Study on Adult Activity and Behavioral Mechanism of *Anoplophora nobilis* Ganglbauer

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Abstract. *Anoplophora nobilis* Ganglbauer is a destructive wood-boring beetle of poplars in northern China. We conducted studies on adult behavior, especially patterns of adult behavior, feeding, mating, and host selection in Longxian county of Shaanxi province and Gangu county in Gansu province from 1980 to 1981. Results showed that the adults of this pest usually move around slowly, with two peak periods of movement each day for feeding and mating. Adults were weak fliers with a maximum dispersal distance of 1,190 m. The intensity of adult activity was affected by environmental temperature, with the optimum ranging from 16 to 28ºC. Height of oviposition on poplar trunks was positively correlated with tree age. We also demonstrated that female *A. nobilis* were attracted to *Populus dakuanensis* for oviposition by certain host specific chemical of the host through its antennae. Our findings provide new information for the integrated management of this pest.

Materials and Methods

Regular Patterns of Adult Activity. Fresh branches of *Populus dakuanensis* were inserted in a conical flask filled with tap water and covered with nylon screen to make a cage. Five pairs of adults were introduced into each cage and placed outdoors in the shade. We observed adult activity hourly for ten days and ten nights. Water was replaced everyday.

Adult Dispersal. Newly emerged adults were collected from the field. The elytra of each adult were marked with red paint before its release. A 7 m diameter release site was placed within a 200 × 1,100 m poplar forest with 2,101 trees, dominated by *P. simonii* and to a lesser extent by *P. tomentosa.* The average diameter at breast height (DBH) of these poplars was 12 cm, with a range of 5 to 30 cm. A total of 500 adults (sex ratio = 1:1) were released from the site at two different times by placing adults individually on different trunks for free dispersal. Samples were taken from trees around the release site at 1, 2, 5, 7, 19 d after initial release. The distance of each marked adult from the release site was recorded before it was released again for continuous observation of adult dispersal.

Flight Ability. A total of 500 newly collected adults were marked with red paint on their elytra. In addition, a secret mark was also made on the pronotum of each adult. Adults were then released sequentially by either throwing them in the air or releasing them locally near sunset in an open space away from residential areas.

Oviposition Location and Host Preference. Standard trees were selected and surveyed from the field for the observation of oviposition selection (direction, bark smoothness, DBH, height, growth vigor, etc.).

Host Selection. Logs (180 × 10 cm) cut from five different species and five poplar species/clones, were planted in soil inside a nylon-screened cage (250 × 200 × 200 cm) with its top covered with tree branches for shading. The top ends of the logs were sealed with soil and wrapped in plastic film. A total of 300 adults were introduced into each cage. Fresh leafy branches were provided as food. Water was sprayed onto the logs several times a day to keep them fresh and moist. Dead insects were removed and new ones added daily to maintain a

density of 300 insects at all times. There were three cages in this study, which provided three replicates for each test species. The number of insects perching on each log was recorded every two hours, while the number of egg pits was recorded daily; these observations were done for 7 – 10 d.

Results and Analyses

Regular Patterns and Mechanism of Adult Behavior. Adult *A. nobilis* were very active during sexual excitement although they moved slowly most of the time. Regular patterns of activity were observed.

Action Patterns. *A. nobilis* was diurnal under natural conditions, i.e. active during the day and resting at night. Two activity peaks were observed for adults during the day, occurring before and after ca. 2:00 pm, when adults tended to hide inside tree crowns due to high temperatures.

Similar adult action patterns were observed in total darkness compared with that under natural conditions. However, more adults perched inactively when in the dark, and the action peaks were delayed for two hours. In addition, when held in the dark, adults crawled around most of the time, with very little feeding, no sexual excitement and mating. A significant increase in number of insects in action as well as the active times was observed when adults were placed in full light conditions, accompanied by the disappearance of diurnal cycle.

Feeding. Supplemental feeding was necessary for *A. nobilis* adults. Females fed more than males. Each adult could consume a maximum area of 10 × 22 mm of leaf or tender bark during each feeding period. Feeding occurred mainly during the day, rarely at night. There were three feeding peaks during the day: dawn, morning, and dusk. Each adult consumed up to 10 g fresh leaves and tender bark during its lifespan.

Crawling and Flying. Crawling was the major way of action for *A. nobilis* adults. Adults were not active but rather perched inside tree crowns for shade during early morning or late afternoon under natural conditions. Flying was rare during these times. Adults were active during the day only after the dew was completely dry. In addition, adults were relatively inactive on overcast and rainy days. Flight occurred mostly around 10 a.m. Field observations showed that male flew at an average speed of 1.8 m/s and female at 1.48 m/s, with a maximum distance of more than 100 m for each flight. Each flight lasted 3-4 min, and during straight flight, adults traveled a distance of 286 - 355 m.

