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Discrimination among Fish Models by Hawaiian *Eleotris sandwicensis* (Eleotridae)[1]

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ABSTRACT

I examined behavioral responses of the benthic fish *Eleotris sandwicensis* to painted models (dummies) of fish that *Eleotris* typically encounter in Hawaii. *Eleotris sandwicensis* were associated with coarse substrates where their mean (±SE) density was 1.5 (±0.30) fish/m^2. I hypothesised that *Eleotris* would retreat from all models in open areas, but not when they were present in shelters. The five models represented *Stenogobius hawaiiensis*, *Awaous guamensis*, *E. sandwicensis* (female coloration), a male *E. sandwicensis* in breeding colors (black), and a 12 cm block of wood (control). Whether or not *Eleotris* held its position or retreated was not a function of body size. Differences among the responses of *Eleotris* to models depended on whether or not the fish was hidden or exposed on substrates. More retreats in response to models occurred when *Eleotris* were exposed on substrates than when fish were hidden. There were no significant differences in the response of *E. sandwicensis* to models when fish were exposed on substrates. In contrast, responses of *E. sandwicensis* to the models were not random for fish that were hidden, indicating that *Eleotris* discriminated among the models. The basis for discrimination among models was most likely visual. Although *Eleotris* are typically secretive, their presence on exposed substrates at this study site may be attributed to the lack of benthivorous fishes and few avian predators. The ability of *Eleotris* to distinguish among fishes when hidden as well as their tendency to retreat in response to all intruders whenever exposed on substrate surfaces could reduce potential interactions between *Eleotris* and other native and nonindigenous fishes.

Key words: *behavior;* Eleotris sandwicensis; *fish models; habitat; Hawaii.*

Fishes of the family Eleotridae (sleepers) are common in tropical coastal habitats throughout the world (Winemiller & Ponwith 1998). *Eleotris sandwicensis*, known locally as ʻoʻopu ʻakupa, is one of only five native freshwater fishes in the Hawaiian islands (Yamamoto & Tagawa 2000). The gobiids (*Lentipes concolor*, *Sicyopterus stimpsoni*, *Awaous guamensis*, and *Stenogobius hawaiiensis*) and eleotrid (*E. sandwicensis*) are amphidromous (McDowall 1992). These fishes spend their adult lives in streams where they spawn. Newly hatched larvae are carried to the seas in currents to feed and return to streams as juveniles (Fitzsimons & Nishimoto 1991). Although eleotrids do not occur upstream of large waterfalls, they often co-occur with *Stenogobius* and *Awaous* in lower river reaches, estuaries, and saline ponds.

Indirect evidence for the importance of visual signals among fishes is their conspicuous color pattern, which is species- or sex-specific (Rowland 1999). The presentation of dummies (models), free of confounding variation observed in live stimuli, is used in ethology to evoke natural responses of fish to conspecifics and others (Barlow & Siri 1994, Rowland 1999). Although there is a well-developed social behavior in the gobiids, behavioral repertoires in *E. sandwicensis* appear to be limited to courtship (Fitzsimons & Nishimoto 1991).

In this study, I examined behavioral responses of *E. sandwicensis* to painted fish models, which represented fishes that *Eleotris* typically encounter. The study was designed to test if *Eleotris* would be able to discriminate among fish models. Because *Eleotris* are rarely reported in the open (Fitzsimons & Nishimoto 1991,Yamamoto & Tagawa 2000), I hypothesised that this species would retreat from all models in open areas, but not when hidden in crevices or behind structures. Responses to models by *Eleotris* may be linked to perceived risk.

MATERIALS AND METHODS

The study site in Hilo, Hawaii, was Loko Waka Pond, a water body that is exposed to the influence of tides. I snorkelled throughout the pond and found *E. sandwicensis* present along rock walls of the pond and on coarse bottom substrates. In these coarse substrate areas, I documented the density of *Eleotris* in 50, 60 × 60 cm quadrats. I characterized the bottom type (after Hynes 1970) as boulders (>256 mm), cobbles (64–256 mm), gravel/pebbles (2–64 mm), silt, and organic matter.

