

Observations of Boring Behaviour and the Drilling Mechanism of *Lunatia fortunei* (Gastropoda: Naticidae) in Western Korea

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ABSTRACT

Boring behaviour and drilling mechanism were investigated by visual observations. In this study, of two kinds of holes (the outer and inner holes) which are formed by drilling of boring gastropod *Lunatia fortunei* (Naticidae), the diameters of the outer holes are broader and larger than those of the inner holes, and their holes look like the crater in shape, as seen in all valves of bivalves bored by Naticidae species. Two kinds of glands (the accessory boring gland and accessory salivary gland) on the foot of boring gastropods have been investigated. Of them, it has been confirmed that only the accessory salivary glands on the foot secreted sulphuric (acidic) components in the mucus (secretion), while the accessory boring glands on the foot did not secrete their components. In this study, we confirmed that *L. fortunei* possess the accessory boring gland on the foot, as seen in most species in Naticidae. According to the results of the experiment of the blue litmus paper tests of the mucus (secretions) secreted from the accessory boring gland the color of the blue litmus paper did not turn red in color because chemical components of mucus (secretion) secreted from the accessory boring gland on the foot of *L. fortunei* (boring gastropod) were not acidic components. It is supposed that the mucus, which is secreted from the accessory boring gland, contained gelatin-like substances or enzymes without acidic components, as already reported in Naticidae species. Therefore, these substances may be involved in softening the surface of the valves of *M. veneriformis*. Consequently, it is assumed that *L. fortunei* bores holes through the shells of molluscs by means of following 3 methods: (1) a softening of the calcareous shells of *M. veneriformis* with chemical secretions (including gelatin-like substances or enzyme except for acidic components) from the accessory boring glands, (2) mechanical rasping with the radula, (3) a combination of both. In this study, particularly, acidic components, which are involved in softening the surface of the shells, are not associated with the boring mechanism of *L. fortunei* because chemical acidic components were not detected in the mucus (secretion), as found in Naticidae species.

Keywords: *Lunatia fortunei*, Boring Behaviour, Drilling Mechanism

INTRODUCTION

The fortune's moon snail, *Lunatia fortunei* is one of the edible gastropods in East Asian countries, including Korea, China, and Japan (Kwon *et al.*, 1993; Min *et al.*, 2004). More specifically, in Korea, this

species is mainly found in the silty sand at the intertidal zone of the south and west coasts of Korea. In the shellfish aquafarms, it was occasionally found that boring snail *Lunatia fortunei* (Naticidae) attacks and bores the valves of some bivalves such as *Crassostrea gigas* and *Macra veneriformis*, and then this species obtains food through holes drilled by them in the calcareous exoskeletons of preys. For that reason, it is well-known that *Lunatia fortunei* is canivorous snail and called as one of the harmful organisms in the shellfish aquafarms. Above all, it is

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important to get some information on feeding ecology associated with boring behaviour and the drilling mechanism of this species.

Previously, there have been many studies on aspects of reproduction, including reproductive ecology (Amio, 1963), on aspects of classification, including nomenclatorial note (Habe, 1969) and catalogue and biography of classification (Higo *et al.*, 1999), and on the aspect of ecology, including distribution, habitat (Kwon *et al.*, 1993) and feeding (Hong *et al.*, 2006) of this species.

To date, there have been many studies on boring behaviour and boring morphology of boring gastropods. In particular, regarding various kinds of boring gastropods, there were many studies on boring gastropods, including boring behaviours of *Neverita didyma* (Tamura, 1960), *Natica janthostoma* (Choi, 1962), *Tectonata janthostomoides* (Hamada, 1961) and *Metrix lusoria* (Lee, 1969). And some gastropods were reported: oyster drill of *C. virginica* by prosobranch (Carriker, 1943) and common oyster drill of *Urosalpinx cinerea* (Carriker, 1943).

The drilling process has not been observed directly and its process is hidden (Turner, 1953). Fisher (1922) obtained a reddening of blue litmus paper when touched to fresh pads and concluded that the hole is dissolved with acid secreted by this organ which he named the 'boring gland'. However, Pelseneer (1925) reported that the salivary secretions contain no acid and concluded that drilling process is purely mechanical.

