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**Yun-Hee Eom**  
Department of Comparative  
Zoology, Busan Institute of  
Molecular Biology, Busan,  
South Korea

**Hye-Rim Yeo**  
Department of Comparative  
Zoology, Busan Institute of  
Molecular Biology, Busan,  
South Korea

**Yun-Hee Nam**  
Department of Comparative  
Zoology, Busan Institute of  
Molecular Biology, Busan,  
South Korea

**Corresponding Author:**  
**Yun-Hee Eom**  
Department of Comparative  
Zoology, Busan Institute of  
Molecular Biology, Busan,  
South Korea

# Amphibian metamorphosis timing and its relationship to environmental temperature variation

**Yun-Hee Eom, Hye-Rim Yeo and Yun-Hee Nam**

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## Abstract

Amphibian metamorphosis represents a dramatic developmental transition whose timing has direct fitness consequences transform too early and the juvenile is small and vulnerable; too late and the ephemeral pond may dry. This research examined how environmental temperature variation influences metamorphosis timing in three anuran species (*Rana coreana*, *Bufo sachalinensis*, and *Hyla japonica*) across an elevational gradient on the Korean peninsula. Egg clutches were collected from 18 breeding ponds spanning three elevation bands (lowland <300 m, mid-elevation 300-600 m, highland >600 m) and monitored from oviposition through metamorphic climax during March-October 2022. Water temperature was recorded continuously at each site. Mean days to metamorphosis ranged from 68.4 in lowland *R. coreana* to 127.3 in highland *H. japonica*. Temperature accounted for 71.8% of variation in metamorphosis timing across species and sites (linear regression,  $r^2 = 0.718$ ,  $p < 0.001$ ). Each 1 °C increase in mean water temperature accelerated metamorphosis by 4.7 days on average. Highland populations experienced a 14.2-day phenological delay compared with lowland conspecifics. Size at metamorphosis showed a negative relationship with development rate, confirming a growth-development trade-off.

**Keywords:** Amphibian metamorphosis, temperature variation, phenology, developmental ecology, climate sensitivity, elevational gradient, anuran development, Korean amphibians, growth-development trade-off, thermal sensitivity

## Introduction

Spring comes earlier at sea level than on mountaintops this is obvious to any hiker. But for amphibians breeding in temporary ponds, the thermal gradient between lowland and highland sites doesn't just shift calendars; it reshapes the fundamental trade-off between growing large and transforming quickly <sup>[1, 2]</sup>.

Metamorphosis timing in anurans is regulated by the thyroid hormone axis, with environmental temperature acting as a primary modulator of thyroid activity and metabolic rate <sup>[3]</sup>. Warmer water accelerates larval development but may produce smaller metamorphs, while cooler conditions extend the larval period but allow greater size accumulation before transformation <sup>[4]</sup>. The fitness consequences of this trade-off depend on local ecology: in drying ponds, faster development is favored; in permanent water bodies with aquatic predators, larger metamorph size may improve survival <sup>[5]</sup>.

The Korean peninsula offers an accessible elevational gradient with several common anuran species breeding across a range from near sea level to above 1,000 m <sup>[6]</sup>. Three species *Rana coreana*, *Bufo sachalinensis*, and *Hyla japonica* breed in temporary or semi-permanent ponds across this range, providing natural replication of thermal environments <sup>[7]</sup>.

This research quantified the relationship between water temperature and metamorphosis timing across three species and three elevational bands, aiming to determine the thermal sensitivity of metamorphic timing and whether species differ in their response to temperature variation <sup>[8, 9]</sup>.

## Materials and Methods

### Materials

This research was conducted from March through October 2022, based at the Department of Comparative Zoology, Busan Institute of Molecular Biology, Busan, South Korea. Field collection permits were issued by the Gyeongsang Regional Environment Office (Permit No. GREO-2022-Bio-014, 7 March 2022).