Mating. Mating occurred repeatedly for both sexes after adult eclosion. Eggs formed sequentially within the females. Mating generally occurred around 6:00 pm, however, a smaller peak was observed at 10:00 am; each mating usually lasted for 1-2 h. No mating was observed in dark.

Correlation between Adult Activity and Temperature. Adult *A. nobilis* emerged during July and August when temperatures are high; peak emergence generally occurred just prior to and during the hottest weeks; e.g. in 1981, from July 19-August 5 in Ganguo county, temperature averaged > 25ºC (maximum > 30ºC) and peak emergence of *A. nobilis* occurred July 10-26.

To understand the relationship between adult activity and temperature, we held 10 adult *A. nobilis* at various temperatures in August 2, 1981; each temperature treatment was replicated three times. After a half-hour adjustment period, behavioral observations of adults were made for half an hour (Fig. 1).

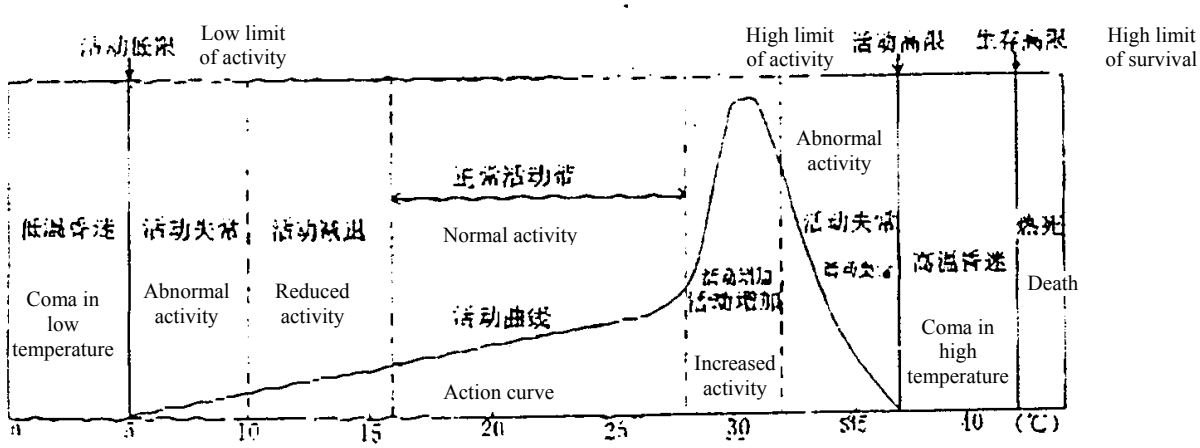

图 1 黄斑虎天牛成虫活动与温度关系

Fig. 1. Correlation between adult activity and temperature

Dispersal and Spread. *A. nobilis* adults were weak fliers. Densely planted (ca. 1-2 m apart), shady poplar stands along roadsides are the preferred habitat for *A. nobilis.* In this type of environment, with sufficient food and shade, the dispersal distance of adult *A. nobilis* was small. Results of a study conducted in 1980 at Longxian county in Shaanxi province demonstrated that the maximum distance of adult dispersal was 72 m/d; the maximum dispersal in 19 d was 214 m, an average of 41.6 m.

Oviposition Behavior and Location Selection on Tree Trunks.

Oviposition Behavior. Female *A. nobilis* crawl around on the trunk looking for proper eggs sites with their antennae and mandibles. When a proper site is identified, *A. nobilis* chews a half-rounded egg pit on the bark (12-13 mm long, 2-3 cm deep), turns around, bends its abdomen, inserts the ovipositor 6-10 mm above the pit, and deposits an egg in the bark. The oviposition hole was then sealed with a mucous material secreted by the female. Only one egg was laid in each site. Of the 308 egg pits we observed, 46 (14.9%) were empty and characterized by a lack of mucous material. Possible mechanisms for *A. nobilis* oviposition behavior were: (1) Oviposition holes were connected to egg pits to help air exchange for eggs and early stage larvae; (2) Eggs were laid above the pit to avoid being flooded by water and toxic fluid; (3) mucous material maintained water content of the egg pits and protected eggs from being attacked by natural enemies; (4) Eggs were laid between phloem and xylem to prevent eggs from drying out; (5) This arrangement was good for foraging and survival of newly hatched larvae.