However, many researchers have still believed that *G. didyma didyma* and Naticidae species secrete sulphuric acid components and gelatin-like substances from the boring gland, and then these gastropods (predators) make a drilled hole on the valves of prey (bivalves) by mechanical rasping with the radula. However, Turner (1953) supposed that Naticidae species do not secrete sulphuric acid from the boring gland, and drill hole by mechanical rasping with the radula of the snail, and the radular is involved in the formation of a drilled hole on the valve of the prey. In case of this species and Naticidae species, it has been confused whether their secretions, which are secreted from the accessory boring gland, contain sulphuric

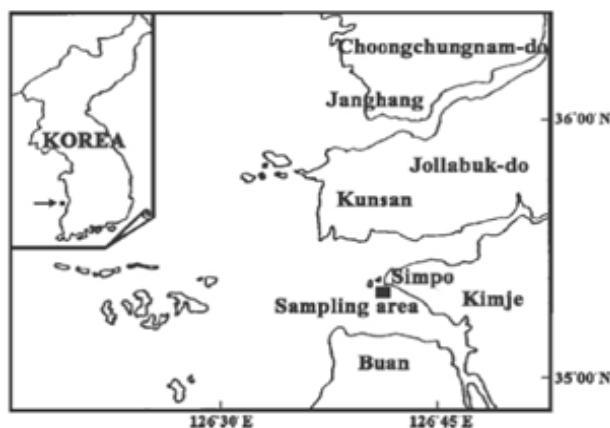


Fig. 1. Map showing the sampling area.

acid or not? Recently, the boring mechanism by penetration is incompletely understood. Therefore, it is important to check chemical components of secretions from boring gland of this species. In addition, it is also important to study boring behaviour and drilling mechanism. The purpose of the present study is to clarify and describe boring behaviour and drilling mechanism of this species.

MATERIALS AND METHODS

1. Sampling Methodology

Specimens of the moon snail, *L. fortunei* (Naticidae) were collected monthly in the intertidal zone of Simpo, Korea, from May to August, 2006 (Fig. 1). A total of 153 moon snails ranging from 49-52 mm in shell height (28-30 mm in width) were collected during the period of the study. Of them, 58 moon snails were transported alive to the laboratory for the indoor experiments, and each individual shell height was measured.

2. Observations on Boring Behaviour, the holes on the valves of *M. veneriformis* by boring snail, *L. fortunei*.

1) Field experiments in the shellfish aquafarm

(1) Boring behaviour

For preparing for the out door experiment on boring behaviour, a total of 153 specimens of *L. fortunei* were found from May to August 2006. In the field experiment at the shellfish aquafarm, special behaviour characteristics for predation of the



Fig. 2. A photograph showing the boring holes drilled on the valves of three kinds of bivalves by boring gastropods in the shellfish farms. Upper; *Mactra chinensis*, Low, left; *Nuttallia Japonica*, right; *Phacosoma japonicus*.

predator, *L. fortunei* were investigated and recorded by time. In the field experiments, ecological characteristics of capture behaviour of *L. fortunei* were investigated.

A total of 85 *Mactra veneriformis* of 30.3-33.5 mm in shell height were collected in the shellfish aquafarm, and they were investigated to clarify their morphological characteristics of the outer and inner holes of *Mactra veneriformis* drilled by *L. fortunei*.

(2) Experiment on detection of chemical components in the mucus in the shellfish aquafarm

A total of 53 moon snails of 25.2-32.7 mm in shell height, which were found in the aquafarm, and they were used for the detection of chemical components of the valves were damp with the mucus of secretions secreted from the accessory boring gland on the foot of *L. fortunei* by blue litmus paper test. To clarify the boring mechanism between predator and prey, the blue litmus papers were touched to around parts of the holes on the valves in the field.

2. Indoor experiments in the laboratory

Sometimes, for observations of boring behaviours of the boring gastropod *L. fortunei*, we carried out the indoor experiment, and observed boring behavior of some snails in detail in the an aquarium in the laboratory. We observed boring behaviours, the

morphologies and size differences of boring holes (inner and outer holes) and detection of chemical components in the mucus in the aquariums.

RESULTS

1. Observations of Boring Behaviour of the boring snail *L. fortunei*

In general, the holes on the died valves of bivalves such as *Mactra chinensis*, *Nuttallia japonica*, *Phacosoma japonicus*, and by boring gastropod, *Glossaulax didyma didyma* were very easily found in the shellfish aquafarm (Fig. 2), while it is hard to find the holes on the died valves of bivalves such as *M. veneriformis* by the boring snail, *L. fortunei* in the shellfish aquafarms. In this study, occasionally, we observed boring behaviour of the boring snail *L. fortunei* as follows.

