UNDERWATER SOUNDS AND ASSOCIATED BEHAVIOR OF THE CHINESE GIANT SALAMANDER *ANDRIAS DAVIDIANUS*

William E. Evans[1] and WANG Ding[2]

(1. *University of Notre Dame, Department of Biological Sciences, Notre Dame IN* 46556 *USA*;
2. *Institute of Hydrobiology, The Chinese Academy of Sciences, Wuhan* 430072)

Abstract: Anuran amphibians exhibit complex vocal behavior, which is an important mechanism in breeding and species identification. In the past it has been assumed that caudate amphibians are generally silent, with the exception of a few which have been shown to emit faint squeaks and barks. More recent researches have indicated that Cryptobranchidae may be the exception, as having a true voice based on anatomical evidence. To test this hypothesis we studied 4 specimens of the giant Chinese Salamanders, *Andrias davidianus*, under controlled laboratory conditions. These observations appear to verify both the presence of underwater vocalization and some behaviors associated with it. It is suggested further research under field conditions is warranted.

Key words: Vocal behavior; Giant salamander; Aggressive behavior

CLD number: Q959.5 **Document code**: A **Article ID**: 1000-3207(2005)05-0544-06

The vocal behavior of amphibians has been reviewed extensively[1-4]. The general conclusions of these reviewers were that anuran amphibians exhibit complex vocal behavior, which is an important mechanism in breeding and species identification, and that caudate amphibians are generally silent, with the exception of a few which have been shown to emit faint squeaks and barks. Maslin concluded that most salamanders could produce sounds of varying types; some of these sounds being incidental to respiration and some being produced deliberately as a part of a defense mechanism[1]. He also attributed some salamanders (*Dicaptodon ensatus*, *Andrias japonicus*, and *Ambystoma maculatum*) with having a true voice since they possess a valvular mechanism in the larynx[1].

Although Maslin's descriptions of salamander vocalizations are enlightening[1], the behavioral significance of these sounds is still vague. With the exception of the spectrograms of a squeak produced by *Aneides lugubris* and a "bark" uttered by *Dicaptodon ensatus*[3], quantitative descriptions of the sounds are lacking. It is not clear whether the sounds heard in some cases were involuntarily produced by handling or prodding; and in the case of aquatic species, whether the sounds were produced in air, under water, or both. Bogert and Maslin each referred to many observations of salamander vocalization[3,1]; one for the Chinese giant salamander, *Andrias davidianus* Blanchard, dating as far back as A.D. 300. These statements are attributed to Koo Po (AD 300) who reported that it makes a sound like an infant cry, resulting in the modern Chinese name Nei-yu or Wawa yu, which means baby fish[5]. Li and Lan made some preliminary descriptions of the natural and evoked calls of *Andrias davidianus*, without observations of the behavior[6]. However, before any firm statement can be made about the possible behavioral significance of salamander vocalizations, controlled observations of behavior, recordings, and spectrographic analyses of associated vocalizations are needed for all species suspected of being true sound producers.

The primary objectives of this study were (a) to determine if this species of *Andrias* produces sound under water without artificial stimulation, (b) to determine peak periods of activity, (c) to determine the extent and type of interaction that may exist among animals in the group, and (d) to determine what effect of the number of animals

Received date: 2005-02-23; **Accepted date**: 2005-05-22

Foundation item: This research was supported by Office of Naval Research, USA

Biography: William E. Evans (1930—), male, visiting professor of University of Notre Dame, Editor American Midland Naturalist USA

has on the amount of vocalization.

1 Materials and Methods

Through the cooperation of the University of Hong Kong and the Biology Branch, Office of Naval Research of USA, six Chinese giant salamanders were made available for study[7]. The animals ranged in size from 42cm to 54cm, snout to vent length. Based on the observations of Yoshihiro, the smallest sexually mature animal he had observed was 57.5cm, snout to vent[8]. Although this would make most of the animals in our study population subadult, based on the skull collection at the University of Hong Kong, the size of individuals in the wild over the past decades has been decreasing (University of Hong Kong, unpubl. data).

Four of the six animals provided were selected for this study. The four experimental animals were placed in a 50-gallon aquarium held to a temperature of 18—24℃. During most of the six month period of the study the temperature was 19℃ ± 1℃ (mean ± S.D.). The four experimentla animals were placed on a 12∶12 hour light-dark cycle. Data collection periods with ten minutes in duration were randomly scheduled every two hours over a 24-hour period. During these periods, visual observations of the animals' behavior were made and tape recordings were made of any associated sound production.