Location Selection on Tree Trunks. Results of 284 standard trees from Tuqian village of Gangu county showed that: (1) Adults chose to lay their eggs in certain directions; of those eggs examined, 40.23% were on the west side of the trunk, 27.00% on the east side, and only 13.15% on the north. This distribution might be correlated with environmental temperature. (2) Most eggs were laid inside bark with a smooth surface; no egg pits were found on rough bark on the same tree trunk. (3) Females preferred to lay eggs on trees with a DBH ranging from 7-12 cm with a minimum of 5.84 cm. (4) Most egg pits were found within 2 m above the ground. Among the 1143 exit holes examined, 66.75% were found between 0-200 cm, and 90.38% within 0-300 cm above the ground; the maximum height was 700 cm above the ground. Major features of location selection include: damage from *A. nobilis* increased positively with tree age and diameter; the height of the position being attacked on the trunk increased positively with tree age; damage caused by each generation was clearly separated vertically; degree of damage on

each tree could therefore be graded by the number of damage generations. (5) Severe damage was observed on single poplar trees due to congregations of ovipositing *A. nobilis* females. (6) Weak trees suffered more than healthy trees. (7) *A. nobilis* usually coexist with carpenter moth, but the latter usually occurred in the lower trunk.

Examination of Host Selection and Its Mechanism.

Host Selection on Different Tree Species. Significantly more *A. nobilis* adults perched and laid their eggs on *P. dakuanensis* compared with other test species (ANOVA and F-test) (Table 1). Tree resistance to *A. nobilis* fell into four categories: highly susceptible - *P. dakuanensis*; susceptible – *Robinia pseudoacacia*; resistant – *Salix* sp.; highly resistant – *Ailanthus altissima* and *Paulownia* sp. Mechanisms of resistance demonstrated by *A. altissima* and *Paulownia* sp. were attributed to "refuse to select", whereas that of *Salix* sp. and *R. pseudoacacia* may have resulted from "antagonistic action" or "tolerance".

Table 1. Host selection by adult *A. nobilis* on different tree species

Species	DBH (cm)	No. of perching adults		No. of egg pits	
		Subtotal	*Percentage (%)*	*Subtotal*	*Percentage (%)*
P. dakuanensis	8.0	362	31.84	145	74.36
Ailanthus altissima	12.2	139	12.23	0	0
Salix sp.	8.2	221	19.44	6	3.08
Robinia pseudoacacia	8.0	233	20.49	44	22.56
Paulownia sp.	11.0	182	15.00	0	0
Total		1137	100.00	195	100.00

Host Selection on Different Poplar Species/Clones. Poplars suffered more from *A. nobilis* compared with other tree species when grown under natural conditions. However, differences in damage among poplar species/clones were also observed. Therefore, we designed the followed tests to determine if these observations were significant.

(1) Logs of five poplar species/clones, *P. alba*, *P. tomentosa*, *P. alba var. pyramidalis*, *P. hopeiensis*, *P. dakuanensis,* were selected and tested inside cages for host selection in three replicates. The results showed that poplar species/clones had significantly different levels of resistance to *A. nobilis* (Table 2). The resistance order can be summarized as: highly susceptible - *P. dakuanensis*; susceptible - *P. tomentosa*; resistant – *P. hopeiensis* and *P. alba var. pyramidalis*; highly resistant - *P. alba*. The high resistant of *P. alba* was once again attributed to "refuse to select". Although rates of adults perch on different poplar species/clones were similar, significantly most egg pits were chewed on *P. dakuanensis* (88.18%) vs. no egg pits on *P. alba* (Table 2).

(2) To observe the strict selectivity of *A. nobilis* to host species, adults were introduced to logs with vertically replaced bark. First, one third of the bark on the log of *P. alba* var. *pyramidalis* and *P. tomentosa* was replaced with bark of *P. dakuanensis* and sealed with tape. Second, one third of the bark on *P. dakuanensis* log was replaced by that of either *P. alba pyramidalis* (replicate I) or *P. tomentosa* (replicate II). Times of adult perching on the portion of original and replaced bark was recorded every two hours, whereas the number of eggs pits on

those portions was recorded daily (Table 3).

Adult *A. nobilis* selected their hosts very strictly (Table 3). Egg pits were only found on *P. dakuanensis* bark inserted into the logs of *P. alba* var. *pyramidalis* and *P. tomentosa*, as well as *P. dakuanensis* logs with bark replacement from other species/clones. No egg pits were found on the bark of *P. alba* var. *pyramidalis* or *P. tomentosa*.

