The Application of Electric Shock as a Novel Pest Control Method for Apple Snail, *Pomacea canaliculata* (Gastropoda: Ampullariidae)

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The apple snail, *Pomacea canaliculata*, brought to Japan from Taiwan for human consumption in the 1980s, has come to be considered as deleterious for rice cultivation. The snail is unable to injure young rice plants while receiving electric shock because the snail retracts its entire body into its shell and shuts its aperture with its operculum. Electric shock should be applied intermittently to reduce the amount of energy that is wasted when the snail is in its shell made of one of the insulator. The minimum electric shock required for controlling snails and the time required for movement after application of electric shock to determine the frequency of each electric shock were investigated using two methods; vertical and horizontal application of the electrical stimulation. The results showed that there is a strong correlation between the strength of electric shock and the reaction of the snails, and electric shock made snails inactive when it was applied 0.35 A/m² in the horizontal direction and 0.45 A/m² in the vertical direction with water of 11 mS/m. A positive correlation was also found between electric shock and the reaction of the snails and shell height. In comparison with larger snails, the smaller snails had higher threshold levels against electric current density because their shorter feet tended to have lower voltage drop. Moreover, the frequency of electric shock should be chosen the minimum duration for the inactive condition, and it was approximately 10 seconds. Consequently the direction of electric current should be in the horizontal direction above 0.35 A/m² and the frequency of electric shock should be less than 10 seconds for practical use. However, electric shock would have to be maintained at greater than 0.35 A/m² because snails might become habituated to electric shock and water in paddy field would have high electric conductivity.

**Keywords**: apple snail, electric shock, rice pest, pest control, preventive method

1. **Introduction**

The apple snail (Fig. 1), *Pomacea canaliculata* (Lamarck), is a fresh water snail indigenous to South America that has become one of the most harmful rice pests in Asia(1). The snail was introduced to Asian countries such as Malaysia, Indonesia, Thailand, Philippines, Korea, China, Taiwan and Japan in the 1980s for human consumption(2) (3). The snail was cultared at many locations in Japan, but over breeding and lack of control resulted in the accidental escape of the snail into the natural environment and subsequent damage to rice in paddy fields(4). Methods directed at control of the snail have been investigated since the importance of the damage caused by the snail has been recognized in Japan.

Perfect preventive methods employed to date to affect management of the snails in directly seeded rice paddies have not been successful although moderate control has been achieved through cultural(5)~(7), chemical(8)~(10) and biological management initiatives(11)(12). The present practical method of snail management is a combination of cultural and chemical management strategies, but it has the disadvantage of being difficult to implement under conditions of heavy or extended rainfall. Promoting the drainage of rice paddies - the main idea of cultural management - is strongly recommended in practice, as it is impossible for snails to feed in the absence of water. However, application of this technique in practice is with difficulty occasionally given that damage to rice by apple snail usually occurs at the beginning of June, which is the onset of the rainy season in Japan. The problem is further complicated by the fact that very low densities of the snail (0.5 snails m⁻²) can cause significant damage to germinating seedlings(13).

The application of electric stimuli has effectively been applied to eliminating insects and managing the behaviour of animals. For example, the use of electrical fences to prevent damage to agricultural fields by wild animals, or conversely, to stop domestic animals escaping from their paddocks. Electric bug killers can eliminate the bugs that are attracted to the electric source by phototaxis, and electroshock wand (stun guns) have been applied to self-defence. Therefore, we set about to determine whether electric shock could be employed to the control of Apple snail infestation from a different angle compared to that adopted by
other approaches.

Control by electric shock is facilitated by the environmental changes that occur during the rainy season; water from the heavy rains is used to conduct the electricity that is necessary for this method. Moreover, because the snail is beneficial as the agent of paddy weeding(1), the application of electricity might be able to reduce the usage of agricultural chemicals such as herbicide.

The purpose of this study was to establish a novel preventive method against the damage caused to rice by the apple snail.

2. Rationale for Controlling the Snail Using Electric Shock

Electric shocks made the snails inactive. The snail retracts its entire body into its shell and shuts its aperture with its operculum (Fig. 2) as it tries to avoid exposure to any hazardous external stimulus. Because the snail is unable to feed on young rice plants while in this condition, keeping the snail inactive in this way would make it possible to prevent damage to young rice plants by snails, and this is in fact the which is the principal idea of controlling snails using electric shock.

However, cessation of electric shock results in almost all of the snails recovering from the inactive condition and resuming their usual feeding behaviour. This means that the application of electricity needs to be continuous in order to keep snails inactive for an extended period. In a paddy field, the majority of the damage caused by the snails is to the young rice plants because they are softer than the adult plants that are too hard to be eaten. The stems of rice seedlings take approximately three weeks to reach this level of hardness and the period over which prevention must be affected is thus estimated as being from three weeks to a month after planting(1).