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I accumulated 30 hours of snorkeling observations of *Eleotris* on coarse substrates from 31 August to 9 September 1999 (water temperature: 22–23°C). To study potential behavioral responses of *Eleotris* to fishes, I painted wood models (after Keenleyside 1971) with nontoxic tempera. The models were painted to mimic my perceived color of the fishes from direct observation and photographs. I presented *E. sandwicensis* with a set of wooden models cut to the shape and adult size of the fish (*A. guamensis*, 14 cm; all others, 12 cm). A section of doweling was placed in a hole drilled in the end of each model and attached with duct tape to a 50 cm length of heavy wire. The five models represented *S. hawaiiensis*, *A. guamensis*, *E. sandwicensis* (female coloration), a male *E. sandwicensis* in breeding colors (black), and a 12 cm block of wood (control). *Eleotris* typically co-occur with *S. hawaiiensis* and *A. guamensis*, but the two species were absent from the study pond.

The side view of each model, selected at random, was held within a body length of 100 *E. sandwicensis* for 10 seconds and responses (hold, retreat, flip, attack, and swim away) were recorded. Randomizing the order of models presented to animals reduces the effects of carryover aggression (Sealy *et al.* 1998). There were many cases in which fish swam away or retreated from the area before all models could be presented. The wood block was marked (cm) so that I could estimate the total length of the fish. I recorded fish size, breeding coloration (if any), and whether or not fish were exposed or hidden under rocks or vegetation. A *t*-test was used to determine if there were significant differences between the size of *Eleotris* that held their position and those that retreated from models. Chi-square analyses were conducted to test if observed and expected frequencies were different from one another in the response of *Eleotris* to models.

RESULTS

General observations.—*Eleotris sandwicensis* were found in the study pond where substrates were coarse; the fish were not found in silt. In areas of the pond occupied by *Eleotris*, mean (±SE) density was 1.5 (±0.30) fish/m^2. The result of a 2 (fish present, fish absent) × 3 (boulder, cobble, gravel) chi-square analysis was not significant ($\chi^2 = 4.259$, df = 2, $P > 0.05$). Thus, as long as the bottom had coarse substrates, the fish distribution was independent of particle size. I found nine native prawns *Macrobrachium grandimanus* in 6 of the 50 quadrats. Of these, seven prawns were found together with *E. sandwicensis* in gravel sediments under cobbles or boulders.

Juveniles and nonbreeding adult *E. sandwicensis* had alternating black-and-olive bands across their dorsal surface that blended with the colors of the substrate. There were distinct black marks on *Eleotris* at the junction of each pectoral fin adjacent to the body. From above, the two marks resembled large eyes (compared with the smaller anterior eyes) and may function to deter predators. Breeding males were black with a golden line along the outer edge of the fins.

Eleotris sandwicensis juveniles and females are characterized by a pointed (arrowhead) snout, which is used to burrow into fine sediments or loose gravel. In contrast, mouths of breeding males are broad and curved. I observed one *Eleotris* with a pointed snout turn abruptly perpendicular to the bottom of the pond and dive directly into soft substrate, leaving a burrow hole at the substrate surface. Another fish used its snout to tap repeatedly at coalesced gravel at the base of a rock, after which it entered the prepared opening.

Courting behavior was uncommon; however, I saw a male and female display within the water column above a submerged palm branch. The male was black (breeding color); its fins were spread out. A female swam through the water column, touching the male as it swam vertically. Another female was nearby when the pair returned to the palm branch. I also saw a male in breeding coloration leave a cavity from under a boulder and display each side of its body back and forth with fins expanded just above the substrate within two body lengths of the cavity opening. During the display, a large female swam out of the cavity toward the male and left the area. The male swam to the back of the boulder and returned to the cavity through this second opening. The largest number of breeding males observed in any one day was 13. Unless males were courting, they were observed under rocks or in cavities with snouts protruding or flush with the overhanging rock.