Table 2. Adult selectivity of *A. nobilis* on poplar species/clones

Species/clone	**No. of perching adults**		**ANOVA on egg pits**					
	Subtotal	*%*	*I*	*II*	*III*	*Subtotal*	*Average*	*%*
P. alba	65	13.95	0	0	0	0	0	0
P. tomentosa	74	15.88	1	17	1	19	6.33	8.64
P. alba var. *pyramidalis*	60	12.88	0	0	2	2	0.67	0.91
P. dakuanensis	146	31.33	96	63	35	194	54.67	88.18
P. hopeiensis	121	25.96	0	1	4	5	1.67	2.17
Total	466	100.00	97	81	42	220	14.67	100.00

Multiple comparison

Species/clone	**Average**	**Sample size**
P. alba	0	n = 3
P. tomentosa	6.33	n = 3
P. alba var. *pyramidalis*	0.67	n = 3
P. dakuanensis	54.67	n = 3
P. hopeiensis	1.67	n = 3

(3) To further demonstrate the accuracy of this selectivity and eliminate the effect of log size on attractiveness to the beetles, the bark-replacement treatments were also conducted horizontally. Three bark strips (20 cm wide) on the logs of *P. tomentosa*, *P. alba* var. *pyramidalis*, and *P. alba* were replaced by that of *P. dakuanensis*. The strips were removed from each log at the height > 50 cm above the ground so each strip was separated from its neighboring strip by 20 cm. There were three logs for each tree species/clone. Surprisingly we found that both the times of adult perching and the number of egg pits on the replacement bark of *P. dakuanensis* were 2-6 times higher than that of the original barks (Table 4).

Table 3. Host selection of adult *A. nobilis* on trees with vertical bark replacement

Species/clone	DBH (cm)	Replacement ratio	No. of perching adults		No. of egg pits	
			Subtotal	*%*	*Subtotal*	*%*
P. alba var. pyramidalis	8.4	1/3	35	18.23	1	4.35
		2/3	22	11.46	0	0
P. dakuanensis	8.0	1/3	28	14.58	0	0
		2/3	65	33.85	9	39.13
P. tomentosa	8.1	1/3	23	11.98	13	56.52
		2/3	19	9.90	0	0
Total			192	100.00	23	100.00

Table 4. Host selection of Adult *A. nobilis* on trees with horizontal bark replacement

Species/clone	No. of perching adults			No. of egg pits		
	Original bark	*Replaced bark*	*Subtotal*	*Original bark*	*Replaced bark*	*Subtotal*
P. alba var. pyramidalis	48	117	165	2	13	15
P. tomentosa	76	173	249	4	12	16
P. dakuanensis	360	-	360	45	-	45
P. alba	57	147	204	0	9	9
Total			978			85

(4) To study mechanisms of host selection by adult *A. nobilis*, water extracts of *P. dakuanensis* leaves and branches were sprayed on logs of *P. dakuanensis*, *Salix* sp., *R. pseudoacacia*, *Ulmus* sp., and *Paulownia* sp. Water extracts were obtained by submerging the leaves or branches in water (2 times of the volume of leaves or branches) in plastic buckets for 24 h before being filtered through a screen. Times of adult perching and numbers of egg pits on each log were recorded.

The application of leaf extract of *P. dakuanensis* on logs affected the adult perching response on different test tree species. Adult perching was highest on *R. pseudoacacia* logs and lowest on *P. dakuanensis* (Table 5). This trend was consistent and greater when branch extracts were used (Table 6).

Table 5. Host selection of adult *A. nobilis* on trees sprayed with leaf extract of *P. dakuanensis* (Gangu, Gansu province, 1981)

