

SWIMMING BEHAVIOR OF AN AQUATIC
WEEVIL, *LISSORHOPTRUS ORYZOPHILUS*
(COLEOPTERA: CURCULIONIDAE)

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ABSTRACT

The swimming behavior of the rice water weevil *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae) is unique in comparison to that of most other aquatic weevils. Propulsion during swimming is provided only by the mesothoracic legs. The legs are moved synchronously during protraction and retraction. The pro- and metathoracic legs serve as diving planes and provide stability. The average rice water weevil swimming speed was 1.53 (± 0.15 SE) cm per s with a range of 0.88 to 2.52 cm per s. Weevils averaged 5.67 (± 0.22 SE) strokes per s.

The mode of swimming by *L. oryzophilus* differs from those described for *Phytobius leucogaster* (Marsham) (= *Litodactylus leucogaster*), *P. comari* (Herbst), *Bagous cavifrons* LeConte, *B. americanus* LeConte and *B. limosus* Gyllenhal. It also differs from descriptions of swimming for other aquatic Coleoptera and Hemiptera. Furthermore, *L. oryzophilus* swims below the surface and was observed at depths of 18.0 cm in the laboratory. This brings the modes of free swimming (exclusive of skating) to at least 3 by adult aquatic curculionids.

Key Words: Rice water weevil, barrier trap, aquatic weevils, swimming behavior

RESUMEN

El comportamiento de natación del gorgojo acuático de arroz, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae) es único en comparación a la mayoría de los gorgojos acuáticos. La propulsión durante la natación es proveída solamente por las piernas del mesotórax. Las piernas son movidas sincrónicamente durante la pro-tracción y retracción. Las piernas del pro- y metatórax sirven como planos de inmersión y proveen estabilidad. La velocidad de natación promedio del gorgojo acuático de arroz fue 1,53 ($\pm 0,15$ SE) cm por s con una variación entre 0,88 hasta 2,52 cm por s. Los gorgojos tuvieron un promedio de 5,67 ($\pm 0,22$ SE) patadas por s.

El modo de natación en *L. Oryzophilus* difiere de otros descritos para *Phytobius leucogaster* (Marsham) (= *Litodactylus leucogaster*), *P. Comari* (Herbst), *Bagous cavifrons* LeConte, *B. Americanus* LeConte and *B. Limosus* Gyllenhal. También difiere de descripciones de natación para otros acuáticos de Coleptera y Hemiptera. Además, *L. oryzophilus* nada bajo la superficie y fue observado a profundidades de 18,0 cm en el laboratorio. Esto eleva los modos de natación libre (exclusivo de patinaje) hasta por lo menos 3 por adultos acuáticos de Curculionidae

The rice water weevil *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae) is the key insect pest of rice, *Oryza sativa* L., in the U.S. (Way 1990). This weevil is native to North America (O'Brien & Wibmer 1982), but has been introduced into

Japan, Korea, Taiwan, India and China (Nagata 1990, Barwal et al. 1994). This weevil is about 2 mm in length and overwinters as an adult. Reproduction is sexual in its native range and parthenogenetic in California and areas where introduced (Takenouchi 1978). The aquatic adults feed on rice leaves, although rice is not its natural host plant. The fully aquatic larvae feed on rice roots and can cause yield reduction. Even though it is the major insect pest of rice in the U.S., published information about adult behavior is limited (Stout et al. 2000). More is known about larval *L. oryzophilus* aquatic behavior and adaptations than adult aquatic behavior and adaptations. The larvae have six pairs of dorsal hooks on abdominal segments two through seven which are associated with the tracheal system (Isely & Schwardt 1930). These hooks are thought to tap root tissues to obtain air. They may also aid in larval locomotion.

Lissorhoptrus LeConte typically have curved blade-like mesotibia equipped with long swimming hairs on the inner and outer margins (O'Brien 1996). Underwater respiration by adult *L. oryzophilus* is accomplished by a plastron (Hinton 1976).

