# EFFECTS OF VARIOUS FACTORS ON THE EFFICIENCY OF MINNOW TRAPS TO SAMPLE MOSQUITOFISH (*GAMBUSIA AFFINIS*) AND GREEN SUNFISH (*LEPOMIS CYANELLUS*) POPULATIONS

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ABSTRACT. The effects of various factors on the efficiency of the Gee® minnow trap to sample populations of mosquitofish, *Gambusia affinis*, in both rice field enclosures and a laboratory tank were assessed. Immature green sunfish, *Lepomis cyanellus*, were assessed in the laboratory tank only. Trap efficiency (percent catch) was greater for larger mosquitofish [≥35 mm total length (TL)] than for smaller mosquitofish. Immature green sunfish (25–40 mm TL) were caught at higher rates than either size class of mosquitofish. In the laboratory, trap efficiency increased with increasing mosquitofish density, but density had no effect in field enclosures. Vegetation did not affect trap efficiency. Minnow traps, lying on the substrate, caught a similar percent of available mosquitofish when water depths were 8 and 16 cm but a significantly smaller percent when 24 cm. In contrast, green sunfish, assessed at 8 and 24 cm, were trapped at a higher rate at 24 cm. These results demonstrate the importance of determining the effects of environmental factors on trap efficiency before using direct trap counts to assess effects of these factors on fish abundance.

## INTRODUCTION

Gee® minnow traps have been used extensively to monitor populations of mosquitofish, *Gambusia affinis* (Baird and Girard), and other fishes used for mosquito control in rice fields and other shallow aquatic habitats. The trap has been popular because it is relatively inexpensive and easy to use (Takahashi et al. 1982). Uses have included determining temporal population dynamics (e.g., Reed and Bryant 1974, Farley and Younce 1977, Botsford et al. 1987), habitat preferences (Reed and Bryant 1972, Norland and Bowman 1976, Miura et al. 1979, Schooley and Page 1984) and size structure of populations (Botsford et al. 1987). Estimates of mosquitofish abundance have been made with minnow traps using mark-recapture techniques (Miura et al. 1982, Stewart and Miura 1985). However, because this technique is more time-consuming and more expensive, most studies have employed direct trap counts—i.e., number of fish per trap— as an index of population size.

An underlying assumption when comparing trap numbers either spatially or temporally is that trap efficiency (i.e., percent catch) is constant under the different environmental conditions. Similarly, when comparing abundances of size classes or different species, it is assumed that the categories are trapped with equal efficiency. This may not be the case. However, few studies have assessed trap efficiency under differing environmental conditions. Norland and Bowman (1976) found trap catch to be highly correlated to mosquitofish field density, yet percent catch appeared to be greater at extremely low densities. Farley and Younce (1978) found the efficiency of minnow traps in catching mosquitofish varied with time of day, presumably because activity levels vary with time of day. Minnow traps have been used to monitor populations of immature green sunfish, *Lepomis cyanellus* Rafinesque (Blaustein 1988), but no studies have assessed trap efficiency for this fish under different conditions.

This study experimentally assessed how water depth and vegetation affect trap efficiency of capturing mosquitofish and immature green sunfish. It also assessed the consistency of replicate samples, the effect of the density of mosquitofish on trapping efficiency, and differences in trapping efficiency between two size classes of mosquitofish and one size class of green sunfish.

## MATERIALS AND METHODS

*The Minnow Trap:* A minnow trap measures ca. 22 cm in diameter at the center and tapers slightly to ca. 19 cm at the ends which act as interception areas (Fig. 1). The interception areas funnel into ca. 2-cm openings into the holding chamber. Minnow traps are generally dropped or placed into the water so that they rest against the bottom substrate in shallow aquatic habitats. The interception area will be completely submerged if the trap lies in at least 20.5 cm of water. At shallower depths (<10 cm), the trap must be forced partially into the substrate until the opening is submerged.

