



Praying Mantis Instar Variation on Number and Duration Caused by Environmental and Genetic Factors

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Abstract:

Praying mantises, which are a kind of hemimetabolous insect, require molting in their lives to grow. Different individuals of praying mantises can have different instar numbers, and this variation is caused by many different factors. From the information collected for this literature review, three major factors have been identified as having an impact on the instar number and instar duration variation. Firstly, both high and low temperatures might increase the number of instars. Temperature fluctuations can cause the growth rate to decline, so some praying mantises might add an extra instar to compensate for this change. Secondly, in the studies analyzed about related insects, both excess and insufficient nutrition can make an insect proceed through each instar faster; therefore, it is hard to infer about praying mantises. Thirdly, genetics and developmental factors have programmed praying mantises to have different numbers of instars due to sexual dimorphism. Due to genetics, some species even adapt the bet-hedging strategy, making the mantises develop at a different rate and maturing at a different time, ensuring the population would adapt to the changing environment. Developmental changes in the last instar before eclosion can also cause variation on the instars. The last instar is the longest because in order to get ready for adulthood, the wing, genital, and antennae have to be grown and modified during this instar, and the hormone types also shift a lot. As a conclusion, both the external environmental factors like temperature and nutrition, as well as genetic and developmental factors contribute to the mantis instar number variation and instar duration.

Introduction:

Praying mantises, like many other kinds of Hemimetabolous insects, perform molting- the act of shedding their exoskeleton to grow bigger between each juvenile stage. The exoskeleton of praying mantises is made of chitin, a hard and rigid material, excellent for providing protection for the mantis's body. However, the exoskeleton will not be able to stretch or grow with the insect. So in order to grow, the mantis must shed their exoskeleton periodically and grow a new one instead. The molting process doesn't simply allow the insect to grow, it is also responsible for wing development, sexual maturation, repairing of the injured/lost body parts, color change, etc. The word instar is used to describe the stage an insect is in between two molts. When an insect first hatches, it is in its first instar. Its instar number increases by 1 each time it molts. There is usually a set number of instars each species and sex has. But observations have shown that variation of instars can happen quite frequently for praying mantises, like prolonged instars or having less instar. This phenomenon happens due to a variety of factors, and the underlying cause of all the changes are the result of the mantis's attempt to adapt to the environment and increase its fitness (Esperk et al.). This is a very interesting phenomenon for two reasons. For one, the phenomenon causes mantis breeders like me issues, such as not being able to predict when they will mature. The second reason is it is important to understand if climate change interacts with this variation and could be an explanation for population decreases of mantises in some areas. Many studies have shown the decline in praying mantis population declines throughout the world mainly because of habitat destruction, invasive species competition, and abnormal life cycle caused by climate change (Entomology Today, Edmunds).

The intention of this literature review is to examine potential causes of instar number and instar duration variation. Specifically, temperature, nutrition, and genetics will be examined. When collecting research online, I found the sources I can find about the topic of instar number and instar duration variation of praying mantises specifically is very limited. For many topics, I have used other insect species closely related to praying mantises that are representative species to find universal patterns that apply to all insects when mantis specific research is limited. By doing so, we can learn from other insects and make predictions as to what would be the case of praying mantises. I have made sure my predictions and the sources about other insects have a referential value based on my own experience of praying mantis behavior as a praying mantis breeder and have put lots of pictures of my own about praying mantises as an supplemental proof to my claim. My intention of writing this literature review article is because research presented online about the topic of instar number and instar duration variation of praying mantises specifically is rare.

1. Exoskeleton Structure and Molting Mechanisms in Praying Mantis

The exoskeleton of praying mantises consists of two main parts, the procuticle and the epicuticle. The procuticle is the thick inner layer made of chitin and protein. The epicuticle is the waterproof and outermost layer, made of protein and waxes. Both of the layers won't grow with the mantis, so they have to be shed in order for the mantis to get bigger. During the molting process, both of the layers will be discarded and the new exoskeleton will be exposed and hardened after molting. The new exoskeleton layer is formed underneath the old layer just prior to the molting process.

The molting process is regulated by hormones. The hormone directly responsible for the process is called ecdysone. This hormone however will not determine when the mantis will molt; the timing is controlled by very complicated factors, like the growth and development level, humidity, temperature, etc.. Epidermis cells are the cells laying below the exoskeleton. After the secretion of ecdysone hormone, apolysis, the process of separating epidermis cells away from the exoskeleton, will start. Epidermis cells will secrete molting fluid to fill in the gap and begin forming the new exoskeleton. Enzymes are released in the molt fluid secreted by epidermal cells, and will dissolve the inner layer of the procuticle called the endocuticle of the old layer of exoskeleton, recycling some of the materials ("Arthropod - Exoskeleton, Segmentation, Jointed Appendages | Britannica", "Morphogenesis").

During the shedding process, the old exoskeleton will split along the genetically predetermined weak point of the praying mantis: the front of the thorax, near the head. The mantis then will pull itself out of the split by increasing its hemolymph (fluid found in invertebrates acting like blood) pressure and contracting its muscles (Truman and Riddiford, "Endocrine Insights into the Evolution of Metamorphosis in Insects", Douglas et al.). This aligns with my observation during praying mantis molting. When they come out of their old molt, their body size increases dramatically, sometimes even reaching 2 times the size of its old molt. After a while when the mantis body hardens, the mantis body will shrink a little, which is likely due to the increase in hemolymph pressure in its body. Their body would also writhe and contract almost every second, showing that they are contracting their muscles.