Nachtigall (1974, 1985) reviewed swimming in adult insects, but descriptions for swimming in weevils were lacking. O'Brien & Marshall (1979) described swimming in the weevils *Bagous cavifrons* LeConte and *B. americanus* LeConte. These weevils swim with "dog paddle" strokes with the prothoracic legs and push with the alternation of the meso- and metathoracic legs against the surface tension. This was consistent with the description given for the mode of swimming in *B. limosus* Gyllenhal (Angus 1966, Menier 1970). Furthermore, *Bagous lunatoides* Blatchley and *B. pictus* Blatchley do not swim (O'Brien & Marshall 1979). These weevils were reported to walk on the upper and lower side of the surface tension. *Litodactylus leucogaster* (Marshall), a junior synonym of *Phytobius leucogaster* (Marshall) (O'Brien & Wibmer 1982), swims on the surface using all three pairs of legs for propulsion (Buckingham & Bennett 1981). Legs on the same segment are typically moved synchronously with the prothoracic legs being retracted while the meso- and metathoracic legs are being protracted. The metathoracic legs of *P. leucogaster* did not appear to contribute much power to propulsion in comparison to the pro- and mesothoracic legs. *Phytobius comari* (Herbst) efficiently swims by using all 6 legs (Read 1985). *Eubrychius velatus* Beck (= *Phytobius velatus*) was reported to be an excellent swimmer (Ruter 1978, Morris 1991). The genus name literally means "good swimmer" and the specific epithet means "velvet" referring to the plastron formed by the hydrofuge scales (Morris 1976, 1991). Langer & Messner (1984) described the plastron of *E. velatus*, *B. longitarsis* Thompson, *B. argillaceus* Gyllenhal, *B. binodulus* Herbst, *B. glabrirostris* Herbst, and *B. puncticois* Boheman. However, descriptions of swimming behavior in *E. velatus* are lacking in the literature. Swimming by *Euhrychiopsis lecontei* (Dietz) was reported (Solarz & Newman 1996), but descriptions of the mode of swimming are lacking.

Two basic modes of swimming have been described in aquatic beetles which are different from swimming systems described for aquatic weevils. Hughes (1958) studied the leg movements of free swimming *Dytiscus marginalis* (L.) (Coleoptera: Dytiscidae) and *Hydrophilus piceus* (L.) (Coleoptera: Hydrophilidae) from films. Further studies of dytiscids were done by Gewecke (1980, 1985) and Gewecke & Rostock (1986). Typically, medium to larger dytiscids use the meso- and metathoracic legs for swimming with the pair on the same segment protracting and retracting simultaneously (Nachtigall 1974, 1985). The mesothoracic legs may row alternately or synchronously with the metathoracic legs. In hydrophilids, retraction of a left mesothoracic leg occurs simultaneously with the right metathoracic leg, and the right mesothoracic leg retracts simultaneously with the left metathoracic leg. Meso- and metathoracic legs play an important part in swimming in *D. marginalis* and *H. piceus* with the prothoracic legs held stationary close to the thorax.

Lissorhoptrus oryzophilus has a unique swimming behavior in comparison to most other aquatic insects. Information on the adult swimming behavior of *L. oryzophilus* was needed to aid in the development of an aquatic intercept trap to monitor adult populations in flooded rice fields. Such a trap may help to determine the need for and appropriately time applications of the adulticide λ -cyhalothrin (Karate®, Zeneca Ag Products, Wilmington, DE) or the ovicide diflubenzuron (Dimilin®, Uniroyal Chemical Company, Middlebury, CT) and prevent unnecessary applications. The larvicide carbofuran (Furadan®, FMC, Philadelphia, PA) was no longer registered for use in rice after 1998, and new population monitoring methods compatible with λ -cyhalothrin and diflubenzuron are urgently needed (Stout et al. 2000). The objectives of this study were to 1) describe the swimming behavior of *L. oryzophilus*, 2) determine *L. oryzophilus* swimming speed, depth and response to barriers encountered, and 3) compare *L. oryzophilus* swimming behavior and survival in water with that of terrestrial weevils and other aquatic insects.

MATERIALS AND METHODS

Adult *L. oryzophilus* were collected from newly flooded rice fields at the Rice Research and Extension Center in Stuttgart, AR 8 June 1998 and 9 August 1999. The weevils were placed in containers with rice plants and transported to Fayetteville, AR. Adults of the plum curculio *Conotrachelus nenuphar* (Herbst), and the rice weevil *Sitophilus oryzae* (L.), were collected near Fayetteville, AR.