Treatment		Leaf extracts of *P. dakuanensis*					Control (water)				
		I	*II*	*III*	*Total*	*Ave.*	*I*	*II*	*III*	*Total*	*Ave.*
P. dakuanensis	DBH	8.8	8.5	8.6	25.9	8.6	8.2	8.8	8.6	25.6	8.5
	Adults	25	29	36	90	30	88	113	121	322	107
	Egg pits	6	18	13	37	12.33	63	44	82	189	63.00
Salix sp.	DBH	9.7	8.9	9.4	28.0	9.3	7.8	8.8	9.9	26.5	8.8
	Adults	40	31	43	114	38	82	74	76	232	77.3
	Egg pits	0	19	17	36	12.00	2	4	2	8	2.70
R. pseudoacacia	DBH	8.9	9.7	10.1	28.7	9.5	7.6	8.9	7.8	24.3	8.1
	Adults	78	55	63	196	65	88	75	52	215	71.6
	Egg pits	1	8	5	14	4.67	15	7	23	45	15.00
Ulmus sp.	DBH	8.3	8.8	8.5	25.6	8.5	9.2	8.5	9.9	27.6	9.2
	Adults	32	23	41	96	32	64	45	55	164	54.7
	Egg pits	0	0	25	25	8.33	4	5	3	12	4.00
Paulownia sp.	DBH	9.5	8.5	9.1	27.1	9.0	9.8	8.1	8.5	26.4	8.8
	Adults	45	34	38	117	39	57	51	84	192	64
	Egg pits	0	0	0	0	0.00	0	0	0	0	0.00
Total	DBH	42.2	41.4	42.7	126.7	8.4	41.3	42.3	41.7	125.3	8.3
	Adults	221	172	220	613	40.8	379	358	388	1125	76
	Egg pits	7	45	60	112	7.46	84	60	110	254	16.94

Results of these tests demonstrated the attractive effects of those two extracts interfered with the normal activity of adult *A. nobilis*, and eventually lead to the confusion in separating *P. dakuanensis* from other tree species. The fact that no egg pit was found on the log of *Paulownia* sp. might be an indication of the presence of some sort of repellent produced by this species, which could have covered the smell of the extracts of *P. dakuanensis*. For other tree species, the smell of the extracts was strong enough to cover that of the original logs.

However, the identity of the attractant(s) in *P. dakuanensis* needs to be determined by future studies.

Table 6. Host selection of adult *A. nobilis* on trees sprayed with branch extract of *P. dakuanensis*

Species	DBH (cm)	No. of perching adults		ANOVA on egg pits					
		Subtotal	*%*	*I*	*II*	*III*	*Subtotal*	*Ave.*	*%*
P. dakuanensis	8.8	89	9.3	1	3	0	4	1.32	11.11
Salix sp.	9.3	248	25.7	5	9	2	16	5.23	44.44
R. pseudoacacia	9.5	370	38.6	0	2	0	2	0.67	5.56
Ulmus sp.	5.6	129	13.5	1	6	7	14	4.67	38.89
Paulownia sp.	9.0	124	12.9	0	0	0	0	0.00	0.00
Total		958	100.00	7	20	9	36	2.4	100.00

Table 7. Effects of various sensors of adult *A. nobilis* on host selection

Species	Treatments							
	Covering antennae				Covering compound eyes			
	Perching adults		*Egg pits*		*Perching adults*		*Egg pits*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
P. dakuanensis	69	6.0	5	9.6	39	15.0	7	58.3
Salix sp.	246	21.4	19	36.5	37	14.2	5	41.7
R. pseudoacacia	541	47.2	28	53.9	131	50.4	0	0
Paulownia sp.	291	25.4	0	0.0	53	20.4	0	0
Total	1147	100.0	52	100.0	260	100.0	12	100.0

Species	Treatments							
	Removing labial palps				Removing maxillary palps			
	Perching adults		*Egg pits*		*Perching adults*		*Egg pits*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
P. dakuanensis	12	2.8	5	36.7	18	10.7	18	81.8
Salix sp.	146	34.7	3	21.4	44	26.2	4	18.2
R. pseudoacacia	198	47.0	6	42.9	72	42.9	0	0
Paulownia sp.	65	15.5	0	0.0	34	20.2	0	0
Total	421	100.0	14	100.0	168	100.0	22	100.0

Correlation between Adult Selectivity and Sensors. Host selection by adult *A. nobilis* was examined on different tree species when either the compound eyes or antennae were covered with red paint, or the labial palps or maxillary palps were physically removed. A total of 100 mated females were used in each treatment; adults were fed fresh leaves of *P. dakuanensis.* The removal of maxillary palps or covering of compound eyes had no significant impact on host selection (Table 7). However, antennae and labial palps were important for host selection by adult *A. nobilis,* whereas visual and contact sensors were of limited importance. We concluded preliminarily that adult *A. nobilis* used mainly chemical sensors on its antennae and labial palps (odor and olfactory sensors) to sense the chemicals produced by trees.

References Cited

Zhang, K., J. Zhou, and W. Wang. 1984. Studies on the development and monitoring of the eggs and pupae of *Anoplophora nobilis*. Journal of Northwest Agriculture College (1): 68-78.

Zhang, K., and J. Zhou. 1984. A brief report on resistant tree species of *Anoplophora nobilis* and resistance mechanism. Journal of Northwest Agriculture College (3): (missing)

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