As soon as predator, *L. fortunei* (Gastropoda: Naticidae) touched the shell of prey, the predator attached on the valve of *M. veneriformis* (prey) in the field of shellfish aquafarm. And then the predator secreted mucus from its pedal part in order to prevent the prey from escaping by covering with secretion (Fig. 3). One hour later, the predator crept into the bottom sand and bury itself accompanying with prey (*M. veneriformis*). After 2.3 hours more, boring was completed, and a small circular hole (being composed of the outer and inner



Fig. 3. The surf clam (*Mactra veneriformis*) captured by the boring gastropod *Lunatia fortunei* showing boring behaviour for feeding in the shellfish farm.



Fig. 4. A boring holes drilled on the valves of *Mactra veneriformis* in the shellfish farms.

holes) was left on the right or left valves of the clam. In the field, the morphology of the holes was crater-like in shape (Fig. 4). For observations of the processes of boring behaviour and drilling mechanism in the indoor experiments, after 30 individuals of *Lunatia fortunei* were collected in the fields, predators were transported alive to several aquariums at the laboratory. and several predators attached on the valves of preys in the aquarium.

In the field experiment, we could catch several good phenomena associated with boring behaviour as follows. For one minute, the predator attached on the valve of *M. veneriformis* by umbonal region where boring gland was located. And then, umbonium region was replaced by odontophore, scraping of the radula and jaw-plates could not observe in detail on the valve surface of the prey because the secretions covered up the the radula and jaw-plates. The hole was completed and widened by such shifts of two processes of operations. And then the mouth is structurally changed and the flesh (meat) of prey was absorbed into the mouth of the predator.

2. Experiment on morphological characteristics of the holes on the valves of *M. veneriformis* by *L. fortunei* in the aquaria

Observations of corelationships between a number of *M. veneriformis* (prey) and several predators were carried out in the aquaria with sands. After boring holes completed, the kinds and morphologies of holes on the valves of *M. veneriformis* drilled by *L. fortunei* were two kinds of holes (inner and outer holes) and crater in shape, respectively. In general, the sizes of

outer holes were larger than those of the inner ones (Fig. 4). The morphology of the holes are craft in shape.

3. Confirmation of lack of acidic components in secretions (mucus) secreted by boring snail around the incompleted hole

A living clam (*M. veneriformis*) which were attached to the foots of boring snail (*L. fortunei*) was found in the sand in the field of shellfish aquafarm, A living clam (*M. veneriformis*) attaching to boring snails was digged out from the sand with bare hands. The results of the field experiments and observations are as follows. Whenever each living clam was took out from the foot of each boring gastropod, an uncompleted hole on the valve of *M. veneriformis* was found during the period of formation of the hole. At that time, each valves of clams was wet with the mucus in secretions secreted from the accessory boring gland (ABO) of the snail. When blue litmus papers immedietely touched to near the hole which was wet by secretion, at that time, the color of the blue litmus paper did not turn red because chemical components of secretions were not acidic component. It is assumed that the mucus in the secretion, which is secreted from the accessory boring gland (ABO), may be, contains gelatin-like substances or enzymes, as reported in other Naticidae species. Therefore, we supposed that some components in these secretions may be involved in softening the surface of the valves of clams.

4. Drilling Mechanism of *L. fortunei*

Regarding boring mechanism of the boring snail, *L. fortunei*, above all, it is very important to investigate various kinds of organs existed on the foot of boring species. There are two kinds of glands such as accessory boring gland and accessory salivary gland on the foot of boring gastropods. However, these organs on the foot of boring snails vary with the species in the family. In case of *L. fortunei*, and Naticidae species (*L. lewisi*, *Natica severa*, *Polinices duplicatus*, *Sinum perspectivum*), accessory boring organs are present, however, accessory salivary glands are lacking. Drilling process is purely mechanical. In this study, there is no evidence that acid contents were not detected in the mucus secreted from the accessory boring glands when the blue litmus paper touched to the mucus of secretions on the valves of *M. veneriformis*. This species drills holes through the shells of their prey by only mechanical rasping with the radula, particular unaided by chemical secretions.

5. Indoor experiments in the aquarium in the laboratory

The results in the door experiments were similar to those of the field experiments, including 1) boring behaviours, 2) the size and morphological differences of the inner or outer holes, 3) lack of acidic components in secretions (mucus) secreted by the boring snail, and 4) final confirmations of the boring mechanism.

DISCUSSION

1. Boring behaviour and drilling mechanism

Of carnivorous gastropods, Buccinidae species belong to non-boring predatory snails such as *Bussinum undatum* and *Neptunea decemcostata* lack both the accessory boring organ and the accessory salivary gland, and their proboscies and radula are equipped for tearing, and pulling flesh rather than for rasping shell.