The recording system used consisted of a Uher Model 4000S tape recorder, a Hewlitt Packard Model 466A AC amplifier, and an Atlantic Research Model LC 57 hydrophone. The system response was limited to that of the recorder, ± 2.5dB from 30Hz to 12kHz at 3—3/4 ips. An monitoring system consisted of a Clevite type CH 15 hydrophone, a Heathkit Model AA3a amplifier, an Argos Ⅱ speaker, and a Heathkit 5-inch laboratory oscilloscope was used to aid in correlating vocalization and behavior without having to rely entirely on the monitor associated with the tape recorder. All of the sounds recorded were analyzed on the Kay Electric Co. Model 6061A sonagraph, with a built-in narrow band filter(40Hz).

2 Results

2.1 Vocalization and Activity

Before the formal stages of the study started, it was apparent that these salamanders did produce sounds since some of the sounds could be heard without the aid of electronic equipment. The more controlled observation and recording periods verified these initial observations. As has been stated in the literature, *Andrias* is primarily nocturnal[8—10], the greatest activity occurring between 1800 hours and 2400 hours. For purposes of this study, activity is defined as movement on the part of one or more of the experimental animals as well as vocalization. Although live food was placed in the test enclosure twice during the study, no feeding was observed. However the prey items (gold fish) disappeared. A graph of observed animal activity is presented in Fig. 1. The periods of the greatest activity were also the periods of maximum vocalization.

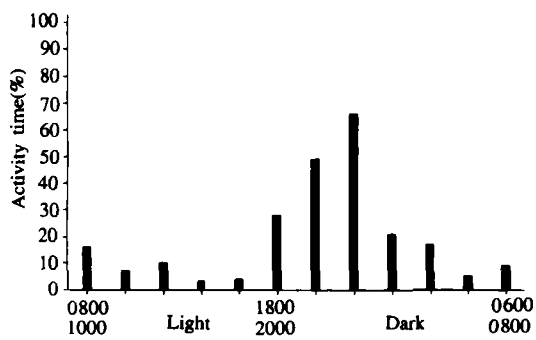

Fig.1 The percentage of time during each two hour observation period while one or more animals were active

A series of different postures seemed to occur consistently during both rest and activity. In the resting posture, the entire ventral surface of the animal was in contact with the substrate, the forelimbs and hindlimbs were pulled up, and the tail was often curved and placed parallel to the body(Fig.2). A second type of posture was associated with air gulping at the surface(Fig.3). Sounds were sometimes made prior to rising to the surface(Fig.4). In some cases, air bubbles were released in association with the sounds. The sonogram in Fig. 4A and B was with a bubble release, and Fig.4C was a similar sound without air release. Sounds of this type varied in duration from 0.07 to 0.18s. The majority of these emissions had a fundamental of 200—210Hz with three to four harmonics.

Fighting was relatively common among our study animals. The posture shown in Fig.5 was assumed prior to actual attack and occasionally during fights. Most fights were of short durations(5—10s) and consisted of the aggressor biting the attacked animal on the tail or hindlimbs. The greatest number, variety, and most complex sounds were produced during these aggressive encounters. These sounds (Fig.6) ranged in duration from 0.20 —

