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Abstract: Conditioned food aversion can be used to train animals to avoid select foods. Generally, aversive conditioning is best applied when animals first encounter a food item. However, almost by definition damage is inflicted to desirable plants very familiar to the culprit. We assessed the potential for training beaver to avoid a known preferred food. During a 5 day day treatment period beavers were offered only corn at 1600 hours. Six hours later, animals that had ingested corn were injected with 150 mg/kg lithium chloride (LiCl), with a control group receiving sodium chloride (NaCl). Alternate foods were then offered with corn to determine whether animals avoided corn when offered a choice. Animals that ingested corn were given an additional LiCl injection. Although beaver significantly reduced their corn consumption after they were treated with LiCl ($P < 0.0001$) they also generalized the induced illness to rodent blox ($P < 0.0001$). The combined effect was an overall reduction of food intake. There was no difference in the control group's intake of corn ($P = 0.189$) or rodent blox ($P = 0.383$) between the pre and post-treatment periods. We conclude aversive conditioning is probably not a feasible approach to reduce beaver foraging of preferred foods.

***Key words*:** beaver, *Castor canadensis*, conditioned food aversion, herbivory

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INTRODUCTION

Beavers (*Castor canadensis*) are a natural and desirable component of a wetland ecosystem (Nolte et al. 2003) but their foraging impact can greatly impact plant communities. A single beaver can consume up to 2 kg of woody plant material per day (Baker and Hill 2003). Their foraging can become a problem when it negatively affects restoration projects or reduces harvest potential of cultivated plants. Lethal removal, by trapping, has long been the predominant method of beaver management (Houston 1998). However, negative public perception and increasing restrictions applied to trappers are reducing its feasibility in some situations. Often non-lethal approaches are the only options available. Several non-lethal methods to protect valuable resources from beavers have been investigated, with varying success (Hammerson 1994, Houston 1998). Relocating is expensive and only temporary, other beaver often quickly invade from surrounding areas (Hammerson 1994, Nolet and Rosell 1998). Fencing has potential to protect small areas but is expensive and generally not effective to restrict beaver entry to larger areas (Müller-Schwarze 1994, Nolte et al. 2003). Textural repellents deter gnawing of tree trunks and chemical repellents can deter browsing of vegetation for a few months (Nolte et al. 2003). Frightening devices and repellents generally are ineffective to reduce beaver activity for extended periods (Nolte et al. 2003).

Animals that suffer gastro-intestinal distress after consuming a food often avoid that food on subsequent encounters (Garcia et al. 1985). Conditioned food aversions are generally induced by injecting animals with a malaise inducing agent after feeding them the food to be avoided. Lithium chloride (LiCl) is a fairly standard agent used when training rodents (Nolte and Mason 1998). Aversive conditioning is generally most effective if animals are conditioned to avoid a food to which they are unfamiliar (Bernstein and Goehler, 1983). Unfortunately when animals are causing damage it is because they are routinely eating plants that are frequently desirable plants which are very familiar to the culprit. Beaver are generalist feeders so if trained to avoid a food they should start foraging on other plants that are equally nutritional (Müller-Schwarze 1994). Thus, training beaver to avoid protected plants should enable the plants to survive in the presence of the conditioned beaver colony. Conditioned food aversion has not been attempted in beaver. Therefore, we assessed the potential for conditioning beaver to avoid a known preferred food.

SUBJECTS

Seventeen beaver were individually housed in pens measuring 5 x 3.5 m at the NWRC Olympia Field Station, Olympia, Washington. Each pen contained a PVC plastic den box (53 cm diameter x 53 cm tall) with wood shavings for bedding. Den boxes had hinged roofs to provide access to the animals and to facilitate cleaning. In addition, each pen contained a galvanized stock tank (1125 liter) for beaver to swim. A series of log steps placed outside the tank facilitated beaver entry. Ponds were regularly cleaned to provide beaver with clean water. Animals were given wood stems for gnawing, along with fresh water and food. Their maintenance diet consisted of apple, corn, carrots and rodent blox (Animal Specialties, Hubbard, Oregon). All procedures described here were approved by the Institutional Animal Care and Use Committee (QA-1099) and conducted during November 2003.

EXPOSURE

During the pre-treatment period, each beaver was individually fed the maintenance diet of apple (half an apple), corn (2 ears), carrots (2, 15-cm carrot sticks) and rodent blox (200 grams). During this period individual foods were weighed before they were fed to beavers at 0900 hours each morning. The amount remaining the following morning also was weighed and then subtracted from the amount presented. Amount consumed by beaver over the 24 hour period was the difference between the amount given and amount remaining. Fresh food was presented each morning.