For boring of the valves of the prey (*M. veneriformis*), the predator crept into the bottom sand and buried itself accompanying with prey. After 2.3 hours more, boring was completed, and each circular hole (being composed of the outer and inner

holes) was left on the right or left valves of the clam. The morphology of the holes was crater-like shaped, and the outer holes were larger than the inner holes. These phenomena appeared by boring gastropods occasionally were found in young bivalves of *Tapes philippinarum* (Choi, 1962) and those of *Meretrix lusoria*. Carriker (1961) reported that experimental studies by several researchers on boring mechanism in naticid, muricid, and thaidid, prosobranch gastropods contributed further information on boring mechanism and support a chemo-mechanical theory of penetration in which abrasive action of the radula removes shell softened by secretion from the accessory boring organ (ABO).

According to the kind of glands on the foot of carnivorous boring gastropods, in general, there are two kinds of glands such as accessory boring gland and accessory salivary gland, the presence of these organs on the foot of boring gastropods vary with the species in the family.

Carriker (1961) also described that the accessory boring organ (ABO) is present in 29 species of boring species examined: under the distal tip of the proboscis in 5 Naticidae, and in the sole of the foot of 24 Muricidae and Thaididae. Regarding Muricidae, Carriker (1961) also reported that in *Thais clavigera*, *T. h. haysae*, *Rapana thomasi*, the accessory boring organ lies at top. And also in *Murex brevisfrons*, *M. cellulo*, *M. fulvescens*, *M. pomum*, *Muricopsis ostrearum*, *Ocenebra erinacea*, *O. japonica*, *Pterorytis foliata*, *T. deltoydia*, *T. amarginaa*, *T. lamellosa*, *T. lustica*, the accessory boring organ appears as a separate organ in the anterior mid-ventral portion of the foot. However, he stated that *Murex pomum* did not contain the accessory salivary gland. Exceptionally, Graham (1941) reported that secretion of the accessory salivary glands of *Thais lapillus* has a pH of 6 and does not each shell or dissolve shell flakes.

Fischer (1922) reported that hole is bored mechanically with the radula working as a rasp, however, he suggested that its action might be facilitated by a softening of the calcareous shells with sulphuric acid secreted by the salivary glands.

However, Pelscener (1925) stated that the salivary gland secretions contained no acid and concluded that drilling process was purely mechanical. In this study, acid components were not detected in the mucus in the secretion secreted from the accessory boring glands when the blue litmus paper touched to the mucus of secretions on the valves of *M. petechialis*. However, in case of the existence of some acidic components in the secretions, it is assumed that boring mechanism of boring gastropods drill holes through the shells of other molluscs by means of following 3 methods proposed by Turner (1953): (1) chemical secretions from the salivary glands or similar organs, (2) mechanical rasping with the radula, or similar organs, (3) a combination of both.

Colton (1908) suggests that the snail waits until the oyster opens and then inserts its shell between the valves. The ventral surface of the foot of the snail secretes a highly viscous mucus. There were the experiments to determine the ability of the Naticidae to drill through other inert materials, two experiments were performed with the American clam drill, *Polynices duplicata*, to test ability to perforate lamellibranch shells coated with paraffin wax and plaster of Paris.

According to Carriker (1951), when a number of clams (*Mya arenaria*) coated with histological paraffin in layers approximately 0.5 mm thick, were placed in a seawater aquarium containing starved *P. duplicata*, the polynices readily attacked the coated clams and drilled typical holes without any interference from the wax layers. This established the fact that the drilling processes basically mechanical but did not preclude auxiliary use of chemical secretions to soften the hard calcareous shell after the wax had been scraped away. The *Polynices* readily attacked clam coated with Plaster of Paris and drilled typical holes through the coatings without apparent difficulty. Therefore, on the whole, I agree with Carriker's (1951) opinions mentioned above.

The function of the so-called boring gland (ABO) is not apparent, but its structure and location suggested that it may be an adhesive pad that holds the anterior extremity of the proboscis firmly against the

shell to facilitate the action of the radula. Therefore, this species drills holes through the shells of other molluscs by means of following 3 methods: (1) a softening of the calcareous shells of the prey with chemical secretions (including gellatin-like substances or enzyme except for acidic components) from the accessory boring glands, (2) mechanical rasping with the radula, (3) a combination of both. Accordingly, boring mechanism of *L. fortunei* is associated with a chemo-mechanical theory of penetration in which abrasive action of the radula removes shell softened by secretion from the accessory boring organ (ABO). In case of the boring mechanism of *L. fortunei* in Naticidae, its main mechanism is formed by mechanical rasping with the radula. Therefore, we agree with Turner's opinion (1953) except for the part of his opinion associated with chemical acid components (secretions).

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