The snail in the inactive condition does not receive continued electric shocks because the shell is made of insulating materials such as calcium. It is therefore meaningless to send electricity into the water while the snail is in the inactive condition. Electricity should thus only be applied intermittently to reduce the amount of energy that is wasted when the snail is in its shell. The frequency of electric shocks should thus be determined by the duration of the inactive condition of the snail. Consequently, this study addresses the minimum value of electric shock that is required to keep snails inactive, the duration of inactivity and how this can be used for estimating the frequency of electric shocks.

3. Experimental Details

3.1 Apple Snails Experimental animals were caught in an irrigation canal (130°30′E, 33°23′N) in Saga prefecture. Snails were maintained in an indoor aquarium (W60×H40×D30 cm) with filtered water after collection. Snails were fed vegetables such as cabbage or carrot. The temperature of the water was maintained at approximately 25 ℃.

3.2 Experimental Equipment A schematic diagram of the experimental design is shown in Fig. 3. The direction of current propagation was considered to be one of the most important factors for making the snail inactive, and it was thus necessary to design electrodes to test this hypothesis and for practical use. We prepared two electrode-types, one for conducting electricity horizontally (Fig. 3(a)) and another conducting electricity vertically (Fig. 3(b)). The experimental equipments were composed of an ele-trical transformer (RSA-5, Tokyo-Rikosya Co., Ltd.), a timer (H3M, Omrom. Co., Ltd.), a plastic water tank and aluminium electrodes. The electrodes for both equipment types were arranged in parallel. The aluminium plates were used for both electrodes for the horizontal propagation arrangement of electrodes. For the vertical propagation, the bottom electrode was an aluminium plate while the upper electrode was constituted by an aluminium mesh used also to observe the behaviour of the snail.

Fig. 2. The inactive condition of the snail in which the body is retracted into the shell ; (a) indicates the condition of moving (the active condition) ; (b), retraction of tentacles, head and foot ; and (c), the condition retracting entire body into the shell ; (d), the inactive condition
snails. A plastic mesh was laid at the bottom of the water tanks to imitate the condition of the ground of a paddy field. Additionally, the water in the experimental tank was passed through the water purifier (TK742, Matsushita Electric Industrial Co., Ltd.), which consisted of an activated coal filter and a hollow fiber filter, to trap dust and to eliminate the chlorine in tap water. The temperature of the water was kept 25°C in the tests.

### 3.3 Experimental Conditions and Methods

The size of the snails and magnitude of electric current were selected as factors affecting inactivity in snails. Shell height (Fig. 4) is normally used as a reference of size in snails. In this study, we divided snails into six size categories at 5 mm intervals between 10 mm to 40 mm. The magnitude of the electric shock to which the snails were exposed was estimated using electric current density. The electric current density was also divided six stages at intervals of 0.05 A/m² between 0.10 A/m² and 0.50 A/m².

The snails were tested individually to exclude the interaction effect. The test was repeated six times for each factor, and was randomly organized in both factors. The duration of electricity supply into the water was set for one second by timer. The conductivity of the water was approximately 11 mS/m. Snails were placed into the experimental water tank from the aquarium. Snails were used if they started moving immediately after being placed into the experimental tank. Snails that remained in their shells for approximately 30 seconds were excluded from the test as inactive snails.

Electricity was applied while snails were in moving. After receiving an electric shock, snails locomotive status was checked to see whether it was active or inactive. If the snail became inactive, the duration of inactivity was measured. The water was changed every time the above process was completed.

### 4. Results

#### 4.1 Inactivity in Snails Affected by an Electric Shock

The number of inactive snails increased in response to an increase in the density of electric current (Kruskal-Wallis ANOVA: Horizontal-type, $P<0.001$; Vertical-type, $P<0.001$) and the effects of electric shock on the behaviour of snails was conclusively demonstrated (Fig. 5). The response of the snails to electric shock differed depending on the type of equipment; snails subjected to horizontally propagated electricity found it easier to close their operculum than the snails subjected to vertically propagated electricity (Mann-Whitney U-test, $P=0.03$). All snails became inactive when electric current density was increased to 0.35 A/m² in the horizontal direction and 0.45 A/m² in the vertical direction. Consequently, the electric current should be applied in the horizontal direction with more than 0.35 A/m² to affect optimal inactivation of the animal in the field.

