva, S. D. G. T. M., Hagyari, D., Wager, J., Tiegs, L., Sadeghian, C., Schriever, T. A., & Schalk, C. M. (2019). Revisiting "what do tadpoles really eat?" A 10-year perspective. Freshwater Biology, 64(12), 2269–2282. https://doi.org/10.1111/fwb.13397.

Moore, M. K., & Klerks, P. L. (1998). Interactive effect of high temperature and low pH on sodium flux in tadpoles. Journal of Herpetology, 32(4), 588–592. https://doi.org/10.2307/1565217.

Morrison, C., & Hero, J. M. (2003). Geographic variation in life-history characteristics of amphibians: a review. Journal of Animal Ecology, 72(2), 270–279. https://doi.org/10.1046/J.1365-2656.2003.00696.X.

Mueller, C. A., Augustine, S., Kooijman, S. A. L. M., Kearney, M. R., & Seymour, R. S. (2012). The trade-off between maturation and growth during accelerated development in frogs. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 163(1), 95–102. https://doi.org/10.1016/J.CBPA.2012.05.190.

Murakami, Y. (2021). Brief note on the life cycle of amphibians. Entomology, Ornithology & Herpetology: Current Research, 10(10), 1–1.

Nascimento, F. A. C., Aguilar, A. V., Pansonato, A., Lisboa, B. S., & Vilela, B. (2022). Reproductive notes and larval development of *Macrogenioglottus alipioi* (Anura: Odontophrynidae) from the northern Atlantic forest. Phyllomedusa, 21(2), 181–203. https://doi.org/10.11606/ISSN.2316-9079.V21I2P181-203.

Newman, R. A. (1992). Adaptive plasticity in amphibian metamorphosis. BioScience, 42(9), 671–678. https://doi.org/10.2307/1312173.

Nicieza, A. G., Álvarez, D., & Atienza, E. M. S. (2006). Delayed effects of larval predation risk and food quality on anuran juvenile performance. Journal of Evolutionary Biology, 19(4), 1092–1103. https://doi.org/10.1111/J.1420-9101.2006.01100.X.

Orizaola, G. N., & Laurila, A. (n.d.). Intraspecific variation of temperature-induced effects on metamorphosis in the pool frog (*Rana lessonae*). https://doi.org/10.1139/Z09-045.

Paul, B., Sterner, Z. R., Buchholz, D. R., Shi, Y. B., & Sachs, L. M. (2022). Thyroid and corticosteroid signaling in amphibian metamorphosis. *Cells*, *11*(10), 1595. https://doi.org/10.3390/cells11101595.

Pad, A. D., And, H., & Ghate, H. V. (1988). Effect of altered pH on embryos and tadoles of the frog *Microhyla ornata.* Herpetological Journal, 1(07), 276-279.

Padiath, Q. S. (2023). Genes and chromosomes. MSD Manual Consumer Version. https://www.msdmanuals.com/home/fundamentals/genetics/genes-and-chromosomes Accessed 19 October 2023.

Phuge, S. K. (2017). High temperatures influence sexual development differentially in male and female tadpoles of the Indian skipper frog, *Euphlyctis cyanophlyctis*. Journal of Biosciences, 42(3), 449–457. https://doi.org/10.1007/S12038-017-9689-2.

Pigliucci, M., Murren, C. J., & Schlichting, C. D. (2006). Phenotypic plasticity and evolution by genetic assimilation. The Journal of Experimental Biology, 209(12), 2362–2367. https://doi.org/10.1242/jeb.02070.

Pough, F. H. (1976). Acid precipitation and embryonic mortality of Spotted Salamanders, *Ambystoma maculatum.* Science, 192(4234), 68–70. https://doi.org/10.1126/SCIENCE.3852.