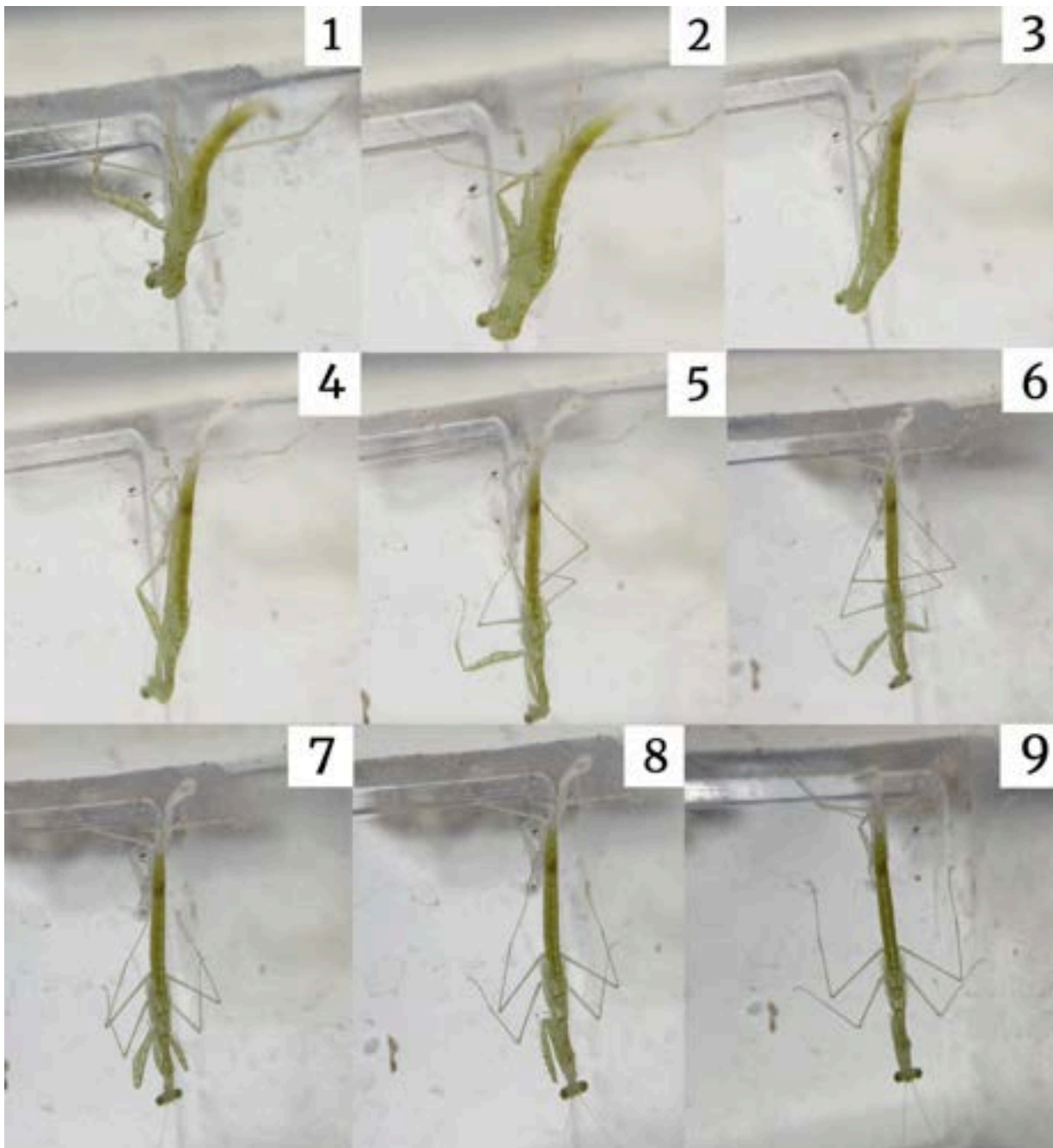


Figure 1. *Eomantis yunnanensis* female raised from ootheca brought from Taobao molting, going into the penultimate instar.

Section labeled 1 and 2 shows the praying mantis squeezing itself from the genetically predetermined weak point on its thorax of the old exoskeleton.

Section labeled 3, 4, 5, and 6 shows the praying mantis pulling the rest of its body parts from the old exoskeleton.

Section labeled 7, 8, and 9 shows the praying mantis resting by hanging onto its old exoskeleton and waiting for its body to dry up and harden at the same time.



Figure 2. (left) *Creobroter vitripennis* nymph raised from ootheca laid by wild caught females from Shenzhen, China molting.

Figure 3. (center) *Stagmomantis carolina* nymph raised from L3 brought from other hobbyists. Picture taken right after its final molt into adulthood.

Figure 4. (right) *Phyllocrania paradoxa* molting (raised from an ootheca bred by me).

2. Effects Of Temperature on Instar Number and Instar Duration and Whether it Causes Abnormality

The temperature is a main cause of instar time and number abnormality. Each kind of insect has its optimum temperature for its growth and development. The development rate typically increases with the temperature until reaching the optimum, and then quickly decreases if the temperature has reached beyond the optimal (Régnière et al.). To adapt with the temperature, insects would adjust their growth accordingly.

There are two concepts that need to be clarified before discussing how high and low temperature affects mantises specifically: “development rate” and “growth rate”. For insects, development rate is usually measured by how quick the insect goes from each one of its life stages to the next, it’s usually about the time it takes per instar, or the days it takes to reach adulthood. Growth rate, however, is about the body mass (how big) the insect grows (Nijhout et al., Hilbert, Régnier et al.).

2.1 High temperature affects

When the temperature is high, the insect’s metabolism will speed up, with shorter and faster hormone cycles (ecdysone release), it will experience faster development, meaning it will take less time for the insect to develop in each instar (Régnière et al.). As a result, the insect might experience insufficient growth rate, because usually the more time the insect spends intaking nutrients in each instar, the more body mass it accumulates. Sometimes to compensate for this issue, the insect would add an extra instar (Esperk et al.). The theory here is not mantis specific, but can be applied to mantises. The articles I referenced gathered their findings from 2

species of budworms, kinds of budmoth, melon fly, and beetle. This tendency gathered from a wide range of insect species can possibly be representative of all insects.