If the trap without bait works solely as an interception device and fish are considered only as projectiles moving randomly through the water, then trap efficiency should be a function of the proportion of the cross-sectional area of the water column displaced by the trap's area of interception. At a depth of 8 cm, only ca. 30% of the interception area is covered by water; 25% is under the substrate and the remaining 45% is above the water. If the width of the water col-

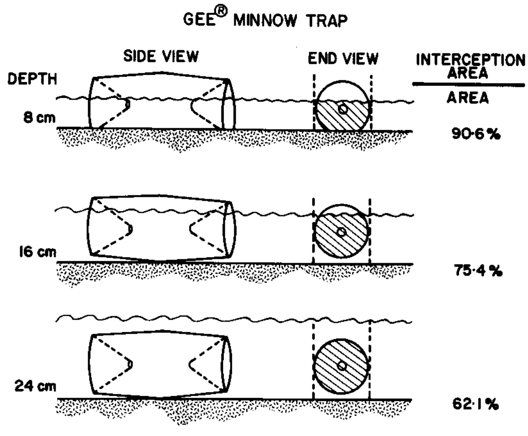

Fig. 1. Schematic diagram of Gee® minnow traps. Two views are shown—side view and end view. The amount of the interception area of the traps (cross-hatched areas) which is submerged at three depths is shown. The ratio of the interception area and the total area of a water column the width of a trap is also given.

umn is equal to the width of the area of interception, then the interception area displaces 90% of the water column. At 24 cm, the entire area of interception is submerged, but the interception area displaces only 62% of the water column. Thus, if fish move at random, one would expect a diluting effect on trap efficiency as the water level increased. However, the differences between the proportions of the areas displaced at different depths become smaller and smaller as the width of the water column increases.

*Rice Field Enclosures Experiment:* The field experiment was conducted in circular sheet aluminum enclosures (diam = 3 m) at the University of California Rice Research Facility located in Davis. These enclosures were set up to study mosquitofish reproductive success under different types and amounts of vegetation (Blaustein 1988). The data collected also allowed an assessment of the effects of vegetation, mosquitofish density and two mosquitofish size classes on trap efficiency. Variability between replicate trap samples was also assessed.

During June 1984, 32 enclosures were forced into the mud substrate. Water depths generally ranged from 10 to 15 cm. Emergent vegetation, including short-stem rice and watergrass (*Echinochloa crusgalli*), grew in each enclosure. The emergent vegetation was allowed to grow in 16 of these enclosures, and by the end of the season, stem density ranged from 218 to 508/$m^2$. In another 16 enclosures, the emergent vegetation was removed and a submergent weed, southern naiad (*Najas* sp.), was planted in its place in late June. Dry weights of the submergent vegetation ranged from 8.0 to 34.6 grams per enclosure at the end of the season. Submergent vegetation growing in the "emergent" enclosures and emergent vegetation growing in the "submergent" enclosures were removed weekly.

In each of these 32 enclosures, one gravid *G. affinis* was introduced on July 16 and a second gravid female was added on August 30. Populations were later sampled in two ways: by minnow traps, modified by lining the inside with window screening, and by sweep nets. For 2 consecutive days (September 9 and 10), a minnow trap was placed in each enclosure at approximately 0900 hr. Fish from these traps were counted the next morning at 0900 hr. Because none of the traps was completely submerged, asphyxia overnight was not a problem. Two size classes were recognized—large females (>35 mm total length (TL)) and small individuals (<35 mm TL). After being counted, the fish were returned to the enclosures. On September 12 and 13, an attempt was made to collect all of the fish from the enclosures. All submergent vegetation was removed and brought back to the laboratory to determine dry weights. Emergent vegetation was cut near the substrate and removed. Estimates of stem density were made a few days later by counting the cut stems in four (0.093 $m^2$) quadrants within each enclosure. The field was drained and when the water level had dropped to ca. 6 cm, two persons with D-nets simultaneously swept the same enclosure. Sweeping continued until both sweepers failed to catch any fish on five consecutive sweeps. Fish were preserved in 10% formalin for later counting and sizing. The following morning, when the field had completely drained, enclosures were checked for any fish missed during the sweeping. Very few fish were observed and there was no evidence of predation by birds on the stranded fish in the enclosures. The total number of fish collected by sweeping and inspection in each enclosure was used as the best estimate of mosquitofish density. Minnow trap efficiency in each enclosure was calculated by dividing the average number caught per trap by the number collected by sweeping and inspecting.