Qian, T., Li, Y., Chen, J., Li, P., & Yang, D. (2023). Tadpoles of four sympatric megophryinid frogs (Anura, Megophryidae, Megophryinae) from Mangshan in southern China. ZooKeys, 1139, 1–32. https://doi.org/10.3897/zookeys.1139.81641.

Qiang, D., Jian-Hong, D., Cheng, L., Zhi-Jun, L., & Yue-Zhao, W. (2004). Anti-predator behavior of tadpoles of *Rana daunchina* to a novel crawfish (*Procambarus clarkii*). Biodiversity Science, 12(5), 481. https://doi.org/10.17520/BIODS.2004059.

Ra¨sa¨nen, K., Ra¨sa, R., Ra¨sa¨nen, R., Laurila, A., Merila¨3, J., & Merila¨3, M. (2003). Geographic variation in acid stress tolerance of the moor frog, *Rana arvalis*. I. Local adaptation. Evolution, 57(2), 352–362.

https://doi.org/10.1111/J.0014-3820.2003.TB00269.X.

RÄsänen, K., Laurila, A., & Merilä, J. (2002). Carry-over effects of embryonic acid conditions on development and growth of *Rana temporaria* tadpoles. Freshwater Biology, 47(1), 19–30. https://doi.org/10.1046/J.1365-2427.2002.00777.X.

Relyea, R. A. (2001). The lasting effects of adaptive plasticity: Predator-induced tadpoles become Long-Legged Frogs. Ecology, 82(7), 1947. https://doi.org/10.2307/2680059.

Relyea, R. A. (2002). Competitors-induced plasticity in tadpoles: consequences, cues, and connections to predator-induced plasticity. Ecological Monographs, 72(4), 523–540.

Relyea, R. A., & Diecks, N. (2008). An unforeseen chain of events: Lethal effects of pesticides on frogs at sublethal concentrations. Ecological Applications, 18(7), 1728–1742. https://doi.org/10.1890/08-0454.1.

Richter-Boix, À., Orizaola, G., & Laurila, A. (2014). Transgenerational phenotypic plasticity links breeding phenology with offspring life-history. Ecology, 95(10), 2715–2722. https://doi.org/10.1890/13-1996.1.

Richter-Boix, A., Llorente, Gustavo A., & Montori, A. (2006). Effects of phenotypic plasticity on post-metamorphic traits during pre-metamorphic stages in the anuran *Pelodytes punctatus*. Evolutionary Ecology Research, 8(2), 309–320.

Rödder, D., & Behr, N. (2014). Larval development stages and husbandry of the Rice Frog *Microhyla mukhlesuri* Hasan et al., 2014 (Anura: Microhylidae). Bonn zoological Bulletin, 67(2), 109-116. https://doi.org/10.20363/BZB-2018.67.2.109.

Rojas, B., Devillechabrolle, J., & Endler, J. A. (2014). Paradox lost: Variable colour-pattern geometry is associated with differences in movement in aposematic frogs. Biology Letters, 10(6). https://doi.org/10.1098/RSBL.2014.0193.

Rowley, J.. Frog sex. The Australian Museum. (2017). https://australian.museum/blog/science/frog-sex/#:~:text=In%20most%20frog%20species%2C%20males,call%20of%20their%20own%20species. Accessed 19 October 2023.

Rose, C. S. (2005). Integrating ecology and developmental biology to explain the timing of frog metamorphosis. Trends in Ecology & Evolution, 20(3), 129–135. https://doi.org/10.1016/J.TREE.2005.01.005.

Ruthsatz, K., Dausmann, K. H., Reinhardt, S., Robinson, T., Sabatino, N. M., Peck, M. A., & Glos, J. (2020). Post-metamorphic carry-over effects of altered thyroid hormone level and developmental temperature: physiological plasticity and body condition at two life stages in *Rana temporaria*. Journal of Comparative Physiology, 190(3), 297–315. https://doi.org/10.1007/S00360-020-01271-8.