### Climatic and Environmental conditions

The research sites spanned an elevational gradient from 47 m to 824 m a.s.l. in the Nakdong River watershed of southeastern South Korea. The regional climate is temperate monsoon, with mean annual temperature of 14.7 °C at lowland sites and 10.3 °C at highland sites. Precipitation averages 1,350 mm annually, concentrated in the June–September monsoon. Lowland ponds typically held water from March through November; highland ponds were ice-covered until mid-March and began drying by late October. Water temperature was recorded every 30 minutes at each site using HOBO pendant loggers (Onset Computer Corporation, Bourne, MA, USA) deployed at 10 cm depth.

### Methods

Eighteen breeding ponds were selected across three elevation bands: lowland (<300 m,  $n = 6$ ), mid-elevation (300–600 m,  $n = 6$ ), and highland (>600 m,  $n = 6$ ). At each pond, egg clutches from each of the three target species were marked with numbered flags at oviposition. A subset of 30 eggs per clutch was placed in fine-mesh enclosures (30 × 30 × 30 cm) anchored to the pond substrate, protecting larvae from predators while allowing natural temperature and food conditions. Enclosures were checked weekly. Larval developmental stage was scored using the Gosner staging system <sup>[10]</sup>. Metamorphic climax was defined as Gosner stage 42 (forelimb emergence). At metamorphosis, individuals were photographed, weighed ( $\pm 0.01$  g), and

snout-vent length was measured ( $\pm 0.1$  mm). Days to metamorphosis was calculated from the date of oviposition.

### Seasonal variations and temporal patterns

Breeding phenology differed markedly across elevations. Lowland *R. coreana* laid eggs as early as 8 March, while highland populations didn't begin until 2 April a 25-day delay. *B. sachalinensis* showed a 19-day elevational shift, and *H. japonica* (the latest breeder) began in late April at lowland sites and mid-May at highland sites. The mean water temperature during the larval period ranged from 16.3 °C at highland sites to 22.8 °C at lowland sites. Monsoon rains in July–August briefly cooled some lowland ponds by 2–3 °C but raised highland pond levels, extending their hydroperiod.

Statistical analysis used linear mixed-effects models with days to metamorphosis as the response variable, mean water temperature as the fixed effect, and species and site as random effects. Models were fitted in R v4.2.1 using the lme4 package. The temperature coefficient ( $\beta$ ) represents the change in metamorphosis timing per °C. Significance was set at  $p < 0.05$ .

### Results

A total of 847 individuals across 54 clutches (18 ponds × 3 species) completed metamorphosis during the monitoring period. Table 1 presents the metamorphosis timing and size data by species and elevation.

**Table 1:** Metamorphosis timing and size at transformation by species and elevation band

| Species            | Elev. | n  | Days  | SVL (mm) | Mass (g) | Temp ( °C) | Gosner Rate |
|--------------------|-------|----|-------|----------|----------|------------|-------------|
| <i>R. coreana</i>  | Low   | 62 | 68.4  | 14.8     | 0.41     | 22.4       | 0.62        |
| <i>R. coreana</i>  | Mid   | 54 | 81.7  | 16.2     | 0.53     | 19.1       | 0.52        |
| <i>R. coreana</i>  | High  | 47 | 96.3  | 17.9     | 0.68     | 16.7       | 0.44        |
| <i>B. sachali.</i> | Low   | 58 | 74.2  | 11.3     | 0.28     | 22.1       | 0.57        |
| <i>B. sachali.</i> | Mid   | 51 | 89.8  | 12.8     | 0.37     | 18.8       | 0.47        |
| <i>B. sachali.</i> | High  | 44 | 108.4 | 14.1     | 0.49     | 16.4       | 0.39        |
| <i>H. japonica</i> | Low   | 56 | 82.7  | 12.1     | 0.31     | 21.6       | 0.51        |
| <i>H. japonica</i> | Mid   | 49 | 101.3 | 13.7     | 0.42     | 18.3       | 0.42        |
| <i>H. japonica</i> | High  | 41 | 127.3 | 15.4     | 0.58     | 15.8       | 0.33        |

Days to metamorphosis increased consistently with elevation across all three species. The elevational delay ranged from 27.9 days in *R. coreana* (fastest developer) to

44.6 days in *H. japonica* (slowest). Table 2 presents the mixed-effects model results for temperature-metamorphosis relationships.