Responses to models.—In response to models presented to within a body length of fish ($N = 100$), most remained still if they were under or against a rock or vegetation (*i.e.*, "protected") compared to fish that were exposed. More *Eleotris* retreated from models when fish were exposed than when they were hidden under structures (Fig. 1). Of the 100 *Eleotris* tested, 52 fish were hidden under structures (plants or rocks) and 48 fish were exposed on sub-

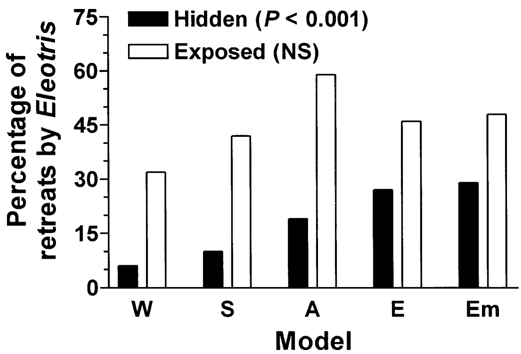

FIGURE 1. Percentage of retreats by *Eleotris sandwicensis* to each model when fish were hidden under structures or exposed on substrates. Models presented to *Eleotris* were: W, wood (control); S, *Stenogobius*; A, *Awaous*; E, *Eleotris*; and Em, *Eleotris* breeding male.

strates. Responses of *E. sandwicensis* to the five models were not random for fish that were hidden ($\chi^2 = 22.57$, df = 4, $P < 0.001$), indicating that sleepers were able to discriminate among the models. There were no significant differences in the response of *E. sandwicensis* to models when sleepers were exposed on substrates ($\chi^2 = 8.44$, df = 4, $P > 0.05$).

When *Eleotris* were hidden, they retreated more often when presented with conspecific models (*Eleotris* or *Eleotris* in breeding colors) compared to models of gobiids (*Awaous* or *Stenogobius*) or wood (Fig. 1). Fewest retreats among fish in protected areas were scored for the control (wood) model (2 retreats of 33 presentations) compared to the fish models (3 of 30 to 11 of 38). *Eleotris sandwicensis* never attacked a model; however, I observed one mature male (blunt snout and black body) leave a cavity within the rock wall and hit an approaching female twice in succession.

Twenty-three of the 100 *Eleotris* tested were obscured in cavities and so could not be measured. Of the remaining fish measured, there was no significant difference in the mean (± SE) size of fish that held their position (8.4 ± 0.48 cm; $N = 46$) or retreated (8.6 ± 0.40 cm; $N = 31$) from models ($t_{0.05[75]} = 0.258$, $P = 0.797$).

DISCUSSION

In streams, *E. sandwicensis* remain still with head and nape projecting from under large boulders (Fitzsimons & Nishimoto 1995). Mean density of *E. sandwicensis* (1.5 fish/m^2) on coarse substrates that I recorded in Loko Waka Pond was similar to the mean density (0.89 fish/m^2) for the same species in Honolli'i and Hakalau streams (Tate 1997). *Eleotris sandwicensis* were not found in areas of the pond dominated by silty, soft substrates. Many *E. sandwicensis* in Loko Waka Pond sat exposed on substrates. The presence of *Eleotris* in open areas in Loko Waka Pond, where their body colors blended with the substrate, likely occurred because of the lack of other fish benthivores in the pond.

The presence of *Eleotris* on exposed substrates in Loko Waka Pond, which contrasted with more secretive habits in other locations (Tate 1997), also may be explained by the limited number of potential avian predators. Three wading bird species that have been recorded at the Loko Waka Pond include Cattle Egret (*Bubulcus ibis*), Black-crowned Night Heron (*Nycticorax nycticorax*), and the Hawaiian Coot (*Fulicia alai*) (Pratt 1993). Of these, the Black-crowned Night Heron, which preys on fish, feeds nocturnally and so would not be a threat to the well camouflaged day-active *Eleotris*. Although the Hawaiian Coot actively feeds during the day, its diet is mainly aquatic plants, not fish. The Cattle Egret feeds on insects. The Green-backed Heron (*Butorides striatus*) and Great Blue Heron (*Ardea herodias*), both daytime fish-eating birds once known to occur in the area, no longer do so at the pond (Pratt 1993; R. T. Nishimoto, pers. comm.).