Sachs, L. M., & Buchholz, D. R. (2019). Insufficiency of thyroid hormone in frog metamorphosis and the role of glucocorticoids. Frontiers in Endocrinology, 10, 287. https://doi.org/10.3389/FENDO.2019.00287/BIBTEX.

Saha, B. K., & Gupta, B. B. P. (2011). The development and metamorphosis of endangered frog, *Rana leptoglossa* (Cope, 1868). International Journal of Advanced Biological Research, 1(1), 67–76.

Sanzo, D., & Hecnar, S. J. (2006). Effects of road de-icing salt (NaCl) on larval wood frogs (*Rana sylvatica*) Road salts have toxic effects on amphibians at environmentally realistic concentrations. Environmental Pollution, 140(2), 247–256. https://doi.org/10.1016/j.envpol.2005.07.013.

Kupferberg, S. J. (1997) The role of larval diet in anuran metamorphosis. American Zoologist, 37(2),146–159. https://doi.org/10.1093/icb/37.2.146.

Sarasola-Puente, V., Gosá, A., Oromí, N., Madeira, M. J., & Lizana, M. (2011). Growth, size and age at maturity of the agile frog (Rana dalmatina) in an Iberian Peninsula population. Zoology, 114(3), 150–154. https://doi.org/10.1016/j.zool.2010.11.009.

Schmidt, B. R., Hödl, W., & Schaub, M. (2012). From metamorphosis to maturity in complex life cycles: equal performance of different juvenile life history pathways. Ecology, 93(3), 657–667. https://doi.org/10.1890/11-0892.1.

Semlitsch, R. D., Scott, D. E., & Pechmann, H. K. (1988). Time and size at metamorphosis related to adult fitness in *Ambystoma talpoideum*. Ecology, 69(1), 184–192. https://doi.org/10.2307/1943173.

Schivo, F., Bauni, V., Krug, P., & Quintana, R. D. (2019). Distribution and richness of amphibians under different climate change scenarios in a subtropical region of South America. Applied Geography, 103, 70–89. https://doi.org/10.1016/j.apgeog.2019.01.003.

Shu, L., Laurila, A., & Räsänen, K. (2015). Acid stress mediated adaptive divergence in ion channel function during embryogenesis in *Rana arvalis*. Nature Publishing Group, 5, 14201. https://doi.org/10.1038/srep14201.

Smith, G. R., Krishnamurthy, S. V., Burger, A. C., & Mills, L. B. (2011). Differential effects of malathion and nitrate exposure on American toad and wood frog tadpoles. Archives of Environmental Contamination and Toxicology, 60(2), 327–335. https://doi.org/10.1007/S00244-010-9559-5/METRICS.

Smith, K. G. (2005). Effects of nonindigenous tadpoles on native tadpoles in Florida: evidence of competition. Biological Conservation, 123(4), 433–441. https://doi.org/10.1016/J.BIOCON.2005.01.005.

Steinwascher, K. (1978). Interference and exploitation competition among tadpoles of rana utricularia. Ecology, 59(5), 1039–1046. https://doi.org/10.2307/1938556.

Stevens, D. J. (2004). Pupal development temperature alters adult phenotype in the speckled wood butterfly, *Pararge aegeria*. Journal of Thermal Biology, 29(4–5), 205–210. https://doi.org/10.1016/J.JTHERBIO.2004.02.005.

Stuart, S., Hoffmann, M., Chanson, J., Cox, N., Berridge, R., Ramani, P., & Young, B. (2008). Threatened Amphibian of the World (1st ed.). IUCN, Conservation International and Lynx Edicions.

Stückler, S., Ringler, M., Pašukonis, A., Weinlein, S., Hödl, W., & Ringler, E. (2019). Spatio-temporal characteristics of the prolonged courtship in brilliant-thighed poison frogs, *Allobates femoralis*. Herpetologica, 75(4), 268–279. https://doi.org/10.1655/Herpetologica-D-19-00010.1.