Of the 32 enclosures originally stocked with mosquitofish, 11 "emergent" and 13 "submergent" enclosures contained fish during the collection period. The number of fish collected in the enclosures ranged from 1 to 111. The upper range exceeds densities which might normally be found in rice fields. A chi-square analysis was performed to determine if trapping efficiency differed for the two size classes of mosquitofish. The two replicate trap samples were correlated with each other to determine the amount of sampling variability within an enclosure. The effect of fish density on trap efficiency was examined in two ways: 1) percent catch (average number of fish caught per trap divided by fish density) was correlated to fish density, and 2) the average number of fish trapped in each enclosure was correlated (Pearson correlation (r)) to fish density. The data were analyzed both ways because, as was shown by Norland and Bowman (1976), even a strong correlation by method 2 may not show deviations in trap efficiency at certain densities. Spearman rank correlations ($r_s$) were calculated to determine if submergent vegetation biomass or emergent vegetation stem density affected the percent trapped. The total number of fish collected in each enclosure (i.e., the denominators for percent catch) was weighed and the percents trapped were transformed to arcsine $(\text{percent})^{1/2}$ to normalize them (Poole 1974). An analysis of variance was then performed to determine if trap efficiency differed between the two vegetation types.

*Laboratory Experiments:* A laboratory test examined the trap efficiency for *G. affinis* when water depths were 8, 16 and 24 cm and in the presence or absence of rice. The experiment was conducted during the fall of 1986 at the Institute of Ecology, University of California at Davis in a room where conditions of 22°C and a 12:12 photoperiod were maintained. A tank, 1 × 2.25 m was filled to a depth of 10 cm with soil. A barrier composed of cinder blocks and soil divided the length of the tank into two equal sections. Mature short-stem rice plants, each containing 15–20 stems, were planted in a 4 × 5 grid on one side of the tank. Water was filled to a specific depth (8, 16 or 24 cm) and aerated. Fifty mosquitofish of various sizes (all >20 mm TL) were added to each side the next afternoon. Mosquitofish used were collected by sweep netting at the USDA Aquatic Weed Station pond located less than 1 km from the Institute of Ecology. Individuals were introduced into the tank the same day they were netted and were used only once. At ca. 1000 hr the next day, 2 traps were placed on each side of the tank. For the 8 cm depth, the trap was forced into the mud substrate until the trap opening was completely submerged and the area of interception was ca. 55% submerged (Fig. 1). Traps at the 16 cm depth were ca. 75% submerged, while at 24 cm, areas of interception were completely submerged by ca. 4 cm. Two hr later, the traps were lifted and the fish were counted. All fish not caught in the traps were netted out and the number was recorded. Due to mortality and occasional penetration by mosquitofish from one side of the tank to the other side, the numbers collected per side by trapping plus netting ranged from 28 to 60. Mosquitofish were classified into two size classes: large (≥35 mm TL) and small (<35 mm TL). To guard against confounding effects of vegetation and the side of the tank, the rice plants were pulled and then replanted on the opposite side after each trial, and the next trial was run at the same depth. This was repeated for the other two depths until each depth-habitat combination had a total of 4 replicates.

The same procedure was used to test the effects of water depth and habitat on trapping efficiency of immature green sunfish (25–40 mm TL) except for the following differences. Only two depths were used, 8 cm and 24 cm. Minnow traps, instead of sweep netting, were used to collect the fish for the experiment. The initial number per side per trial ranged from 7 to 30 due largely to different numbers caught on a particular day. The design was unbalanced: 5 trials for the 8 cm depth and 4 trials for the 24 cm depth.

Two-way analyses of variance for both mosquitofish and green sunfish were used to assess the effects of rice and water depth on trap efficiency. As in the enclosure experiment, the total numbers of fish available to be caught were weighted and the responses, percents caught, were transformed to arcsine $(\text{percent})^{1/2}$ prior to the analyses. If density appeared to be important, it was added as a covariate to the model. Least significant differences with Bonferroni adjustments were used for pair-wise treatment comparisons (Jones 1984) of the 3 depths used for mosquitofish.

To determine whether the densities of green sunfish and mosquitofish affected trap efficiencies in the laboratory experiments, regression analyses were performed. If either vegetative habitat or water depth was found to be important, then that factor was added as a covariate to the model.

Chi-square analyses were performed to determine if the immature green sunfish and the two size classes of mosquitofish were trapped differentially.