2.2 Lower temperature affects

Low temperature also tends to increase the instar number of the insect. Low growth rate is associated with low temperature, which means the insect would grow less during each instar, so a “compensation scenario” would be triggered. The insect would add another instar, to compensate for the insufficient amount of growth during previous instars (Esperk et al.).

3. Effects of nutrition on instar number and Instar duration and whether it causes abnormality

3.1. Having faster development when more nutrition are given to insects

In the previous section, we discussed how nutrition intake per instar is affected by temperature and development rate. Now we will focus on how nutrition intake will be the factor affecting instar numbers and instar duration. A study of a mosquito species *Anopheles darling* can be a valuable reference to the understanding of this concept in praying mantises. From this study, it has shown that the increase in nutrient availability have both increased the growth rate and development rate of *A. darling*. *A. darling* individuals are given three types of food supply: low, medium, and high food supply. In Figure 1, it has shown that the more nutrients provided to the mosquito, the faster it will grow and reach each instar with lesser time, which means there is a positive correlation between nutrients and development rate (Araújo et al.).

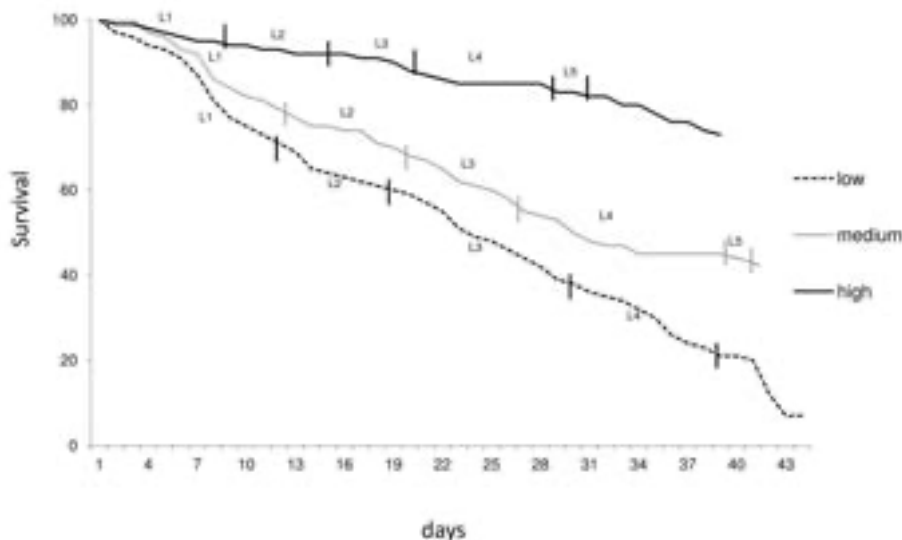


Figure 5. The duration of each instar and survival rate of *Anopheles darling* during different developmental stages in relation to different food amounts. The developmental time and survival rate of *A. darling* has decreased with increasing food provided in general ($p < 0.001$) (From Araújo et al.).

3.2 Having faster development when less nutrition are given to insects

In another study of the growth of *Nilaparvata lugens* (brown planthopper, a single feeding rice pest), have produced results somehow different than the one mentioned above. In this lab,

researchers fed the *N. lugens* nymphs with food of different nutrition concentration (25%, 50%, and 100%). Although in this study, the survival rate also increased (Figure 5) and the overall growth rate increased, shown by figure 3 and figure 4 (shown by the increase in body length and body weight), with the increased food availability, interestingly, the development rate actually increased with the decreased food availability (Figure 2). That is to say, when given an insufficient amount of food to the *N. lugens*, it takes them less time to go through each instar (Kang et al.).

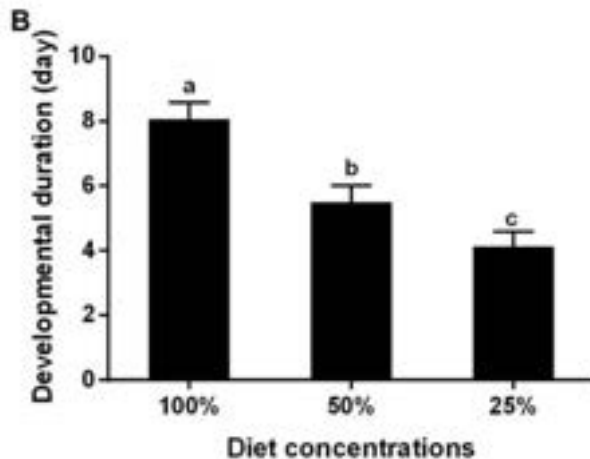


Figure 6. Developmental period of *Nilaparvata lugens* in relation to diet concentration. With the increase in diet concentration, developmental duration of *Nilaparvata lugens* increased, with individuals fed with 25% nutrient having the shortest developmental duration and individuals fed with 100% nutrient having the longest developmental duration. The differences in developmental duration measured in days are statistically significant among different treatment groups ($p < 0.05$) (From Kang et al.).

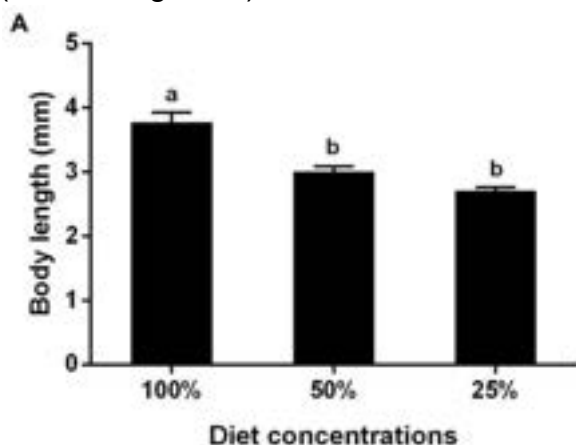


Figure 7. Body length of *Nilaparvata lugens* in relation to diet concentration. The greater the concentration of diet, the greater body length *Nilaparvata lugens* had, with individuals fed with 25% nutrient having the shortest body length and the individuals fed with 100% nutrient having the longest body length. The differences in body length measured in millimeters are statistically significant among different treatment groups ($p < 0.05$) (From Kang et al.).