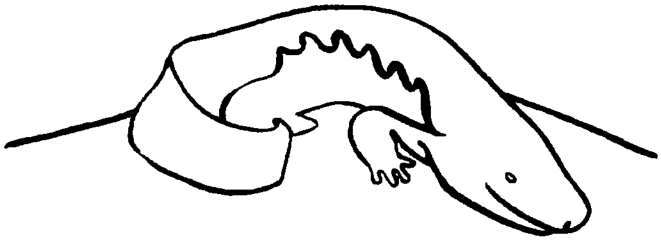

Fig.2 Typical resting posture of the *A. davidianus* used in this study

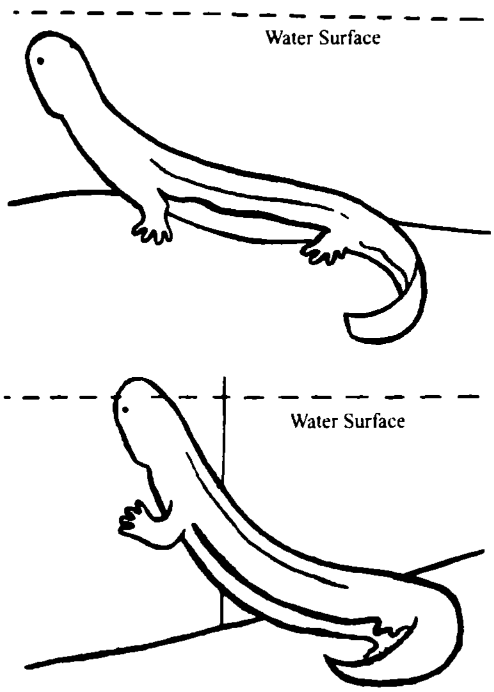

Fig.3 Typical postures of the *A. davidianus* assumed prior to and during air breathing at the surface

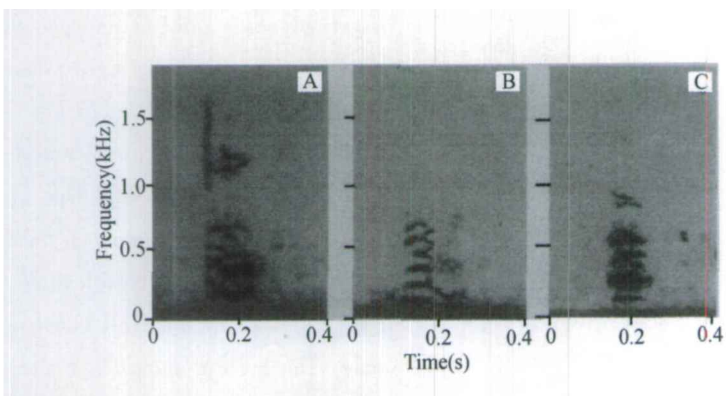

Fig.4 Sonagrams(40Hz filter)of sounds produced by *A. davidianus* prior to rising to the water surface. A & B: sound with a bubble release; C: sound without a bubble release

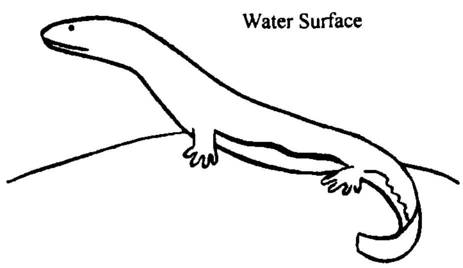

Fig.5　Typical posture assumed prior to and during aggressive behavior

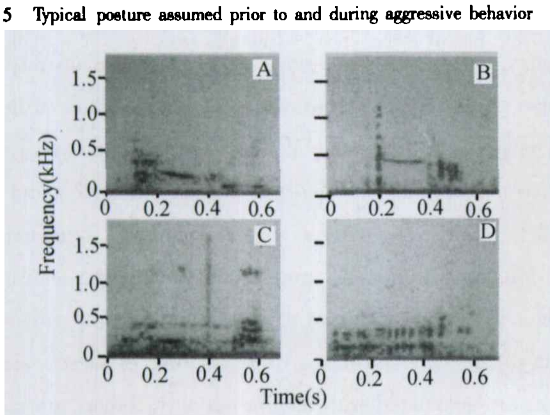

Fig.6　Sonagrams (40Hz filter) of sounds produced by *A. davidianus* during fightin

0.50s. Some contained pulses with repetition rates of 30—35pps (pulses per second) (Fig.6D) and almost sinusoidal components at 125Hz, 250Hz, and 400Hz (Fig.6A and 6B). The latter, on occasion, had one or two harmonics. Some of the pulses contained energy up to 1.2kHz.

During foraging for food and investigating areas of the tank other than that normally inhabited, *Andrias* raised its body on all four limbs with head level (Fig.7). Feeding was also initiated from this posture. This same posture was also assumed by an animal retreating from a fight. The sounds associated with this posture consisted of two types: (a) almost sinusoidal with frequencies of 220—300Hz, and (b) pulses at a rate of 30pps, which are the same as D in figure 6, with energy from 100—400Hz and pulse duration of 0.017—0.022s. It is interesting to note that each of these sounds also occurred as a component of the sounds associated with fighting behavior (Fig.6A and 6B). This could indicate vocalization by the attacked animal as well as the aggressor.