## RESULTS

*Field Enclosures Experiment:* Large mosquitofish females were trapped at a much higher rate (78.8%, n = 33) than smaller individuals (9.6%, n = 887) in these enclosures (Table 1). The numbers of mosquitofish trapped on 2 consecutive days in the enclosures were highly correlated in emergent vegetation ($r = 0.90$, $P < 0.001$, $n = 11$), submergent vegetation ($r = 0.93$, $P < 0.0001$, $n = 13$) and both types of vegetation considered together ($r = 0.88$, $P < 0.0001$, $n = 24$; Fig. 2).

Large females were deleted from the analysis when correlating percent catch to fish abundance because the enclosures which only had a few fish had almost only large females. Since large females were much more likely to enter traps, this would make it appear as if trap efficiency was greater at lower densities. After this adjustment, percent catch showed no relation-

Table 1. Trap efficiency of different-sized mosquitofish.

| | Large females | | | Others | | | |
|---|---|---|---|---|---|---|---|
| Experiment | Trapped | Total | Percent | Trapped | Total | Percent | Chi-square |
| Enclosures | 26 | 33 | 78.8 | 85 | 887 | 9.6 | 143.68* |
| Laboratory | 119 | 173 | 68.8 | 434 | 877 | 49.5 | 19.80* |

* $P < 0.001$.

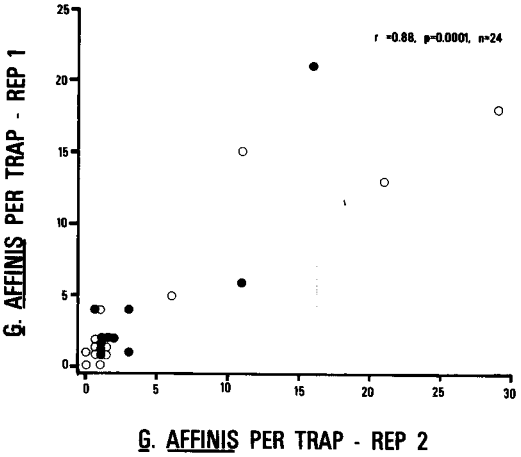

Fig. 2. Correlation between two replicates of minnow trap counts in the enclosures. Open circles represent values for enclosures containing emergent vegetation while closed circles represent values for submergent vegetation enclosures.

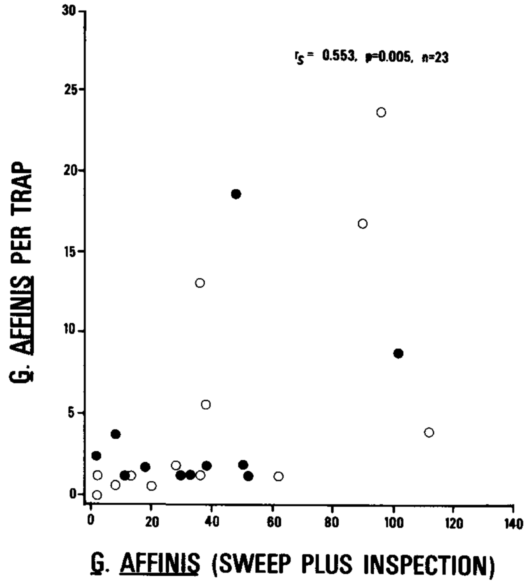

Fig. 3. Relationship between the average of the two minnow trap counts for each enclosure and the enclosure densities (sweep plus inspection counts). Open circles represent values for the emergent vegetation enclosures while closed circles represent values for the submergent vegetation enclosures.

ship to fish density in either the enclosures containing emergent vegetation ($r_s = -0.37$, $P = 0.26$, $n = 11$), the enclosures containing submergent vegetation ($r_s = 0.42$, $P = 0.18$, $n = 12$) or both types of vegetation considered together ($r_s = -0.004$, $P = 0.99$, $n = 23$). The average number trapped over the two sampling efforts and mosquitofish abundance as measured by sweeping plus inspection showed a significant correlation in the enclosures with submergent vegetation ($r = 0.62$, $P = 0.03$, $n = 13$) but not in the enclosures with emergent vegetation ($r = 0.40$, $P = 0.23$, $n = 11$). The correlation was also significant when all enclosures were considered together, although not strongly so ($r = 0.55$, $P < 0.01$, $n = 24$; Fig. 3).