Following the five-day pre-treatment period, beaver were randomly assigned to treatment groups (8 NaCl, 9 LiCL). On the first day of exposure, subjects were food deprived until 1600 hours and then given only corn to eat. At 2200 hours, the amount of corn ingested by each animal was determined. Subjects that ingested corn received either a sterile saline solution (control group-0.4 ml saline/kg body mass) or a lithium chloride (treatment group-150 mg LiCl/kg body mass) intraperitoneal injection. Animals were then given their normal ration of other foods (apple, carrot and rodent blox). Over the next 4 consecutive days, animals were given their normal rations (apples, corn, carrot and rodent blox) at 1930 hours. The amount of corn and other food ingested was determined the next morning at 0800 hours. Any subject in the treatment group that ingested corn was given an additional injection of LiCl. Thus, treatment animals could potentially receive up to 5 injections of LiCl over the treatment period. The LiCl dosage was the same as the initial injection regardless of the amount of corn ingested. The control subjects only received the initial injection of sterile saline regardless of corn consumption during the treatment period.

After the five-day treatment period, beaver were fed their normal maintenance ration (apple, corn, carrot and rodent blox), and intake was determined as described for the pre-treatment period. Post-treatment monitoring continued for four days after the conclusion of the exposure period.

METHODS

Statistical Analyses

Food intake data consisted of four responses: daily consumption of corn, apple, carrot, and rodent blox. Separate analyses were conducted for each response. Repeated measures analyses of variance (ANOVA) were conducted with treatment (NaCl or LiCl) the fixed effect and days the repeated measure (SAS® Version 8.0, SAS Institute Inc., Cary, N.C.).

A mixed effects ANOVA was employed to evaluate the effect of a conditioned aversion on food consumption for each response (corn, apple, carrot, rodent blox). For these analyses, a class variable called "phase" coincided with the three phases of the experimental design: "pre-treatment" (days 1 – 5), "treatment" (days 6 – 10), and "post-treatment" (days 11 – 14). Analyses of variance were conducted with subjects (nested in treatment) the random effect, while the fixed effects were treatment, experimental phase (pre-, treatment, post-) and the treatment*phase interaction. Three post-hoc comparisons were made for each response and comparison-wise error rate controlled by setting the decision criteria to $\alpha = 0.0167$ according to the Bonferoni adjustment (Rice, 1989). These comparisons of food consumption were: pre-treatment LiCl vs. post-treatment LiCl, pre-treatment NaCl vs. post-treatment NaCl, and post-treatment NaCl vs. post-treatment LiCl.