Sumida, M., Islam, M. M., Igawa, T., Kurabayashi, A., Furukawa, Y., Sano, N., Fujii, T., & Yoshizaki, N. (2016). The first see-through frog created by breeding: Description, inheritance patterns, and dermal chromatophore structure. Scientific Reports, 6. https://doi.org/10.1038/SREP24431.

Tanaka, K., & Nishikawa, K. (2022). Developmental stages of Lotic-breeding Toad, *Bufo torrenticola*, with a Comparison to Lentic-breeding *B. japonicus formosus* (Amphibia: Anura: Bufonidae). Current Herpetology, 41(1), 8–23. https://doi.org/10.5358/hsj.41.8.

Teasdale, P., Hendry, L. (n.d.). How to find frogspawn, tadpoles and froglets. Natural History Museum. https://www.nhm.ac.uk/discover/frogspawn-tadpoles-and-froglets.html Accessed 19 October 2023.

Tejedo, M., Marangoni, F., Pertoldi, C., Richter-Boix, A., Laurila, A., Orizaola, G., Nicieza, A. G., Álvarez, D., & Gomez-Mestre, I. (2010). Contrasting effects of environmental factors during larval stage on morphological plasticity in post-metamorphic frogs. Climate Research, 43(1–2), 31–39. https://doi.org/10.3354/CR00878.

Thambirajah, A. A., Koide, E. M., Imbery, J. J., & Helbing, C. C. (2019). Contaminant and environmental influences on thyroid hormone action in amphibian metamorphosis. Frontiers in Endocrinology, 10. https://doi.org/10.3389/fendo.2019.00276.

Thompson, C. M., & Popescu, V. D. (2021). Complex hydroperiod induced carryover responses for survival, growth, and endurance of a pond-breeding amphibian. Oecologia, 195(4), 1071–1081. https://doi.org/10.1007/S00442-021-04881-3/METRICS.

Toft, C. A. (1985). Resource partitioning in amphibians and reptiles. Copeia, 1985(1), 1. https://doi.org/10.2307/1444785.

Townsend, D. S., Stewart, M. M., & Pough, F. H. (1984). Male parental care and its adaptive significance in a neotropical frog. Animal Behaviour, 32(2), 421–431. https://doi.org/10.1016/S0003-3472(84)80278-X.

Trachantong, W., Promya, J., Saenphet, S., & Saenphet, K. (2013). Effects of atrazine herbicide on metamorphosis and gonadal development of *Hoplobatrachus rugulosus*. Maejo Int. J. Sci. Technol, 7, 60–71.

Traijitt, T., Kitana, N., Khonsue, W., & Kitana, J. (2021). Chronological changes in the somatic development of *Hoplobatrachus rugulosus* (Wiegmann, 1834) (Anura: Dicroglossidae). Tropical Natural History, 21(1), 184-199.

Uchiyama, M., & Yoshizawa, H. (1992). Salinity tolerance and structure of external and internal gills in tadpoles of the crab-eating frog, *Rana cancrivora*. Cell and Tissue Research, 267(1), 35–44. https://doi.org/10.1007/BF00318689.

Upton, R., Clulow, S., Mahony, M., & Clulow, J. (2018). Generation of a sexually mature individual of the Eastern dwarf tree frog, Litoria fallax, from cryopreserved testicular macerates: proof of capacity of cryopreserved sperm derived offspring to complete development. Conservation Physiology, 6(1). https://doi.org/10.1093/conphys/coy043.

Urbina, J., Bredeweg, E. M., Cousins, C., Blaustein, A. R., & Garcia, T. S. (2020). Reproductive characteristics of American bullfrogs (*Lithobates catesbeianus*) in their invasive range of the Pacific Northwest, USA. Scientific Report, 10(16271). https://doi.org/10.1038/s41598-020-73206-w.