Adult weevil swimming sequences of 25 *L. oryzophilus*, 10 *C. nenuphar* and 10 *S. oryzae* were videotaped from a: 1) dorsal view in a Petri dish, 2) lateral view in an aquarium, and 3) ventral view in a Petri dish. Videotaping equipment consisted of an Optem Zoom 70 macro lens (Optem International, Fairport, New York) mounted on a CCD color video camera and a S-VHS tape deck. The Petri dish had graduations on the bottom to determine swimming speed of the weevils. Videotaping was conducted while the weevils swam freely between 10:00 a.m.-2:00 p.m. and 4:00 p.m.-8:00 p.m. with an air and water temperature of 24°C. The video tape was evaluated in real time and by manual advancing to determine leg movements during swimming sequences. *Lissorhoptrus oryzophilus* swimming movements were compared to descriptions of swimming of dytiscid (Hughes 1958), hydrophilid (Hughes 1958), curculionid (O'Brien & Marshall 1979, Buckingham & Bennett 1981), belostomatid (Lauck 1959), nepid (Wendler et al. 1985) and notonectid adults. Videotape sequences of 20 weevils were used to determine average weevil swimming speeds.

Individuals of *L. oryzophilus* were placed in an aquarium (18.9 liters) with a water depth of 18.0 cm to determine the weevils response when encountering a 10.0 cm by 35.0 cm screen barrier positioned perpendicular to the surface of the water. This experiment was replicated with 100 weevils. Reactions of swimming weevils were recorded when the screen barrier was encountered. An event recorder (Unwin & Martin 1987) was used to calculate the amount of time each weevil spent swimming at depths of 0-3.0, 3.0-6.0, 6.0-9.0, 9.0-12.0, 12.0-15.0, and 15.0-18.0 cm for a 5 min period per weevil.

Thirty weevils of each species were placed in an aquarium with no resting places and monitored every 12 h to determine the status (alive or dead) until all weevils were dead or 120 h had elapsed. Notes were taken on the status (alive or dead) of 9,416 *L. oryzophilus* weevils removed from 32 aquatic barrier traps every 24 h over a 9 d period during August 1999. The trap design is described by Hix et al. (2000).

RESULTS AND DISCUSSION

Lissorhoptrus oryzophilus swims beneath the surface film. Propulsion for *L. oryzophilus* during swimming is provided only by the mesothoracic legs. The legs are

moved synchronously during protraction (Fig. 1a-d) and retraction (power stroke) (Fig. 2a-c). The swimming hairs on the mesotibia were deployed at the onset of retraction. The prothoracic legs (extended forward) and metathoracic legs (extended backwards) serve as diving plains and stabilizers (Figs. 1 and 2). Turning is accomplished with the mesothoracic leg opposite the direction of the turn going through normal protraction and retraction sequences and the mesothoracic leg on the turn side going through a shorter protraction and retraction sequence as depicted in Fig. 3. Paddling on the turn side tends to be across the body. The average rice water weevil swimming speed was $1.53 (\pm 0.15 \text{ SE})$ cm per s with a range of 0.88 to 2.52 cm per s. Weevils averaged $5.67 (\pm 0.22 \text{ SE})$ strokes per s with a stroke consisting of a complete protraction and retraction.

The terrestrial weevil *C. nenuphar* was able to swim only marginally by using tripod type movements associated with insect walking as described by Hughes (1952). The other terrestrial weevil *S. oryzae* was less successful at using tripod type movements for swimming and frequently struggled in the surface film.

Lissorhoptrus oryzoophilus spent 82.9% of their time swimming between the surface film and a depth of 6.0 cm and 17.1% between 6.0 and 18.0 cm (Fig. 4). Only 5.3% of the weevils swam deep enough to actually go under the 10 cm by 35 cm barrier. When encountering the barrier during swimming, 53 weevils turned right and mi-