No fish attacked a model. Most *E. sandwicensis* located in crevices or behind structures, held their position in response to fish models. Whether or not *Eleotris* held its position or retreated was not a function of body size. The difference between the response of *Eleotris* to models depended on whether the fish was hidden ("protected") or exposed on substrates. Whenever *E. sandwicensis* were exposed on substrates, there was no significant difference in their response to the various models. In contrast, *E. sandwicensis* were able to discriminate among models when the fish was under a boulder or vegetation. When *Eleotris* was hidden, a retreat occurred more often in response to a conspecific model than to other fish models. These findings suggest that *Eleotris* were able to perceive differences in visual cues. Fitzsimons and Nishimoto (1995) reported frequent aggressive interactions in mature males of *S. stimpsoni* with conspecifics. This tendency to respond more to conspecifics than to other species is common among other animals (Lack 1953, Huntingford 1982).

Historically, painted models pioneered by Nobel (1938) and Tinbergen (1948) have been used in many ethological studies with respect to mate choice and schooling (Keenleyside 1955, Rowland

1999). There is a trend across several fish species for a response of a fish to be greater toward a dominant male than those that resemble females (Stacey & Chiszar 1978, Barlow & Siri 1994). While it is often assumed that models with color of the most dominant fish will evoke most attacks, few researchers assume that an intimidating dominant model will evoke the fewest attacks (or retreats) (Vodegel 1978, Barlow & Siri 1994). In this study, the highest percentage of retreats occurred when the reproductive (dominant) black male model was presented to *Eleotris*. I painted the models to match my perceived color of the fish species. Barlow and Siri (1994) tested whether or not the more aggressive gold morphs of the Midas cichlid *Cichlasoma citrinella* inhibited attacks; they found that gold dummies were attacked most often. Barlow and Siri (1994) emphasized that the gold color (or threat markings in a species) may evoke attack or escape responses depending on whether or not the subject is exposed to high (escape) or low (attack) risk. Perhaps *Eleotris* that retreated from the dominant black male perceived high risk.

The ability of *E. sandwicensis* to dive suddenly into loose gravel and to create cavities using its arrowhead snout will enable all but breeding males (with their blunt snout) to actively avoid risky situations. All eleotrids commonly dart into crevices in response to sudden movements. Parental males are aggressive (at least to conspecifics) and defend their clutches in rock cavities.

Downstream river reaches or low elevation pools are typically comprised of two guilds, benthic and pelagic fishes. McRae (2001) showed high overlap in microhabitat use among a benthic guild of fishes in the downstream reach of Wailoa Stream, Hawaii, suggesting potential for competitive interactions. Accordingly, *Eleotris* would likely be exposed in the downstream reaches or ponds to competitive interactions among native and nonindigenous benthic fishes. Examples of nonindigenous benthic species include common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), Chinese catfish (*Claria fuscus*) and oriental weatherfish (*Misgurnus anguillicaudatus*) (Yamamoto & Tagawa 2000). Because *E. sandwicensis* mate in the water column (Fitzsimons & Nishimoto 1991; Corkum, pers. obs.), *Eleotris* could be exposed to pelagic predators during courtship displays.

In summary, *E. sandwicensis* use several strategies to avoid predators including camouflage, burrowing activities, occupation of rock crevices, and an ability to retreat effectively from intruders. Despite these behavioral repertoires, the open-water courtship displays of *E. sandwicensis* could put them at risk to predators. Eleotrids in New Zealand can coexist with predators by hiding completely under boulders (Staples 1975). I anticipate that there will be a gradation of behavioral responses by *E. sandwicensis* to intruders from habitats in which they are the sole benthivore to habitats in which they share with gobiids and to other habitats shared with nonindigenous fishes. Because *E. sandwicensis* occupy spaces under boulders, cobbles, and other debris, contact with other species is reduced. Moreover, when *Eleotris* are hidden, they are able to distinguish among intruders. This strategy reduces interactions between *Eleotris* and other fishes.

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