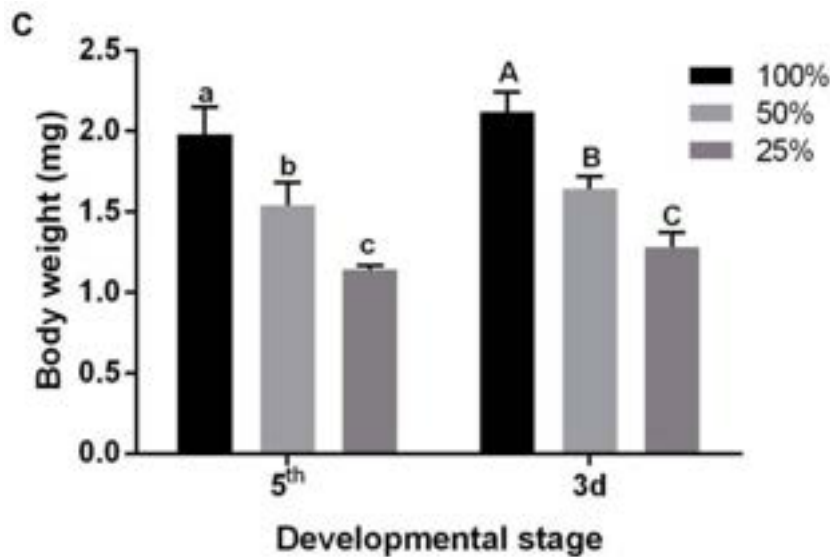


Figure 8. Body weight of *Nilaparvata lugens* in relation to diet concentration measured during two developmental stages. The greater the concentration of diet, the greater body weight *Nilaparvata lugens* had in both developmental stages: fifth instar nymph (5th) and 3 day old adult (3d). In both developmental stages, individuals fed with 100% nutrient had the largest body weight and individuals fed with 25% nutrients had the least amount of body weight. The differences in body weight measured in milligrams are statistically significant among different treatment groups ($p < 0.05$) (From Kang et al.).

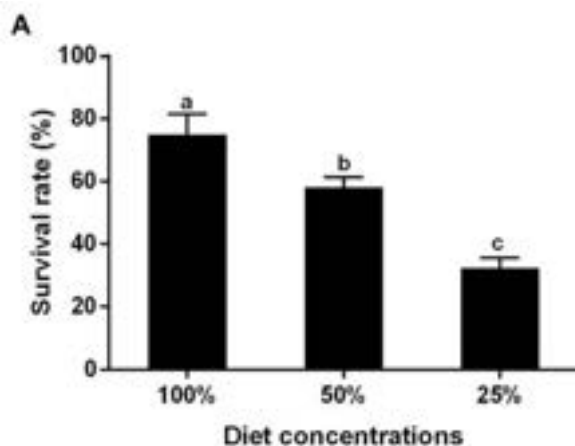


Figure 9. Survival rate of *Nilaparvata lugens* in relation to diet concentration. With the increase in diet concentration, survival rate of *Nilaparvata lugens* increased, with individuals fed with 25% nutrient having the lowest survival rate and individuals fed with 100% nutrient having the highest survival rate.. The differences in developmental duration measured in percentage are statistically significant among different treatment groups ($p < 0.05$) (From Kang et al.).

3.3 Valid prediction for praying mantises

From the two studies in section 3, it has shown that although better growth is always associated with sufficient amounts of nutrition, the relationship between development rate and nutrition amount could be both positive and negative. Because of this, little valid prediction can be made

about the relationship between praying development rate and nutrition received. However, because of the shared hemimetabolous development strategy between praying mantis and *N. lugens*, praying mantis probably has a greater chance of having similar instar duration response to nutrition compared to *N. lugens* than *A. darling*. Therefore, praying mantises probably also have faster development when less nutrition is given.

4. Instar number variation due to genetics

4.1 Instar number variation due to sex

For many praying mantises, there is an instar number difference between the males and the females, and the difference is usually 1-2 instars, as shown in the table below, which contains some of the different praying mantise species I have raised:

Species	Photo of species (taken by author)	Usually observed male instar number	Usually observed female instar number	Source
<i>Stenophylla lobivertex</i>		6	7	From my own experience
<i>Tenodera sinensis</i>		6	7	From my own experience

<i>Hymenopus coronatus</i>		6	8	(Svenson et al.) and my own experience
<i>Phyllocrania paradoxa</i>		6	7	("Ghost Mantis - Phyllocrania Paradoxa Keeping Insects") and my own experience
<i>Pseudoxypops perpulchra</i>		7	9	From my own experience

<i>Theopropus sp.</i>		7	9	From my own experience
<i>Hierodula patellifera</i>		6	7	From my own experience
<i>Stagmomantis carolina</i>				From my own experience



<i>Deroplatys lobata</i>		6	8	From my own experience
<i>Deroplatys truncata</i>		6	8	From my own experience
<i>Deroplatys desiccata</i>		6	8	From my own experience



<i>Pseudempusa pinnapavonis</i>		7	9	From my own experience
<i>Parablepharis asiatica</i>		7	8	From my own experience
<i>Epaphrodita musarum</i>		6	7	From my own experience



<i>Hestiasula sp.</i>		5	6	From my own experience
<i>Rhombodera basalis</i>		8	9	From my own experience
<i>Tropidomantis gressitti</i>		7	8	From my own experience