The type of vegetation in the enclosures did not affect trap efficiency ($F_{1,23} = 0.07$, $P = 0.79$), with 11.3% trapped in the emergent vegetation and 12.9% in the submergent vegetation. Neither the biomass of the submergent vegetation ($r_s = 0.32$, $P = 0.29$, $n = 13$) nor the emergent stem density ($r_s = -0.29$, $P = 0.39$, $n = 11$) affected trap efficiency.

*Laboratory Experiments:* Trap efficiency was affected by mosquitofish size (Table 1). Sixty-nine percent of the larger mosquitofish (>35 mm TL) were caught while only 49.5% of the smaller individuals (<35 mm TL) were caught when considering all 3 depths together. When combining data for depths 8 cm and 24 cm, 82.4% of the immature green sunfish were trapped, which was significantly greater than the 40.0% for small mosquitofish and 65.8% of the larger mosquitofish (Table 2).

A two-way (vegetation, depth) analysis of covariance (covariate = depth) of the laboratory mosquitofish data revealed the following. The presence or absence of rice did not affect percent catch ($F_{1,17} = 0.84$, $P = 0.37$); 56.1% were caught in rice while 48.9% were caught in the absence of vegetation. Water depth affected trap catch ($F_{2,17} = 10.16$, $P < 0.001$) but only at the greatest depth; trap catch was similar at 8 cm (60%) and 16 cm (65%) $F_{1,11} = 0.09$, $P = 0.78$), but significantly fewer fish were caught at 24 cm (32%) than either 8 cm ($F_{1,11} = 27.05$, $P < 0.001$) or 16 cm ($F_{1,11} = 11.53$, $P < 0.01$). Percent catch increased with increasing mosquitofish densities. When percent catch at 24 cm and the combination of 8 and 16 cm were both regressed against the mosquitofish density, the data suggested positive relationships ($0.10 < p < 0.05$)

Table 2. Comparison of trap efficiency between immature *Lepomis cyanellus* and two size classes of mosquitofish.

| | *Gambusia affinis* | | | *Lepomis cyanellus* | | | |
|---|---|---|---|---|---|---|---|
| Size | Trapped | Total | Percent | Trapped | Total | Percent | Chi-square |
| Small | 210 | 525 | 40.0 | 220 | 278 | 82.4 | 131.64* |
| Large | 104 | 158 | 65.8 | | | | 15.34* |
| Total | 314 | 683 | 49.2 | | | | |

* $P < 0.001$.

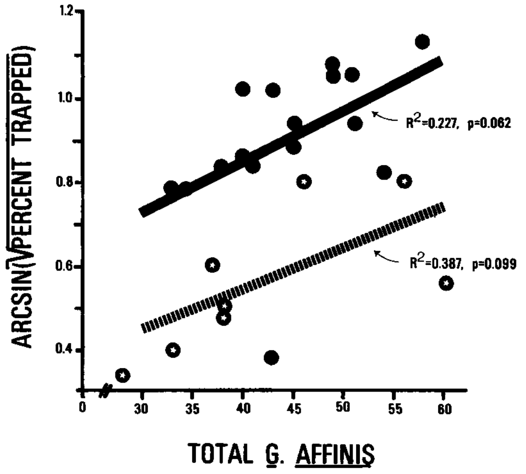

Fig. 4. Effects of density of mosquitofish on percent trapped in the laboratory experiment. Dark circles and solid line are data and regression line, respectively for depths 8 cm plus 16 cm. Starred circles and striped line are data and regression line respectively for 24 cm. An analysis of covariance including all three depths (covariate = density) showed the density of mosquitofish to significantly affect percent trapped ($F_{1,17} = 6.27$, $P = 0.02$).

(Fig. 4). However, density as the covariate in the ANCOVA model was significant ($F_{1,17} = 6.27$, $P = 0.02$).

An analysis of covariance (covariate = depth) did not demonstrate that the density of sunfish affected trapping efficiency ($F_{1,15} = 1.51$, $P = 0.24$). Therefore, sunfish density was not used as a covariate when assessing the effects of vegetation and depth on trapping efficiency of this fish. Vegetation was unimportant in affecting the catch of immature green sunfish; 83.2% were trapped in rice and 79.1% in the open ($F_{1,17} = 0.14$, $P = 0.72$). Water depth had the opposite effect on green sunfish than it had on mosquitofish. Trap catch was greater in deeper water; 73.5% at 8 cm and 95.0% at 24 cm ($F_{1,17} = 13.75$, $P < 0.01$).