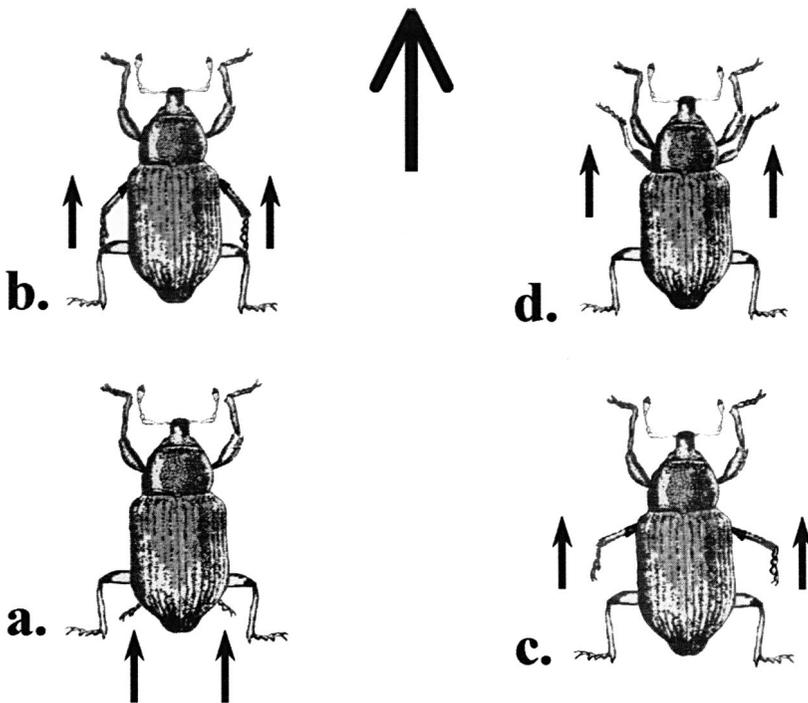


Fig. 1. Protraction sequence (a-d) by *Lissorhoptrus oryzoophilus* during swimming. Large arrow indicates the direction of insect travel. Small arrows indicate direction of mesothoracic leg movement. Swimming hairs are folded during this sequence.

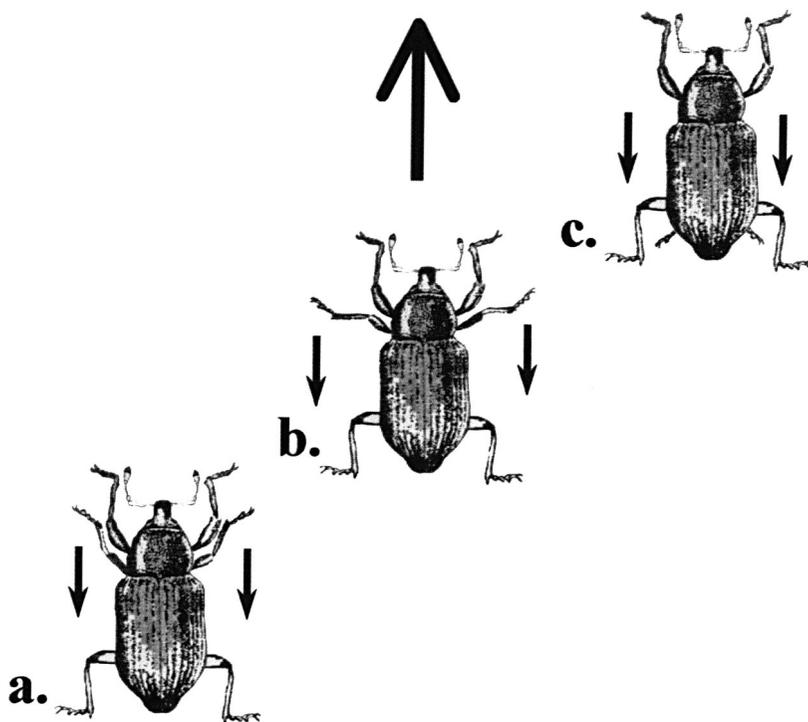


Fig. 2. Retraction sequence (power stroke) by *Lissorhoptrus oryzophilus*. Large arrow indicates direction of insect travel. Small arrows indicate direction of movement of mesothoracic legs. Swimming hairs on the mesotibiae are deployed between a and b.

grated along the barrier, 39 weevils turned left and migrated along the barrier, 7 weevils clung to the barrier, and 1 weevil failed to contact the barrier.