Fig.7　Posture assumed by animal foraging for food and also retreating from a fight

2.2 Territoriality and dominance

When the four animals were initially placed in the test tank, they all occupied one end of the tank for the first two days. The animals then divided into two groups, each group occupying a separate end of the tank. Using the viewing window as a reference, the animals on the observer's right were designated A and B, those on the left C and D (Fig.8). In the group A-B, A was judged to be dominant since this animal was always the aggressor. Likewise in C-D, C was the aggressor. There were initially three directions of interaction, A-B-D, C-D, and D-B. In the latter cases when B or D was chased from their "territory", they would retreat to the opposite end of the tank and come in contact with animals occupying that end [Fig.8(a)]. Fighting would then ensue. A fight originated at either end of the tank would initiate interaction at the opposite end.

The original plan of the study was to progressively remove one animal at a time from the tank and observe interaction and vocalization as a function of the number of animals. This phase of the study was initiated earlier than scheduled due to injury to individual test animals. Animal D received several cuts and abrasions during the previously described skirmishes. These injured areas developed a white fungus-like growth, which was found to have a bacterial growth associated with it (*Pseudomonas* sp.). The animal was removed from the tank for treatment and subsequently died.

The distribution of the remaining three animals was unchanged, A and B occupying the right end of the aquarium and C, the left end. The increased space available to each animal decreased the number of contacts and thus the number of fights [Fig.8(b)]. When animal C was removed, animal B shifted its location to the left of the tank [Fig.8(c)]. In each case, the "subordinate" animals removed (D, C, and B) had several cuts and abrasions on the tail, hind-limbs, and head, which were infected with *Pseudomonas*.

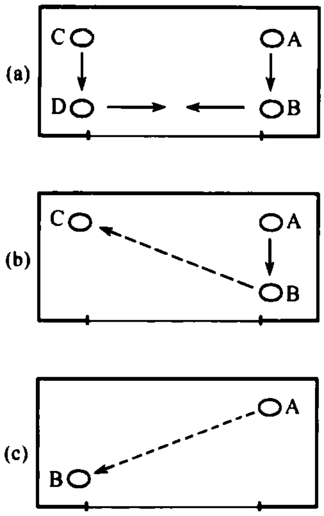

Fig.8 Graphic of location of animals in the tank and direction of aggressive interaction as a function of the number of occupants. Arrow solid line indicates main interaction, Arrow with dotted line indicated secondary interaction. Number of animals decreases as injured individuals are removed from the experiment due to infections.

The extent to which decreasing the number of animals reduced the fighting activity can be seen clearly by looking at the average number of sound emissions for each study group size (Fig.9). With the removal of one animal, the average number of sound emissions per period of peak activity decreased approximately 60 percent; however, the removal of an additional animal further reduced the number of emissions only by 15 percent. With a single animal in the aquarium, the number of vocalizations dropped to near zero.

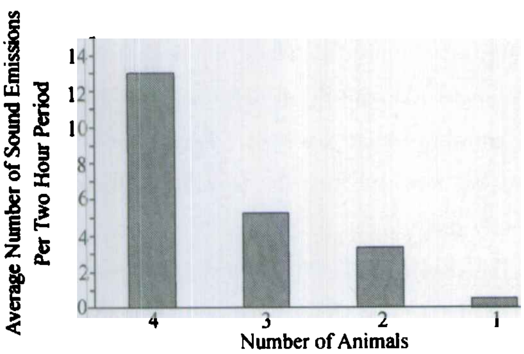

Fig.9 Average number of sound emissions as a function of the study group size.

3 Discussion and conclusions

In its natural habitat, *Andrias* is known to be a largely solitary animal. It occupies burrows under banks, logs, or large flat rocks. These burrows are seldom occupied by more than one animal. When placed in confinement, they are also cannibalistic[8,11]. The animals used in this study aquarium fit this description well.

There is some evidence that salamanders have a functional hearing mechanism[10], and that some will respond to frequencies of 194—244Hz[12]. In the case of *Andrias davidianus*, the frequency range of the signals produced has energy well within the range of hearing demonstrated for these other species. However, there are signals with frequency beyond this range of hearing. Until we have quantitative measurement of *Andrias* hearing range this question will be mute. The current observations have indicated that *Andrias davidianus* does produce a variety of vocalizations under water as a function of regular interaction with members of the same species. Although some of these vocalizations are associated with respiration only, others are closely correlated with aggressive and defensive behavior.

This study adds emphasis to Bogert's original speculation that, "To judge by recent studies of fishes, some aquatic salamanders conceivably produce sounds under water that have gone undetected"[3]. It would be surprising if under water vocalization in aquatic or semi-aquatic salamanders were limited to *Andrias davidianus*. An interesting field of investigation is open, especially in the study of those forms with relatively complex behavior patterns that can be easily observed under natural conditions.