RESULTS

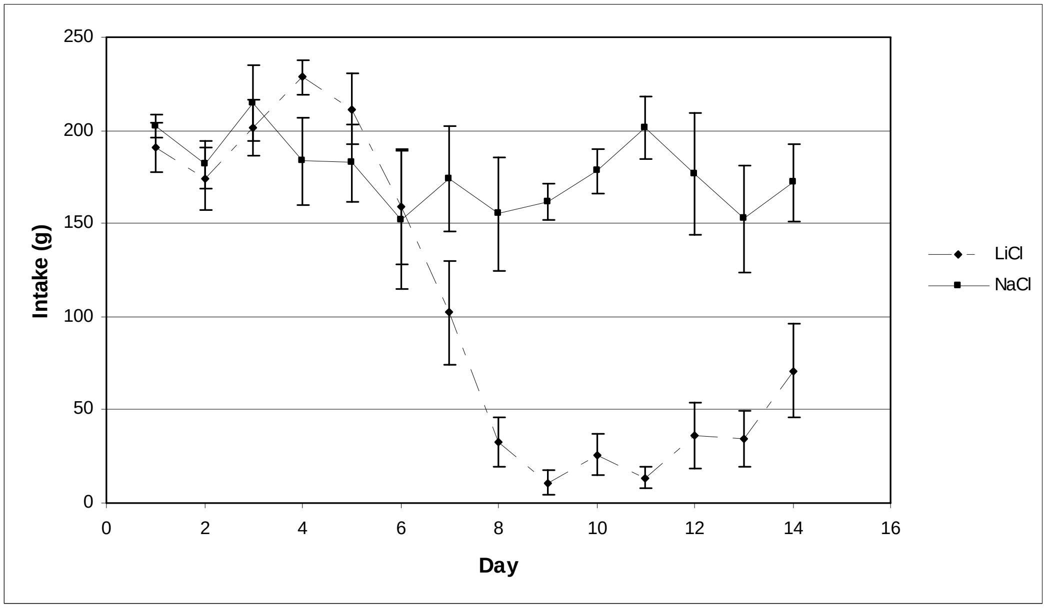
Corn Consumption

Repeated measures ANOVA indicated that corn consumption was subject to the interaction of treatment and experiment day ($P < 0.0001$). Further investigation of this interaction demonstrated that an aversion to corn was produced by repeated exposure to LiCl during the treatment phase of the experiment. Among the LiCl treatment group, post-treatment corn intake (37.1 g) was significantly reduced from pre-treatment intake (201 g). Conversely, NaCl administration did not produce an aversion to corn ($P = 0.189$). Mean pre-treament corn intake was 193 g for the NaCl treatment group and 176 g during the post-treatment period. Post-treatment corn consumption by the NaCl treatment was significantly greater than for the LiCl group ($P < 0.0001$). The LiCl treated group decreased their corn intake following the treatment phase, demonstrating that LiCl exposure can be employed to produce a learned aversion to a familiar food (i.e. corn) by repeated exposure (Figure 1).

Apple Consumption

The treatment effect was a significant component of apple consumption ($P = 0.0402$). Post-treatment intake was not reduced by either LiCl ($P = 0.107$) or NaCl ($P = 0.999$), but post-treatment apple consumption was significantly greater in the LiCl group (50.0 g) versus the NaCl group (26.1 g; $P = 0.0153$). These results indicate that learned aversion of corn was not generalized to apple. In fact, the increased apple consumption among the LiCl treatment indicates that apple intake increased in response to avoidance of corn (Figure 2).

Figure 1. The mean corn consumption over the pre-exposure period (days 1-5), exposure period (days 6-10), and post-exposure period (days 11-14) for the treatment (LiCl) and control (NaCl) groups.



Carrot Consumption

A significant time effect demonstrated that carrot intake was reduced over the course of the experiment, regardless of treatment ($P = 0.0048$). Further examination of the time effect indicated that post treatment carrot intake was reduced among both the LiCl group (94.0 g vs. 26.8 g; $P < 0.0001$) and the NaCl group (53.3 g vs. 7.78 g; $P < 0.0001$). These results suggest that consumption of carrots was reduced by exposure to both LiCl and NaCl (Figure 3). However, while LiCl is known to produce conditioned aversions because it causes emesis and malaise, NaCl is not toxic. Thus, lithium-induced toxicosis is probably not responsible for the observed reduction in carrot consumption.

Rodent Blox Consumption

Similar to corn consumption, rodent blox consumption was subject to a significant time*treatment interaction ($P = 0.0494$). Also similar to the corn response, post-treatment intake (34.2 g) was significantly lower than pre-treatment intake (117 g) among the subjects receiving LiCl ($P < 0.0001$). Rodent blox consumed by animals in the NaCl group during the post treatment period (108 g) was not different than their pre-treatment intake (117 g; $P = 0.383$). Post-treatment intake was significantly different between the LiCl and NaCl groups ($P < 0.0001$). The decrease in rodent blox consumption within the treatment group suggests that lithium induced toxicosis was generalized to rodent blox – despite the attempt to specifically associate LiCl exposure with corn only (Figure 4).

Figure 2. The mean apple consumption over the pre-exposure period (days 1-5), exposure period (days 6-10), and post-exposure period (days 11-14) for the treatment (LiCl) and control (NaCl) groups.