<i>Ceratomantis saussurii</i>	 A photograph of a dark-colored mantis, Ceratomantis saussurii, perched on a light-colored, possibly glass, surface. The mantis has a robust, somewhat rounded body and long, thin legs.	5	6	From my own experience
<i>Titanodula formosana</i>	 A photograph of a bright green mantis, Titanodula formosana, resting on a white surface. The mantis has a slender, elongated body and long, thin legs. A small black object is visible next to it.	7-8	8-9	From my own experience
<i>Hierodula chinensis</i>	 A photograph of a bright green mantis, Hierodula chinensis, being held gently in a person's hand. The mantis has a slender, elongated body and long, thin legs. The background shows an outdoor setting with trees and a building.	7-8	8-9	From my own experience

<i>Hierodula pistillinota</i>		7-8	8-9	From my own experience
<i>Chilidonoptera sp.</i>		5	7	From my own experience

Table 1. The instar number variation by sex of different praying mantis species. The instar number shown only represents the most common instar number of the male and females from each species.

Many praying mantises sexual dimorphism, and some of them display it to an extreme degree. Sexual dimorphism means “the systematic difference in form between individuals of different sex in the same species” (“Sexual Dimorphism”). Using *Hymenopus coronatus* as an example: the females have a way larger body size compared to the males, which won’t be greater than ½ of the body length of the female. There are several explanations to this sexual dimorphism phenomena. First of all, females could increase their fertility by increasing their body size, because a bigger body means greater amount of offspring produced per female. On the other hand, being small can benefit the male by increasing the dexterity of the male matis when moving locations to find mates and escape the female after mating to avoid being eaten (Huang et al.). *Hymenopus coronatus* females could also benefit from relatively large body size because of their strategy of hunting prey. They use their own body to mimic a flower to attract prey like bees and flies, so being bigger probably means they would be more conspicuous to the prey, therefore they can catch and consume more prey for their greater demand of nutrition compared to males (Huang et al.). This hypothesis could also be applied to other praying mantis

using a similar approach of hunting, especially for many of whom belonging to the family of Hymenopodidae.

Because of these reasons, female mantises need more growth and development to reach their larger body size. To do this, females in some species need more instars to develop and a longer total growth period overall.



Figure 10. *Titanodula formosana* specimens from Chongqing, China made by myself. The female (right) is wild, and the male (left) is the offspring of the female raised in captivity.



Figure 11. *Theopropus elegans* specimens from Cameron Highlands, Pahang, Malaysia made by myself. Both the female (right) and the male (left) are wild.



Figure 12. *Hierodula patellifera* male and female mating from Chongqing, China made by myself. Both the female (insect on the bottom) and the male (insect on the top) are wild.



Figure 13. *Deroplatys lobata* specimens made by myself. The females (left, center) are wild from Cameron Highlands. The male (right) is brought online from eBay and artificially raised from L2.



Figure 14. *Phyllocrania paradoxa* specimens made by myself. The female (right) and male (left) are both brought from Taobao and raised by myself from ootheca.



Figure 15. *Hymenopus coronatus* (from Malaysia) female (larger insect) and male (smaller insect) adults mating. Both were brought from Taobao as nymphs and raised in captivity.



Figure 16. (left) *Hymenopus coronatus* (breed from Guangxi, China) female (larger insect) and male (smaller insect) adults mating. Both were brought from hobbyists as L2 nymphs and raised in captivity.

Figure 17. (right) Same pair of female (left) and male (right) *Hymenopus coronatus* as shown in Figure 16 both at the penultimate instar.



Figure 18. *Theopropus* sp. female wild caught in Xishuangbanna, Yunnan, China (larger insect) and male (smaller insect) wild caught in Xishuangbanna, Yunnan, China adults mating.



Figure 19. *Acromantis japonica* female (larger insect) and male (smaller insect) mating. Figure also shows the ootheca the female has previously laid. Both were brought from Taobao as nymphs.



Figure 20. *Hierodula zhangii* female (insect on the bottom) and male (insect on the top) mating. Both were brought from another hobbyist as nymphs.



Figure 21. *Pseudempusa pinnapavonis* specimens made by myself. The female (left) and male (right) were both purchased on eBay as nymphs.

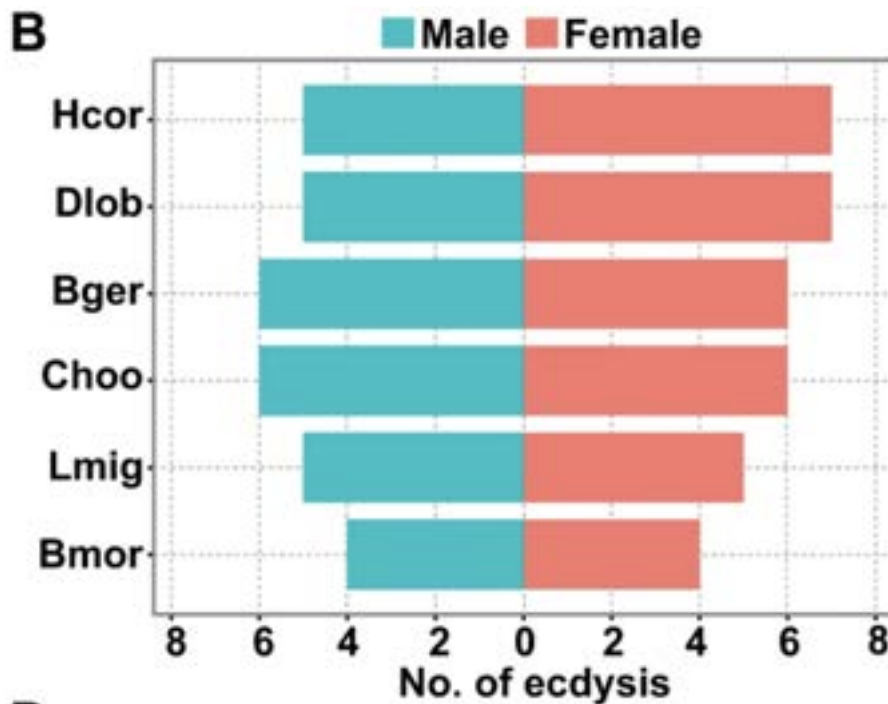


Figure 22. The lifetime average amount of molts (ecdysis means molt) Hcor (*H. coronatus*), Dlob (*D. lobata*), Bger (*B. germanica*), Choo (*Clitarchus hookeri*), Lmig (*Locusta migratoria*), Bmor (*Bombyx mori*) of both sexes have. Hcor and Dlob displayed a difference in average instar

numbers, with females having 2 more instars in average compared to the males (From Huang et al.).