The observation that vocal activity appears to be related to the number of animals presented could be that the presence of other individuals stimulates vocal behavior. Some observations of other Cryptobranchidae indicate that *Andrias davidianus* may be solitary except during periods where they aggregate[11]. This could be an indication that this is the only period when vocalization is active.

These and some of the other observations need to be compared with detailed observations in the field. Since the 1970's, China has been conducting research on this important and critically endangered species both in the laboratory and in the field. The Giant Salamanders is a rare amphibian. There are only three species in the world. Unfortunately the Giant Salamander meat is very delicate and high in nutritional value. Also it brings a very high price on the black market which stimulates poaching. It has been suggested by some Chinese scientist that research on behavior, cultivation and reproduction should be increased[11]. With the assistance of the Institute of Hydrobiology of the Chinese Academy of Sciences in Wuhan, it is hoped these field studies on the vocal behavior of *Andrias davidianus* can start in the near future.

Acknowledgements: We thank Dr. Xiao Jianqiang for his assistance on editing an early version of this paper and modifying the figures. Also we recognized post humorously the early contribution of Dr. Howard Campbell. We also thank Dr. Tang Qisheng of Huanghai Sea Fisheries Research Institute of the Chinese Academy of Fisheries Sciences. He provided copies of publications by his group on the giant Salamander.

References:

[1] Maslin T T. The production of sound in caudate amphibian[J]. *University of Colorado. Studies Series in Biology*, 1950, 1: 29—45

[2] Neill W T. Remarks on salamander voices[J]. *Copeia*, 1952, **48**: 195—196

[3] Lanyon W E, Tavolga W N. Animal Sounds and Communication. Publication No.7[R], Washington: American Institute of Biological Science, 1960, 137—306

[4] Busnel R G. Acoustic Behavior of Animals[M]. Amsterdam: Elsevier, 1963, 694—706

[5] Liu C C. Amphibians of Western China[J]. *Zoology Memoirs*, 1950, 2:1—400

[6] Li D F, Lan S C. Analysis of the sonograms of *Andrias davidianus* [J]. *Journal of Northeast Normal University*, 1997, **29**:55—57[李东风,蓝书成. 大鲵鸣叫语图的初步分析. 东北师大学报(自然科学版), 1997, **29**:55—57]

[7] Evans W E, Campbell H. Preliminary observations of underwater sounds and associated behavior of the Chinese giant salamander[R]. 1967 AAAS Conference abstract. American Association for the Advance of Science

[8] Yoshihiro I Collected Works on the Giant Salamander(*Megalobatrachus japonicus*) in Japan[M]. Tsuyama City, Japan: Tsuyama Museum of Science Education, 1973(in English and Japanese)

[9] Safranek V. Some remarks on breeding of the Chinese giant salamander[J]. *Przegled Zoologiczny*, 1961, **5**:390—394

[10] Schmalhausen J J. The sound transmitting mechanism of amphibians [J]. *Zoologicheskii Zhurnal*, 1957, 36:1044—1063

[11] Lin F S, Zen X Z, Wang P L, *et al*. Precious and Rare Aquatic Animals in China, No. 13[M]. Hangzhou: Zhejiang Scientific and Technical Press, 1987

[12] Ferhat-Akat S. Unlersuchunger uber den Gehorsum der amphibian [J]. *Zeitschrift fuer Fergleichende Physiologie* 1939, **36**:253—281

大鲵的水下发声与相关行为

William E. Evans[1]　王　丁[2]

(1. University of Notre Dame, Department of Biological Sciences, Notre Dame IN 46556 USA; 2. 中国科学院水生生物研究所,武汉　430072)

摘要:无尾类两栖动物的复杂的声行为对其繁殖与物种的识别具有重要的作用,而有尾类除了少数种类可以发出微弱的"吱吱"声或吠声外,在过去一直被认为是基本不发声的。但是,最近的基于解剖学的证据的研究显示隐腮鲵科(Cryptobranchidae)可能是一个例外。为了检验这一假说,作者对实验室严格控制的条件下的4只中国大鲵(*Andrias davidianus*)进行了观察。观察结果不仅表明动物在水下发声,同时也观察到了与之相关联的行为。作者对进一步在野生条件下开展研究提出了建议。

关键词: 声行为;大鲵;攻击行为