However, many of the snails did not respond to electric shock below 0.15 A/m² in the horizontal direction and 0.2 A/m² in the vertical direction. The response of the snails to electricity was manifested as retraction of tentacles, head (Fig. 2(a)) and foot (Fig. 2(c) and (d)) into the shell to attempt to avoid the stimulus. The former two responses were usually exhibited at approximately 0.2 A/m² for horizontal propagation and 0.25 A/m² for vertical propagation, and retraction of the foot always associated with the inactive condition.

Figure 6 shows that the larger snails tended to exhibit the inactive condition more frequently than the smaller specimens (Kruskal-Wallis ANOVA: Horizontal-type, $P<0.001$; Vertical-type, $P=0.006$). The data points in Fig. 6 were calculated considering the effect of electric shocks varying from 0.1 A/m² to 0.5 A/m². The positive relationship between the inactivity of snails after exposure to both vertical and horizontal current-types and shell height was clearly demonstrated.

#### 4.2 Duration of the Inactive Condition Affected by an Electric Shock

The duration of the inactive condition, taken as the time from when the application of electricity was stopped to when the snails resumed locomotion, is shown in Fig. 7 and Fig. 8. The data in both Fig. 7 and Fig. 8 were shown without the data of the walking snails for evaluating the duration of the inactive condition on each snails exactly.

In Fig. 7, there was significant difference between the duration of inactivity in snails subjected to horizontally and vertically administered current and response to the intensity of the electric shock (Kruskal-Wallis ANOVA: Horizontal-type, $P<0.001$;
Response of Apple Snail against Electrical Stimulation

5. Discussion

5.1 Responses of Snails to Electric Shock

It is likely that the snails feel electric shock through muscle fasciculation. The parts of the body that receive electric shock are primarily the tentacles (the snail has two pairs of tentacles), the head and the foot. It is however believed that the organs do not receive electric shock because they are protected by the shell.

Photographs of the typical snail taken from (a) the front, (b) the side and (c) above are shown in Fig. 9. For a horizontally administered electric stimulus, it is thought that most of the electric current flowing into the body would occur through the foot and the tentacles (Fig. 9(a) and 9(b)). However, a vertically administered electric current would pass through the tentacles, the posterior end of the foot and the part of head (Fig. 9(c)).

Electric current is thus likely to pass through those areas of muscle according to the pathway described above. The strength of this current and its effect on the snail is thus likely to be dependent upon the size of the snail. The solid lines at minimum electric shock (0.1 A/m²) and maximum electric shock (0.5 A/m²) in Fig. 11, which was calculated from electric field and the regression line in the relationship between length of the foot and shell height (shown in Fig. 10), show that the voltage drop of the foot of the larger snails with their longer feet is greater than smaller specimens. Therefore, the larger snails appear to have greater electric shocks than the smaller snails when they are in same strength of electric field.

A simple model of the snail to explain electric shock in response to differences in electric current is shown in Fig. 12 for a (a) large snail and a (b) small snail. Assuming similar levels of conductivity among snails, the total amount of electric current passing through the muscle of a large snail is greater than it is for a small one. For example, assuming the shell height of the small snail in this model is half as large as the large snail, and that the height of the path that the electric current must follow in the small snail is also half that of the path it must follow in the large snail, then the total amount of electric current in the large snail is four times that of the small snail. The reason for the increased incidence of the inactive condition of the larger snails compared to

Fig. 7. Relationship between the duration of the inactive condition and electric current density: The correlation \(r_s\) was calculated using Spearman’s rank method; Regression lines indicated in the graph were calculated by weighted least-squares methods; Horizontal-type regression \(P<0.001, r_s=0.719, N=9~36\); Vertical-type regression \(P<0.001, r_s=0.60, N=2~36\). Vertical bars indicate one side of SE

Fig. 8. Relationship between the duration of the inactive condition and shell height: The correlation \(r_s\) was calculated using Spearman’s rank method; Regression lines indicated in the graph were calculated by weighted least-squares methods. Horizontal-type regression \(P=0.034, r_s=0.32, N=31~46\); Vertical-type regression \(P=0.041, r_s=0.33, N=28~42\). Vertical bars indicate one side of SE

Fig. 9. Proposed paths of an electric current in the snail: (a) the front, (b) the side and (c) above
smaller snails is because the level of shock is dependent on size. The larger snails thus become inactive more easily, even if the same electric current density is applied to smaller snails.

However, the larger snails exhibit more resistance to electric shock, the smaller snails seem to have exhibit a higher tolerance toward it. Interestingly, in the case of estimating inactivity rates in relation to a voltage drop with individual snails, the larger snails were less likely to become inactive. For instance, the minimum voltage drop required for making 10-14 mm snails inactive was 0.36 V, which was approximately 0.58 times lower than the snails of size 35-39 mm. Additionally, the total amount of electric current that snails can withstand also tends to become higher with increasing the shell height from the Eqs. (2) and (3).