Vassilieva, A. B., & Nguyen, T. Van. (2023). Restricting living space: Development and larval morphology in sticky frogs (Microhylidae: Kalophrynus) with different reproductive modes. Vertebrate Zoology, 73. https://doi.org/10.3897/vz.73.e98618.

Vidal-García, M., Byrne, P. G., Roberts, J. D., & Keogh, J. S. (2014). The role of phylogeny and ecology in shaping morphology in 21 genera and 127 species of Australo-Papuan myobatrachid frogs. Journal of Evolutionary Biology, 27(1), 181–192. https://doi.org/10.1111/JEB.12292.

Viertel, B. (1999). Salt tolerance of *Rana temporaria*: spawning site selection and survival during embryonic development (Amphibia, Anura). Amphibia-Reptilia, 20(2), 161–171. https://doi.org/10.1163/156853899X00178.

Vitt, L. J., & Caldwell, J. P. (2008). An introductory biology of amphibians and reptiles. In Herpetology: An introductory biology of amphibians and reptiles. https://doi.org/10.1016/B978-0-12-374346-6.X0001-6.

Vodrážková, M., Šetlíková, I., Navrátil, J., & Berec, M. (2022). Different time patterns of the presence of red-eared slider influence the ontogeny dynamics of common frog tadpoles. Scientific Report, 12(1), 1–9. https://doi.org/10.1038/s41598-022-11561-6.

Wake, D. B., & Koo, M. S. (2018). Current biology magazine amphibians.

Walsh, P. T., Downie, J. R., & Monaghan, P. (2008). Predation-induced plasticity in metamorphic duration in *Xenopus laevis.* Functional Ecology, 22(4), 699–705. https://doi.org/10.1111/J.1365-2435.2008.01429.X.

Welch, A. M., Bralley, J. P., Reining, A. Q., & Infante, A. M. (2019). Developmental stage affects the consequences of transient salinity exposure in toad tadpoles. Integrative and Comparative Biology, 59(4), 1114–1127. https://doi.org/10.1093/ICB/ICZ109.

Weygoldt, P. (2009). Evolution of parental care in dart poison frogs (Amphibia: Anura: Dendrobatidae). Journal of Zoological Systematics and Evolutionary Research, 25(1), 51–67. https://doi.org/10.1111/j.1439-0469.1987.tb00913.x.

Wijethunga, U., Greenlees, M., & Shine, R. (2015). The acid test: pH tolerance of the eggs and larvae of the invasive Cane Toad (*Rhinella marina*) in Southeastern Australia. https://doi.org/10.1086/681263.

Wilbur, H. M. (1990). Coping with chaos: Toads in ephemeral ponds. Trends in Ecology & Evolution, 5(2), 37. https://doi.org/10.1016/0169-5347(90)90043-D.

Zachariah, A., Kurian Abraham, R., Das, S., Jayan, K. C., & Altig, R. (2012). A detailed account of the reproductive strategy and developmental stages of *Nasikabatrachus sahyadrensis* (Anura: Nasikabatrachidae), the only extant member of an archaic frog lineage. Zootaxa, 3510, 53–64.

Zartman, J. J., & Shvartsman, S. Y. (2010). Unit operations of tissue development: Epithelial folding. Annual Review of Chemical and Biomolecular Engineering, 1, 231. https://doi.org/10.1146/ANNUREV-CHEMBIOENG-073009-

100919.

Zaya, R. M., Amini, Z., Whitaker, A. S., Kohler, S. L., & Ide, C. F. (2011). Atrazine exposure affects growth, body condition and liver health in *Xenopus laevis* tadpoles. Aquatic Toxicology, 104(3–4), 243–253. https://doi.org/10.1016/J.AQUATOX.2011.04.021.

Zheng, Y. (2021). Suction anchoring with an umbelliform oral disc by the surface-feeding tadpole of *Brachytarsophrys chuannanensis* Fei et al., 2001. Herpetology Notes, 14, 557–561.