4.2 Instar variation and bet-hedging

In a study of *Stagmomantis limbata*, the researchers have found that even though coming from the same ootheca, the number of instars it takes for the mantises of both sex still varies: 64% of females underwent 6 nymphal instars, 36% of females underwent 7 instars, 91% of males underwent 6 instars, and 9% of the males underwent 5 instars. The researchers have predicted this might be because of a bet-hedging strategy. “The laboratory data allowed for the detection of six-instar and seven-instar patterns among the field-collected females. The field-collected data suggest that females undergoing 6 nymphal instars reach adulthood later in the season, and at smaller body size, than seven-instar females.” (Maxwell)

The habitat of *Stagmomantis limbata* is mainly in Southwestern United States and Mexico. The annual temperatures and precipitation varies a lot from year to year in this area. The temperature in the US naturally fluctuates in an interannual cycle lasting about 2.2- 3.3 years (with 3.3 year cycle present mostly in Western states) and an decadal-scale temperature oscillations about 7 to 10 years (Dettinger et al., “Climate Change in the Southwest - Introduction and Current Climate (U.S. National Park Service)”), which are something *S. limbata* has to adapt to. So praying mantises, at least for the case for *Stagmomantis limbata*, have probably had this mechanism of instar number fluctuation bet-hedging strategy to better adapt to the changing annual climate of their habitat. By doing so, they can make sure that at least some of its offspring would have a chance to survive and reproduce under the optimal climate conditions.

In the study of *S. limbata*, there is still a very interesting detail that’s worth mentioning. Although some females have one more instar, the 7 instar females have reached 4th, 5th, and 6th instar faster than 6 instar females, and had a shorter pronota. The case for males is similar. The 6 instar males have passed each instar faster than 5 instar males on average (Maxwell) This indicates that while some females and males have an more instars, the extra growth is counteracted to a certain degree by reducing the growth in each instar to reduce the effect, as shown by the shorter developmental period and shorter pronota of these two groups on Figure 7, Figure 8, and Table 2.

	6-instar Females	7-instar Females	All females	t-test ^a {6i vs 7i}	5-instar Males	6-instar Males	All Males	t-test ^b {F vs M}
n	23	13	36		4	39	43	
Hatch date (mean)	May 15 (2)	May 15 (2)	May 15 (1)	$t_{16} = 0.03$ ^a $p > 0.9$	May 12 (1)	May 13 (1)	May 13 (1)	$t_{42} = -1.14$ ^a $p > 0.2$
4 th instar								
Hatch-to-4 th (d)	33 (1)	30 (1)	32 (1)	$t_{16} = 3.28$ $p = 0.003^*$	36 (1)	34 (1)	34 (1)	$t_{72} = -3.10$ $p = 0.003^*$
Instar duration (d)	13 (1)	10 (1)	12 (1)	$t_{16} = 3.53$ $p = 0.002^*$	18 (1)	13 (1)	13 (1)	$t_{72} = -2.05$ $p = 0.047$
5 th instar								
Pronotum length (mm)	10.6 (0.1)	9.5 (0.2)	10.2 (0.1)	$t_{16} = 7.63$ $p < 0.001^*$	10.8 (0.2)	9.6 (0.1)	9.7 (0.1)	$t_{72} = 3.65$ $p < 0.001^*$
Instar duration (d)	14 (1)	10 (1)	13 (1)	$t_{16} = -7.73$ ^a $p < 0.001^*$	25 (1)	15 (1)	16 (1)	$t_{72} = 4.40$ ^a $p < 0.001^*$
6 th instar								
Pronotum length (mm)	14.7 (0.2)	13.1 (0.2)	14.1 (0.2)	$t_{16} = 6.62$ $p < 0.001^*$	—	12.5 (0.1)	—	$t_{72} = 7.08$ $p < 0.001^*$
Instar duration (d)	20 (1)	12 (1)	17 (1)	$t_{16} = -9.43$ ^a $p < 0.001^*$	—	24 (1)	—	$t_{72} = 7.25$ ^a $p < 0.001^*$
Dyar's coefficient	1.34 (0.01)	1.37 (0.01)	1.38 (0.01)	$t_{16} = 0.78$ $p > 0.4$	—	1.31 (0.01)	—	$t_{72} = 6.47$ $p < 0.001^*$
7 th instar								
Pronotum length (mm)	—	17.0 (0.3)	—	—	—	—	—	—
Instar duration (d)	—	20 (1)	—	—	—	—	—	—
Dyar's coefficient	—	1.31 (0.01)	—	—	—	—	—	—
adult								
Adult emergence date	Aug 3 (2)	Aug 5 (2)	Aug 4 (1)	$t_{16} = -0.54$ $p > 0.5$	Jul 29 (2)	Aug 7 (3)	Aug 6 (1)	$t_{72} = -1.24$ $p > 0.2$
Hatch-to-adult (d)	80 (2)	82 (2)	81 (1)	$t_{16} = -0.70$ $p > 0.4$	77 (2)	86 (3)	85 (1)	$t_{72} = -2.54$ $p = 0.013$
Pronotum length (mm)	19.4 (0.3)	22.0 (0.4)	20.4 (0.3)	$t_{16} = -5.59$ $p < 0.001^*$	13.6 (0.1)	15.2 (0.1)	15.0 (0.1)	$t_{72} = 17.39$ $p < 0.001^*$
Dyar's coefficient	1.33 (0.01)	1.30 (0.02)	1.32 (0.01)	$t_{16} = 1.78$ $p > 0.05$	1.26 (0.02)	1.22 (0.01)	1.22 (0.01)	$t_{72} = 9.33$ $p < 0.001^*$
Growth rate (mm/d)	0.246 (0.008)	0.270 (0.009)	0.255 (0.008)	$t_{16} = -2.00$ $p = 0.054$	0.176 (0.005)	0.178 (0.003)	0.178 (0.003)	$t_{72} = 11.93$ $p < 0.001^*$

^a t-test comparison of 6-instar females vs 7-instar females.