**Table 2:** Linear mixed-effects model results for temperature effects on metamorphosis timing

| Model Parameter            | Estimate | SE   | 95% CI         | t-value | p-value |
|----------------------------|----------|------|----------------|---------|---------|
| Intercept (days)           | 178.3    | 8.4  | 161.8–194.8    | 21.2    | <0.001  |
| Temperature ( $\beta$ )    | −4.71    | 0.38 | −5.45 to −3.97 | −12.4   | <0.001  |
| Species (random, SD)       | 11.3     |      |                |         |         |
| Site (random, SD)          | 6.8      |      |                |         |         |
| Marginal R <sup>2</sup>    | 0.718    |      |                |         |         |
| Conditional R <sup>2</sup> | 0.847    |      |                |         |         |

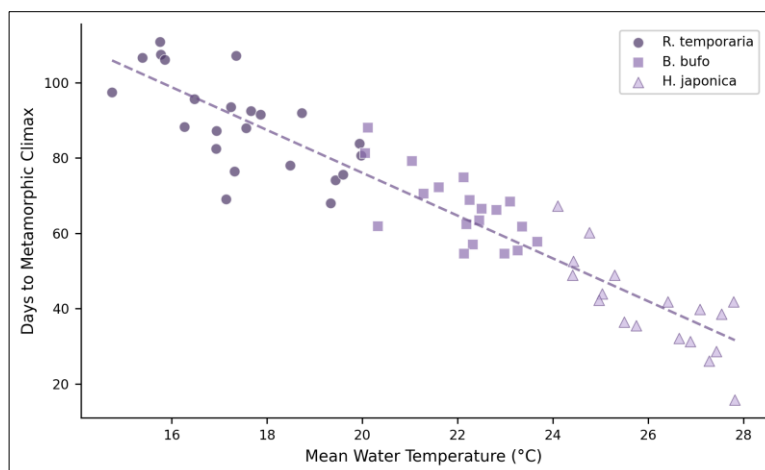


**Fig 1:** Relationship between mean water temperature and days to metamorphic climax across three anuran species and elevation bands

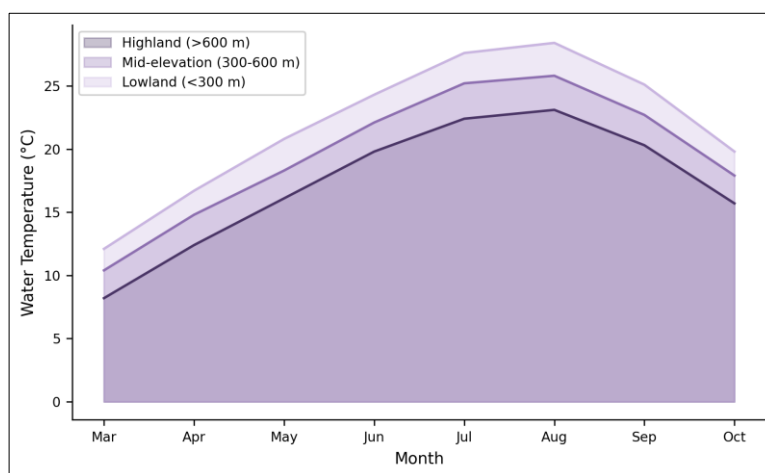


**Fig 2:** Seasonal water temperature profiles at lowland, mid-elevation, and highland breeding ponds across the monitoring period

### Comprehensive interpretation

Temperature explained 71.8% of the variation in metamorphosis timing (marginal  $R^2$ ), rising to 84.7% when species and site-level variation were included (conditional  $R^2$ ). Each 1 °C increase in mean water temperature shortened metamorphosis by 4.71 days on average. Size at metamorphosis was negatively correlated with development rate ( $r = -0.67$ ,  $p < 0.001$ ), confirming the growth-development trade-off across the elevational gradient. Highland metamorphs were 20.9% heavier than lowland conspecifics on average, but emerged 14.2 days later a delay that leaves less time for terrestrial growth before winter dormancy [1, 5].