Twenty-seven *S. oryzae* expired by 12 h and all 30 had expired by 24 h. Seven *C. nenuphar* expired by 24 h, and all had expired by 36 h. All 30 *L. oryzophilus* placed in the aquarium were still alive and swimming after 120 h which was consistent with the reports by Blatchley & Leng (1916) that *L. simplex* (Say) could stay submerged for over 96 h. In a revision of *Lissorhoptrus*, Kuschel (1952) recognized *L. simplex* (Say) as *L. simplex* and *L. oryzophilus*. Of the 9,416 *L. oryzophilus* removed from the barrier traps in August 1999, only 38 of them had expired.

The mode of swimming in *L. oryzophilus* is different from those described for *P. litodactylus*, *B. cavifrons*, and *B. americanus* (O'Brien & Marshall 1979, Buckingham & Bennett 1981). It is also different from descriptions of swimming for other aquatic Coleoptera and Hemiptera. Furthermore, *L. oryzophilus* swims efficiently beneath the surface film and was observed at depths of 18.0 cm in the laboratory.

It appears unique for adult beetles in a family to have more than 1 mode of free swimming. There are at least 3 modes of free swimming by adult aquatic curculionids. In addition, some aquatic curculionids can walk on either side of the surface tension (O'Brien & Marshall 1979). An informal generic group of aquatic weevils in the tribe Stenopelmini, subfamily Erihriniinae are referred to as the "rice water weevils"

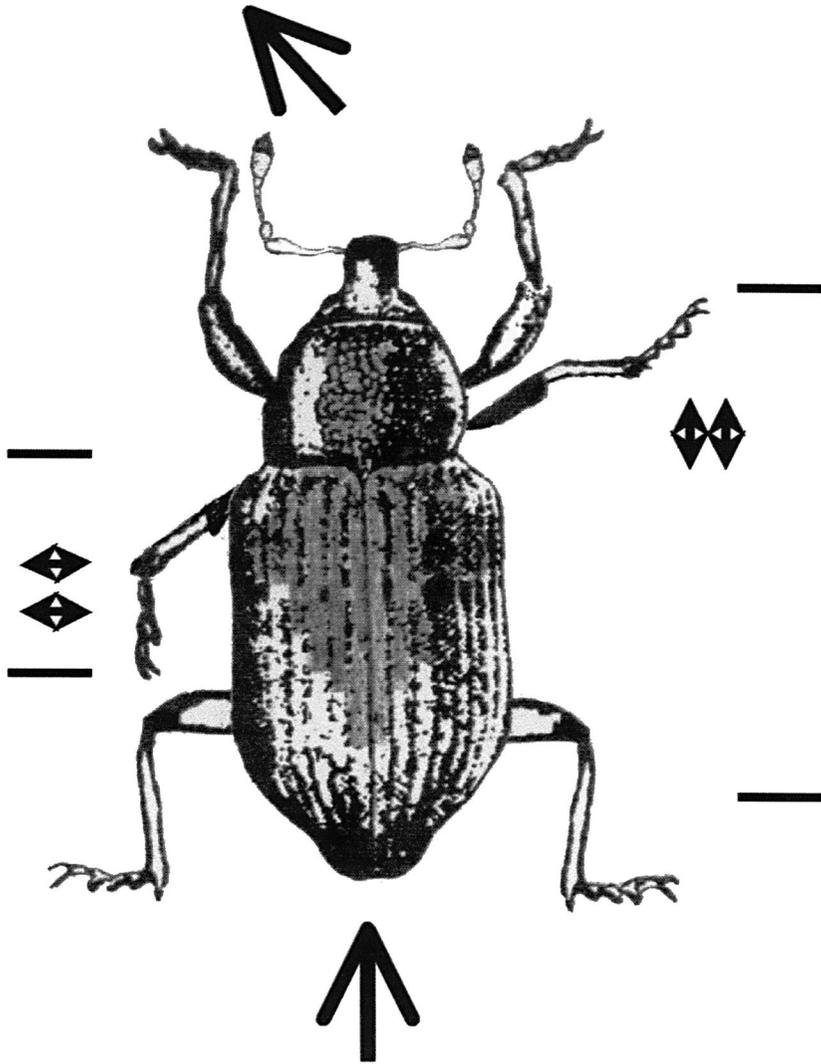


Fig. 3. Left turn sequence by *Lissorhoptrus oryophilus*. Large arrows indicate direction of insect travel. Small double arrows indicate direction of mesothoracic leg movements. Lines mark the range of leg movement during turn. Mesothoracic leg movement is shorter on the turn side with turn side strokes across the body at an oblique angle.