^b t-test comparison of all females vs all males.

* significant at adjusted α level by the sequential Bonferroni technique.

^c t-test results for reciprocal transformed data ($X' = 1/X$).

Table 2. Growth and developmental parameters measured for laboratory-reared *Stagmomantis limbata* (1992). The table compares growth developmental parameters of different *S. limbata* individuals categorized into groups: 6-instar females, 7-instar females, 5-instar males and 6-instar males. Row 5, 7, 10, 15 shows the pronotum length of different groups of *S. limbata*, which can be used to indicate the growth rate. Column 17 directly shows the growth rate. Developmental rate can be indicated by row 4, 6, 8, and 11 which shows the instar duration and row 14 shows hatch to adult date which can be used to compare the development rate of different *S. limbata* groups. (From Maxwell).

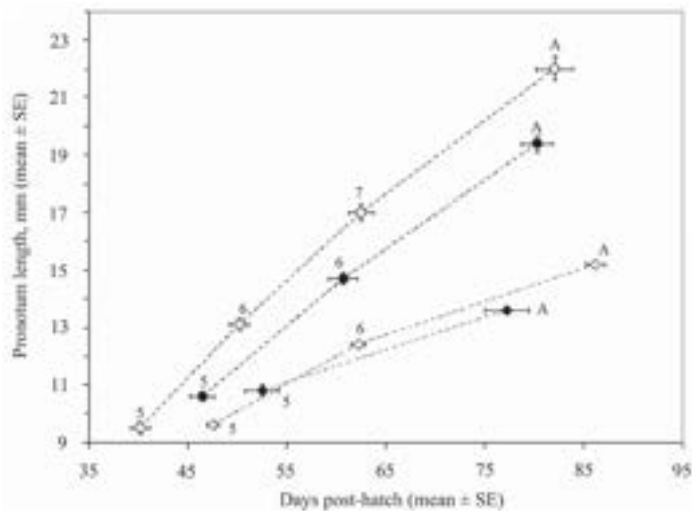


Figure 23. Pronotum length of *Stagmonantis limbata* in different developmental stages and days since hatching. 5=5th instar, 6=6th instar, 7= 7th instar, and A= Adult. 7 instar females are indicated by white circles, 6 instar females are indicated by black circles, 6 instar males are indicated by white diamonds, and 5 instar males are indicated by black diamonds (From Maxwell).

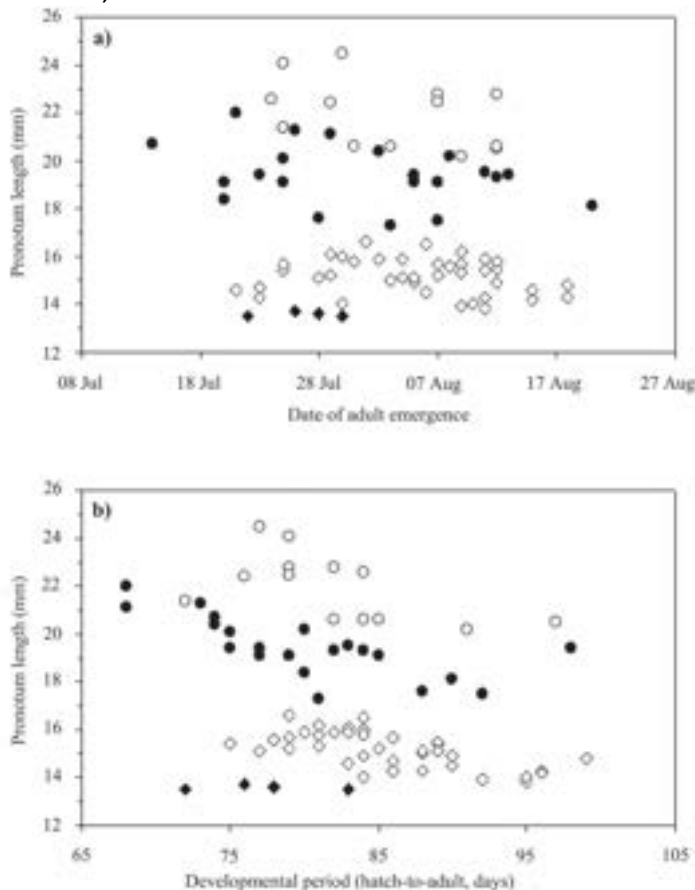


Figure 24. a) Pronotum length in relation to the date of emergence of *Stagmonantis limbata* adults. b) Pronotum length in relation to *S. limbata* developmental period, in days since

hatching. 7 instar females are indicated by white circles, 6 instar females are indicated by black circles, 6 instar males are indicated by white diamonds, and 5 instar males are indicated by black diamonds (From Maxwell) .

4.3 Last instar before eclosion being the longest

4.3.1 Transition to Adulthood in Praying Mantis

Eclosion marks the transition of an insect to adulthood. Praying mantises, like many other hemimetabolous insects, experience many molts and finally experience eclosion, reaching their adulthood, which is called their terminal stage where they no longer molt again for the rest of their lives. After reaching adulthood, many major changes take place, for example the wing pads of the nymphal stage will turn into real wings, adult antennae will be fully formed, hormone types will shift and the genitalia will be formed and matured, making the insect reproductively competent (Truman and Riddiford, Belles, Carle et al.).