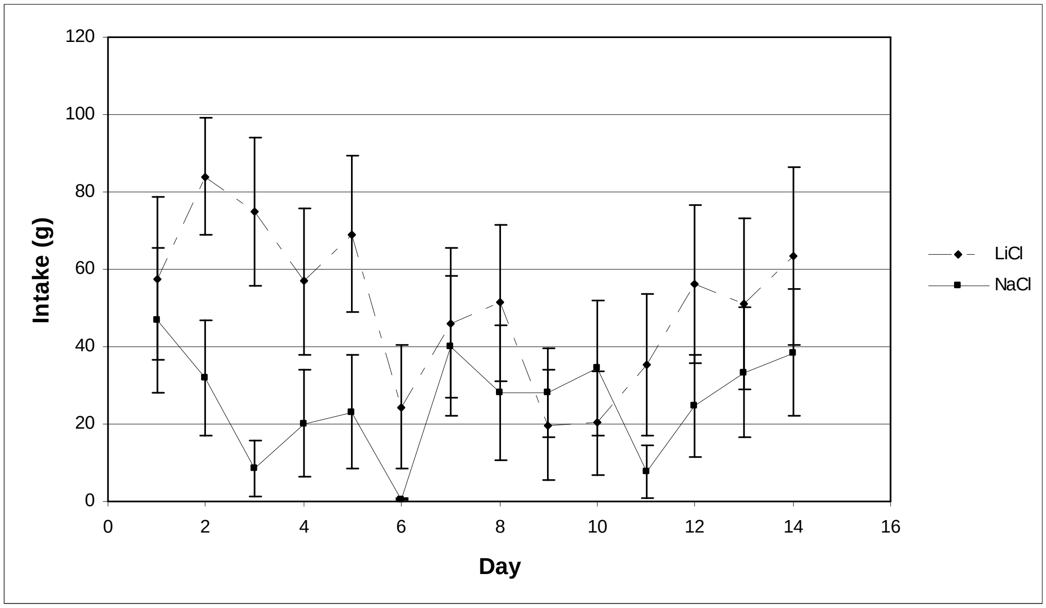


Figure 3. The mean carrot consumption over the pre-exposure period (days 1-5), exposure period (days 6-10), and post-exposure period (days 11-14) for the treatment (LiCl) and control (NaCl) groups.

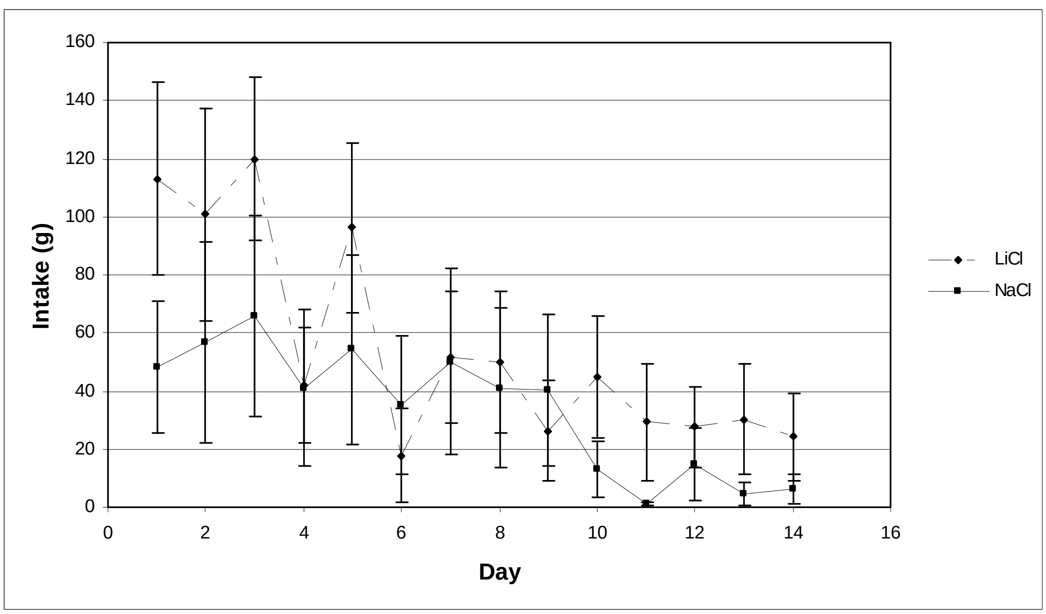
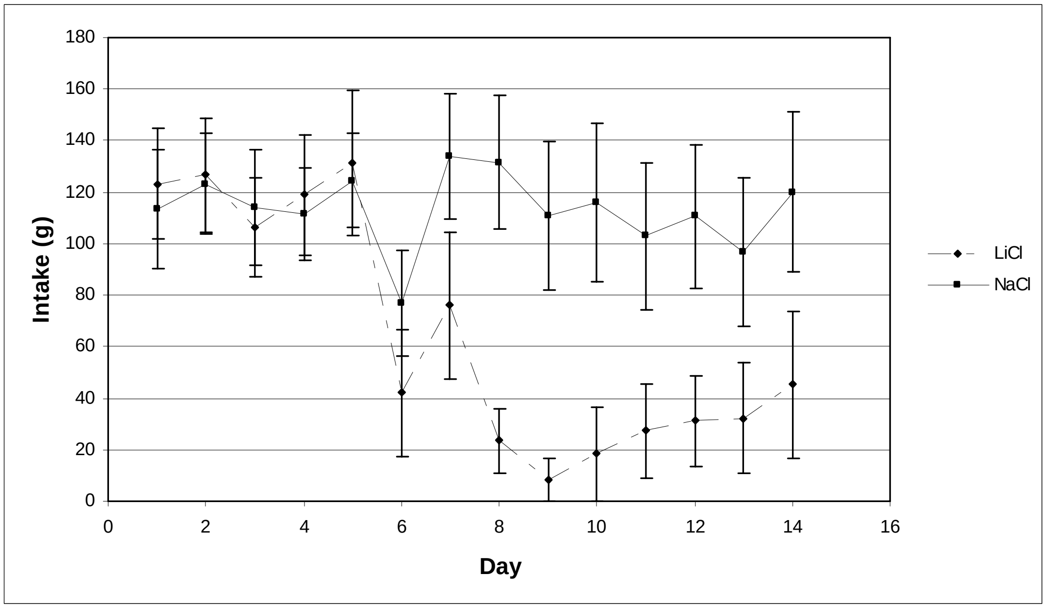