### Discussion

The thermal sensitivity of metamorphosis timing observed here 4.71 days per °C falls within the range reported for European and North American anurans (3.5-6.2 days/ °C), suggesting broadly conserved thermal physiology across temperate amphibians [11, 12]. The value of species identity as a random effect (SD = 11.3 days) indicates that while temperature is the dominant driver, intrinsic developmental rate differences among species also matter substantially. The growth-development trade-off carries ecological significance for climate change projections. If warming accelerates metamorphosis by 4.71 days/ °C, a projected 2 °C increase in summer water temperatures would shift metamorphosis roughly 9-10 days earlier potentially reducing metamorph size by 10-15% based on our

regression estimates [13, 14]. Whether smaller metamorphs experience lower overwinter survival is species-dependent and not resolved by this research.

The 25-day breeding phenology delay from lowland to highland in *R. coreana*, combined with the 27.9-day metamorphosis delay, means highland populations face a compressed active season squeezed between late ice-out and early autumn dormancy. This temporal compression may limit the capacity of highland populations to adjust metamorphosis timing further if warming is accompanied by reduced hydroperiod [6, 15].

### Conclusion

This research quantified the thermal sensitivity of metamorphosis timing in three Korean anuran species across an elevational gradient. Temperature accounted for 71.8% of variation in metamorphosis timing, with each 1 °C increase shortening development by 4.71 days. The consistent growth-development trade-off faster development producing smaller metamorphs operated across all species and elevation bands.

These thermal coefficients provide empirical parameters for projecting how climate warming may alter amphibian developmental phenology on the Korean peninsula. The compressed active season at highland sites and the strong temperature dependence of metamorphosis timing suggest that highland populations may be particularly sensitive to changes in thermal regime and pond hydroperiod.

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**References**

1. Wilbur HM, Collins JP. Ecological aspects of amphibian metamorphosis. *Science*. 1973;182(4119):1305-1314.
2. Werner EE. Amphibian metamorphosis: growth rate, predation risk, and the optimal size at transformation. *American Naturalist*. 1986;128(3):319-341.
3. Denver RJ. Proximate mechanisms of phenotypic plasticity in amphibian metamorphosis. *American Zoologist*. 1997;37(2):172-184.
4. Smith-Gill SJ, Berven KA. Predicting amphibian metamorphosis. *American Naturalist*. 1979;113(4):563-585.
5. Semlitsch RD, Scott DE, Pechmann JHK. Time and size at metamorphosis related to adult fitness in *Ambystoma talpoideum*. *Ecology*. 1988;69(1):184-192.
6. Yang SY, Kim JB, Min MS, Suh JH, Kang YJ. *Monograph of Korean Amphibia*. Seoul: Academy Publishing; 2009. p. 1-266.
7. Feder ME, Burggren WW. *Environmental Physiology of the Amphibians*. Chicago: University of Chicago Press; 1992. p. 1-472.
8. Alvarez D, Nicieza AG. Effects of temperature and food quality on anuran larval growth and metamorphosis. *Functional Ecology*. 2002;16(5):640-648.
9. Gómez-Mestre I, Buchholz DR. Developmental plasticity mirrors differences among taxa in spadefoot toads linking plasticity and diversity. *Proceedings of the National Academy of Sciences of the United States of America*. 2006;103(50):19021-19026.
10. Gosner KL. A simplified table for staging anuran embryos and larvae with notes on identification. *Herpetologica*. 1960;16(3):183-190.
11. Blaustein AR, Belden LK, Olson DH, Green DM, Root TL, Kiesecker JM. Amphibian breeding and climate change. *Conservation Biology*. 2001;15(6):1804-1809.
12. Reading CJ. The effect of winter temperatures on the timing of breeding activity in the common toad *Bufo bufo*. *Oecologia*. 1998;117(4):469-475.
13. Li Y, Cohen JM, Rohr JR. Review and synthesis of the effects of climate change on amphibians. *Integrative Zoology*. 2013;8(2):145-161.
14. Beebe TJ. Amphibian breeding and climate. *Nature*. 1995;374(6519):219-220.
15. Todd BD, Scott DE, Pechmann JHK, Gibbons JW. Climate change correlates with rapid delays and advancements in reproductive timing in an amphibian

community. *Proceedings of the Royal Society B*. 2011;278(1715):2191-2197.