The reason for the difference in the inactive condition of the snails between in the horizontally and vertically propagated electric currents can also explain the total amount of electric current in the body. In the case of vertically administered electricity, the snails are mainly exposed to electric shock through a part of their head and their tentacles. In comparison to snails exposed to the horizontally administered electricity, the voltage drop was considered smaller. In other words, because more of the body is exposed to electricity when the propagation of electricity is horizontal, the voltage drop becomes higher and thus the snails receive a stronger impact of electricity. The snails exposed to vertically administered electricity did not receive as much a shock that specimens subjected to horizontally administered electricity despite electric current being similar.

However, the duration of the inactivity between treatments was not very different. This might be due to the duration of the residual influence of the electric shock in the snail. When the input is vertical, the electric current is concentrated on an important part of the nerve system (part of the head and the tentacles). It is suggested that an electric shock to such important parts tends to remain in the snail and the duration of the inactive condition is influenced, not only the force of the applied electric shock, but the parts receiving the stimulus.

5.2 Waveform and the Factors for Control The factors affecting control by electrical shock are indicated in Fig. 13. The results of this study indicate that the minimum value of electric

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Fig. 10. Relationship between shell height and the length of foot: The correlation (r) was calculated using Pearson’s product moment; Significance was tested by the correlation to Fisher’s z; The relationship between shell height and the length of the foot can be represented by $y = 0.93x$ ($P < 0.001, r^2 = 0.93$); The relationship between shell height and the width of the foot can be represented by $y = 0.59x$ ($P < 0.001, r^2 = 0.96$).

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Fig. 11. Dependence of the voltage drop through the foot for snails at 0.1 A/m$^2$ (minimum electric shock) and 0.5 A/m$^2$ (maximum electric shock). Dotted line indicated by least-squares methods ($P = 0.012, r^2 = 0.83$) is the minimum voltage drop required for making snails inactive.

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Fig. 12. Simplified model of the path of an electric current in a (a) large snail and (b) small snail: $I_L = 0.59 \times H \times S_H \times E$ (2) $I_S = 0.1475 \times H \times S_H \times E$ (3) $I = \kappa \times E$.

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Fig. 13. Practical application of electric shock.
current required for making snails inactive was 0.35 A/m². In the study, the snails exhibited considerable variation in periods they were inactive (approximately 10 seconds to 10 minutes). The minimum duration for the inactive condition will be chosen in the event practical application.

Moreover, snails might become habituated to electrical shock. The minimum electric shock for making snails inactive determined in this study was observed to become progressively greater. The fact that the snails became less sensitive to repeated electric shocks was observed in preliminary tests. However, snails appear to have different thresholds against an electric shock insofar as the inactive condition is concerned.

Stronger electric shocks tend to make the snails inactive for longer. For instance, in response to electric shocks of 1.1 kV/m, 70% of snails shut their operculum tightly for 20 minutes[23]. High electric shock is probably an effective means of controlling snails. However, applying large amounts electricity to a paddy field is impracticable and dangerous. It is therefore proposed that the minimum electric shock of short duration be applied against the snail. The duration of the electric shock could be shorter than one second, and electric shock for 0.2 seconds has been tested and found out that it was able to make the snails inactive.

The electricity required to make snails inactive is approximately 11 W/m² in the case of horizontally administered electricity. Consequently, for a paddy field 5 cm-deep and 10 ares in extent, the total energy consumption for 3 weeks of prevention and the same parameters employed in this study is approximately 28 kWh.

In 1970, a water quality guideline for agricultural use was promulgated by the Ministry of Agriculture, Forestry and Fisheries of Japan. The standard is currently applied to water quality in paddy fields. Electric conductivity of less than 30 mS/m is recommended. Recommended amount of electric conductivity is approximately 3 times higher than the water used in this test, which would mean that the total energy required for keeping snails inactive would also be tripled. However, many paddy fields do not meet this standard in reality and the required electric current density would have to be maintained at higher levels in practice.

6. Conclusion

The possibility of controlling the snail using electric shock was clearly demonstrated in this test. The duration of the inactive condition in snails was positively correlated to the strength of electric shock and shell height. It was also demonstrated that larger snails have higher tolerance to the electrical shock, although smaller snails also seem to exhibit relatively high tolerance to electrical shock.

Furthermore, the minimum electric shock required for making the snail inactive is 0.35 A/m² and the time required for inducing the inactivity was determined as being less than 10 seconds.

However, factors for the application of this technique to the control of snails should be carefully considered, particularly the effect of habituation to shocks by snails and aspects related to electric conductivity in paddy fields.

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References


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