Figure 4. The mean rodent blox consumption over the pre-exposure period (days 1-5), exposure period (days 6-10), and post-exposure period (days 11-14) for the treatment (LiCl) and control (NaCl) groups.



DISCUSSION

Beaver are a beneficial component to wetlands, increasing plant and animal diversity, but many times their presence can conflict with human activities (McKinstry et al., 2001). Beaver foraging causes millions of dollars through damage to crops and timber in some states each year (Miller and Yarrow, 1994). Attempts at reducing beaver foraging through lethal and non-lethal methods have had varied success. Repellents have been shown to be ineffective or cost and time prohibitive due the necessity of repeated applications (Owen et al. 1984, Cooper, 1970). Fencing and frightening devices have also been unsuccessful in providing long-term protection of valued plants from beaver (Woodward 1983). Trapping has long been the preferred and effective method of beaver control but due to increasing negative public perception and trapping bans in many states it is becoming a less feasible option (Byford 1974). The need is growing to increase the number of effective techniques for reducing damage inflicted by beaver.

Conditioned food aversion occurs when induced illness is paired with a food item, producing an aversion for the selected food item (Schafe and Bernstein 1996). This technique has long been thought of as a possible tool in wildlife damage management but was not previously attempted with beaver (Gill et al. 2000). Conditioned food aversions are generally most successful when a novel food is the protected item but it can be possible with a familiar food (Pfister 2000). Müller-Schwarze et al. (1994) suggested that beaver can learn to avoid unpalatable plants by feedback from illness, making them excellent food aversion candidates. We found that beaver could indeed be averted from corn, but they also generalized their aversion to a main staple of their diet, rodent blox. This generalization raised serious concerns because avoidance of pertinent dietary components may induce malnutrition if the aversion persists. The increased apple intake observed after the treatment period may have been the beaver trying to compensate for reducing their corn and rodent blox consumption. The beaver may have also increased their gnawing on the native wood stems placed in their pens to compensate for their lowered intake of other food items, illustrating the need for alternative forage.

This study illustrates some of the potential problems with the operational use of conditioning beaver to avoid targeted foods in the field. Food aversion conditioning requires extensive labor and time to implement. All beaver within a colony or targeted area need to be trained and untrained beaver will need to be kept from moving into the area. Beaver colonies require an adequate food supply to sustain themselves (Allen 1983). Therefore, if conditioning were to eliminate a food item from their diet, other alternative abundant foods will need to be available to sustain the colony. Müller-Schwarze et al. (1994) observed beaver as being frequent samplers, biting into experimental logs and naturally growing trees. This frequent sampling may reduce persistence of conditioning because they are likely to learn that targeted plants are not always toxic and over time they will consume increasing amounts of these plants. Beaver activity would need to be monitored to detect resumed foraging of protected plants and reinforcement of training may be necessary.

Novelty of the food item is an important aspect of increasing the likelihood of successfully inducing a persistent food aversion (Kimball et al., 2002). Conditioning beaver to avoid a novel plant may be more successful. However, beaver are generally reluctant to readily eat new items, so it may be problematic to treat beaver when they first sample these new foods. Restoration projects in riparian areas or wetlands offer potential where new plants are being established and animals could be conditioned on initial encounters. The plant species used may not have existed in the area for quite some time and are therefore novel to the existing beaver. Even when the food item is novel, it is still critical that there be alternative forage. The Tres Rios project in Maricopa County, Arizona is a restoration project that has successfully established wetland habitats and offers an opportunity to test conditioned food aversion as an operational tool. Cottonwood and willow trees are among the plants being restored. These plants are generally a desirable food source for beaver. If beaver were trained to avoid willow and cottonwood trees, at present their only readily available alternative food source is salt-cedar. A species that is substantially less palatable and unlikely to be readily eaten by beaver. Beaver most likely would leave the area or begin sampling and then resume consuming cottonwood and willow. Planting a species equally desirable to cottonwood and willow would offer an alternative food source for the beaver and increase potential for the species targeted for restoration to become established.

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