4.3.2 Changes prior to adulthood and relation to the long duration of the last instar before eclosion.

In hemimetabolous insect nymphs, the wings are developed inside of wing pads. The wings pads are filled with hemolymph, tracheae (used to supply air to the wings), nerves, and tightly folded wings. During the last instar before eclosion, the wings get ready to come out, the wing pad thickens and the folded wing becomes visible. During the eclosion, the wings will unfold and inflate, driven by hemolymph. The functional adult wings are only developed during the final molt from pre-existing wing pads because the process of molting with mature wings is very complicated and are only present in a few species of insects (Salcedo et al., Salcedo, Ellis, et al., Belles, "Investigating the Origin of Insect Metamorphosis").

The shift in hormone type is another major change to the insect. During the last instar before eclosion, the juvenile hormone (JH) level drops significantly, and is replaced by adult program E93 transcription factor. The drop of the juvenile hormone will prevent the insect from performing processes like molting. When the juvenile hormone has great abundance, the E93 will be repressed through the MEKRE93 pathway. Now, as the juvenile hormone concentration declines, E93 level rises, and will switch on the growth towards adulthood, for example promoting the growth of mature genitals and wings, and make the insect lose the gland that produces molting hormone, since molting is no longer wanted (Belles, "Investigating the Origin of Insect Metamorphosis").

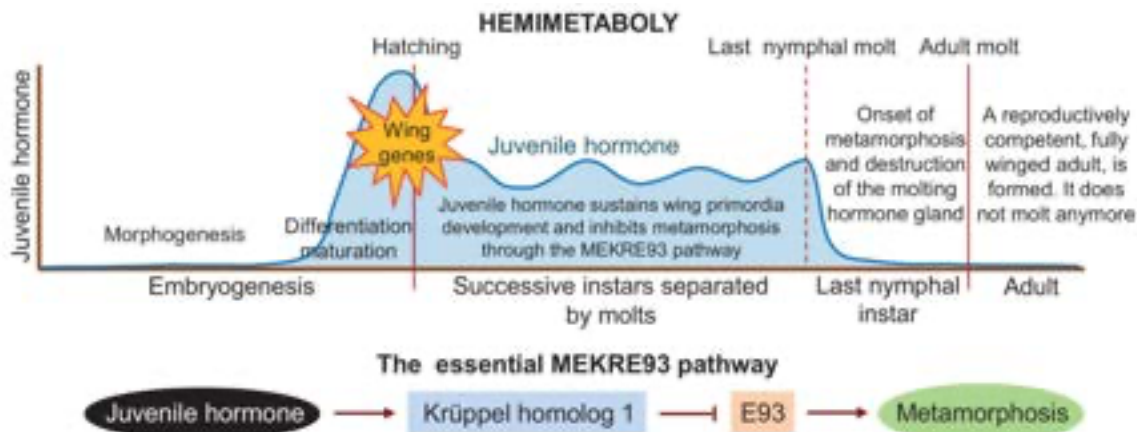


Figure 25. Juvenile hormone level during the life cycle of hemimetabolous insects. As shown in the graph, the juvenile hormone decreases dramatically after the going into the last nymphal instar, and almost totally disappears in adulthood (From Belles, “Investigating the Origin of Insect Metamorphosis”).

The final instar is the longest in duration for hemimetabolous insects (Klowden and Palli). During the last instar prior to the eclosion, many complicated processes happen. The wings and genitalia are formed mainly in the last instar. Many other body parts become modified, for example the antennae. Also, the hormone, transcription factor, and repressor level fluctuates dramatically during this time. All of these changes demand energy and time from the insects. This is the reason why the last instar is longer than all the other instars. Additional time is needed to complete all these shifts before getting ready for adulthood.

5. Opportunities for future research

There are still some topics and their underlying mechanisms that haven't been discussed in this literature review that could be addressed in future research. The first one is genetically predetermined stagnant development of praying mantises. Some praying mantises, especially the ones living in areas with distinguished seasonal temperature fluctuations, have developed strategies to deal with the cold season. Some praying mantis species, like *Tenodera sinensis* will pass the winter as eggs, while other species like *Hierodula pistillina* will pass the winter in the stage of large nymphs. During this period, the nymphs experience some kind of dormancy. They will consume a limited amount of food, and would stay in one instar for a very long period of time. In artificial environments, predicting the duration of the length of the instars during dormancy can be very challenging, likely because the artificial environment can be very different from the natural habitat of the praying mantis species, and it may involve unrecognized factors contributing to the unpredictability beyond those discussed in this literature review. The underlying mechanisms of these phenomena could be further discussed in detail in future research.

Conclusion

This literature review focuses on finding the cause of praying mantis instar number and instar duration variations. Through reading research papers about praying mantises and other insects and also making connections to my own experience of raising numerous species of



praying mantises over the years, this literature review has identified three main factors contributing to the praying mantis instar number and instar duration variations: temperature, nutrition as well as genetics and developmental physiology

The patterns and findings found in this literature review can provide variables and reference when understanding the effects of environmental changes on praying mantises and the potential causes of changes among praying mantis populations. This literature review can be also used to infer how praying mantis populations would adapt to different changing environments throughout the world. The findings could, therefore, be important for conservation of praying mantis under the influences of climate change.

The research in this area about praying mantises is very limited. Many of the conclusions have to be coming from studying and inferring from the findings of other insects that could potentially resemble the case for praying mantises. Some sources provide contradictory findings and therefore make it very hard to infer how praying mantises would be affected. Future research should focus on collecting raw data from praying mantises, and would therefore provide more accurate, praying mantis specific results.

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