## DISCUSSION

This study demonstrated that trap efficiency differs for different sizes of mosquitofish. Therefore, the use of minnow traps to estimate size structure of a population of mosquitofish would not be valid unless adjustments could be made. A more detailed study assessing more size classes would be needed. Fry densities would probably be underestimated by trap counts because mosquitofish are cannibalistic and predation intensity should be greater in a confined chamber without any cover. Fry might also avoid traps where larger mosquitofish were already trapped. Cannibalism and avoidance of cannibalism may explain part of the large difference in the proportions of the different size classes caught in the enclosures. However, cannibalism cannot explain the different trapping efficiencies of the two size classes in the laboratory experiments since none of the fish used were small enough to be eaten by conspecifics. Green sunfish were also trapped at a higher rate than either size class of mosquitofish. This difference may be overestimated if green sunfish learn to enter traps or underestimated if green sunfish learn to avoid traps because they were originally collected by minnow traps while mosquitofish were not. Nevertheless, the results of this experiment indicate that a comparison of the abundances of the two species based on direct trap counts may not be valid.

The results of the rice field enclosure study suggest that trap efficiency is unaffected by the density of mosquitofish in the field. However, efficiency increased with increasing mosquitofish density in the laboratory experiment. This is in contrast to Norland and Bowman's (1976) tank study; they found percent catch to be unaffected by fish density except at very low densities.

The correlation between the average trap counts and densities of mosquitofish in the field enclosures was not a strong one; enclosure densities only explained 30% of the variation in trap catch. Error in estimating fish density (sweep plus inspection) may have accounted for some, but not much, of this unexplained variation. Similarly, error in estimating trap averages within the individual enclosures was also low; the strong positive correlation between the two replicate minnow trap samples demonstrates that estimates within enclosures were consistent (Fig. 2). Even the outliers in the correlation between trap average and density generally had consistent numbers trapped over the 2 replicates. Hence, if a relatively small proportion of fish is consistently trapped in one enclosure while a larger proportion is consistently trapped in another enclosure, some factor which varies amongst the enclosures must affect trap efficiency. There were probably other factors which varied amongst the enclosures which were not considered in this experiment.

Both the field and laboratory experiments in this study failed to demonstrate that the presence, type or amount of vegetation affects trap efficiency for mosquitofish. The laboratory experiment also failed to demonstrate that the presence or absence of rice affects trap efficiency for green sunfish. Based on these experiments, inferences drawn from direct trap counts measuring preferences for type or presence of vegetation in previous studies (e.g., Miura et al. 1979) are valid. Similarly, population estimates of mosquitofish and green sunfish through time should not be affected by an increase in vegetative biomass.

The reduced trap efficiency of mosquitofish at the greatest depth was not surprising. Since the percent of the water column (measuring the width of the trap) taken up by the area of interception was reduced by ca. 12% from 16 to 24 cm (much less if one considers an area greater than the width of the trap) and the reduction in trap efficiency was ca. 50%, this reduction in trap efficiency could not be attributed to a dilution effect alone. The explanation most likely lies in the vertical distribution of mosquitofish. Mosquitofish were generally found near the surface above traps placed at 24 cm.

Certain studies have found mosquitofish abundance, as measured by direct trap counts, to increase with increasing depth (Blaustein 1988, Reed and Bryant 1972, Miura et al. 1979). According to the results of this study, this relationship is valid but the effect of depth on mosquitofish abundance in the entire water column is underestimated.

Because green sunfish are generally found at the bottom, raising the water level should not have a dilution effect on trap count. Increasing the water level in this study actually increased trap efficiency. Because an extremely high percentage of green sunfish were caught in the deeper water, it appears that green sunfish either choose to enter the trap at this depth or possibly avoid entering the trap at the 8 cm depth. This may be because at this shallower depth the trap opening is at the surface and green sunfish are generally not found at the surface.

The artificial environments of the field enclosures and the laboratory tank may affect fish behavior and, hence, direct extrapolations to field data may not be valid. Assessments of various factors on trap efficiency should be made on larger scales. However, the results of this study stress the importance of assessing trap efficiency under various environmental conditions and for different size classes and species before making inferences from direct trap counts.

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