(O'Brien 1990). This informal group consists of the following New World genera: *Bagoidellus* Hustache, *Bagoidus* Kuschel, *Helodytes* Kuschel, *Hydrotimetes** Kolbe, *Ilyodytes** Kuschel, *Lissorhoptrus**, *Neobagoidus* O'Brien, and *Oryzophagus** Kuschel. Adults in the "rice water weevil" group for which swimming behavior is known (indicated by *) have a similar mode of action to the one described in this paper for *L. oryzo-*

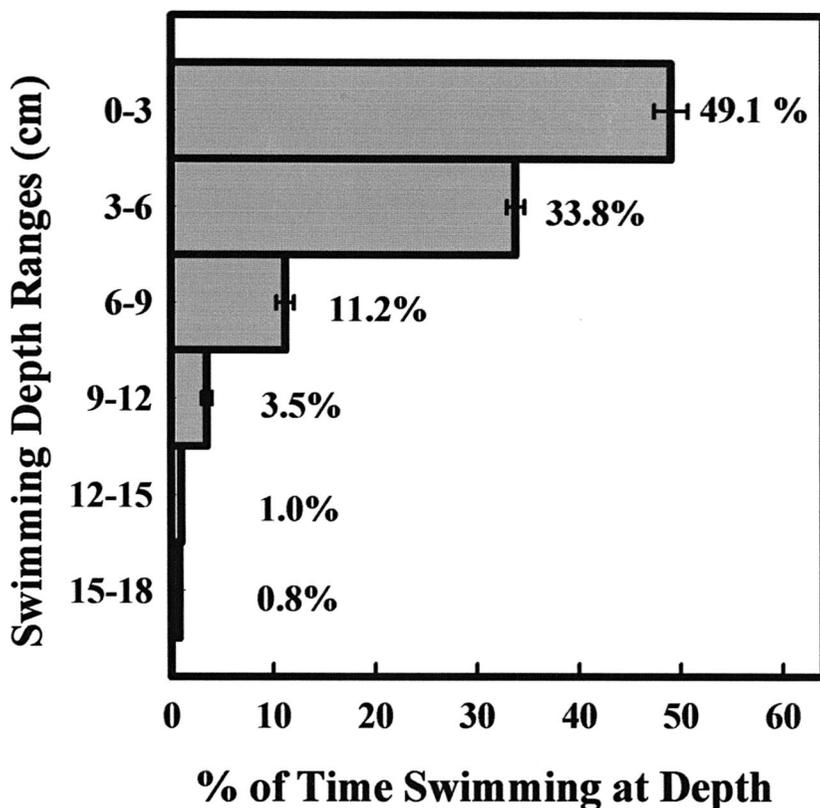


Fig. 4. Percentage of time that adult *Lissorhoptrus oryzophilus* spent swimming at 3.0 cm intervals to a maximum depth of 18.0 cm. The observation period for each weevil was 5 min (n = 100). Error bars represent SEM.

philus (C. W. O'Brien, Center for Biological Control, Florida A & M University, personal communication). Furthermore, some skate on the surface. *Poophagus sisymbrii* (F.) skates by using each pair of legs as sculls (Morris 1976, 1991, 1995). It is apparent that swimming and skating behavior is diverse in adult aquatic curculionids and more studies are needed in this area of weevil behavior.

The information learned from these studies was used in part to develop an aquatic barrier trap to sample *L. oryzophilus*, a key pest of rice in the U.S., within 10 d after applying permanent flood to rice fields. The barrier trap functions passively by intercepting swimming weevils much like a Malaise trap functions by intercepting flying insects. Development of the sampling tool for *L. oryzophilus* adults is an important part of the future integrated pest management program for rice.

ACKNOWLEDGMENTS

We thank Charles O'Brien (Center for Biological Control, Florida A & M University) for information on aquatic weevils. We thank the anonymous reviewers for read-

ing the manuscript and for their suggestions. These studies were funded in part by the University of Arkansas Experiment Station and the Arkansas Rice Research and Promotion Board.

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