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Attractiveness of food and avoidance from contamination as conflicting stimuli to habitat selection by fish

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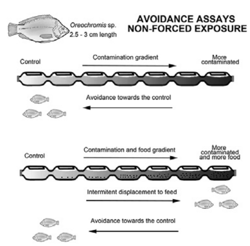
HIGHLIGHTS

- Habitat choice by fish was studied using food and contaminant as conflicting stimuli.
- Fish were exposed to a gradient of contaminant and food in a non-forced system.
- The avoidance pattern to contamination was altered in presence of the food.
- Fish were more strongly attracted to feed than propelled to avoid the contamination.

GRAPHICAL ABSTRACT



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ABSTRACT

Habitat selection by fish is the outcome of a choice between different stimuli. Typically, the presence of food tends to attract organisms, while contamination triggers an avoidance response to prevent toxic effects. Given that both food and contaminants are not homogeneously distributed in the environment and that food can be available in contaminated zones, a key question has been put forward in the present study: does a higher availability of food in contaminated areas interfere in the avoidance response to contaminants regardless of the contamination level? Tilapia fry (*Oreochromis* sp.; 2.5–3.0 cm and 0.5–0.8 g) were exposed to two different effluent samples, diluted along a free-choice, non-forced exposure system simulating a contamination gradient. Initially, avoidance to the effluents was checked during a one hour exposure. Afterwards, food was added to the system so that the availability of food increased with the increase in the level of contamination, and the avoidance response to contamination was checked during another hour. Results clearly showed a concentration-dependent avoidance response for both effluents during the first hour (i.e., with no food). However, in presence of the food, the avoidance pattern was altered: organisms were propelled to intermittently move towards contaminated areas where food availability was higher. The incursions were taken regardless of the potential risk linked to the toxic effects. In conclusion, even when the risk of toxicity was imminent, tilapia fry were more intensively stimulated by the attractiveness of the food than by repulsion to the contamination.

1. Introduction

The ability to detect, interpret and respond to different stimulus

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is crucial for organisms to recognize a favorable habitat and be successful in it. In fish, the olfactory, gustatory, vision cues and lateral line permit them to differentiate a variety of stimulus and modulate the majority of their behavioral responses: defense, dominance interaction, feeding, homing, locomotor activity, mate selection, migration, schooling, shoaling, species recognition, etc (Atchison et al., 1987; Lemly and Smith, 1987; Baatrup, 1991; Bleckmann, 2006; Tierney et al., 2010; Kermen et al., 2013). One of the essential stimuli to be perceived is most likely food, as it is the mean to obtain energy for all vital processes and, therefore, a critical factor for habitat selection by fish (Wildhaber and Lamberson, 2004). Obviously, other stimulus linked to food itself, as quality (taste) and nutritional value, might also play an important role if correctly recognized (Hara, 1994; Riddell et al., 2005). Although higher population abundance and even diversity are generally expected in areas where food is abundantly available, fish counterbalance between the probability to obtain food and the presence of risk factors in a given area (Engström-Öst et al., 2006). Therefore, external biotic factors (e.g., presence of predators, and other intra- and inter-specific interactions) not essentially related to food are similarly important (Riddell et al., 2005; Kin et al., 2015). As shown by Kin et al. (2015), ahead of imminent risk such as predator presence, stimulus produced by food tends to become secondary.

Besides biotic factors, physical-chemical factors (e.g., abundance and quality of refuge areas, pH, salinity, dissolved oxygen, light condition, turbidity, water current, temperature and others) are similarly important and exert a strong role on habitat selection. Among chemical stimulus, the presence of contaminants has become of concern to the selection for or evasion from a habitat by fish (Gunn and Noakes, 1986; Atchison et al., 1987; Baatrup, 1991; Hansen et al., 1999a; Kasumyan, 2001; Tierney et al., 2006; Azizishirazi and Pyle, 2015). The capacity of fish to detect and avoid contaminants has attracted the attention of many researchers. Avoidance response has been verified for different fish species when exposed to many contaminants: *Micropterus salmoides*, *Lepomis macrochirus* and *Oncorhynchus mykiss* avoided cadmium, copper, phenol, and zinc (Black and Birge, 1980); *Morone saxatilis*, *Oncorhynchus tshawytscha* and *O. mykiss* avoided domestic and industrial wastewater samples (Smith and Bailey, 1990); *O. mykiss*, *Vimba vimba*, *Gasterosteus aculeatus*, *Rutilus rutilus*, *Perca fluviatilis*, and *Leuciscus leuciscus* avoided copper, zinc and metal mixtures (Cu, Zn, Cr, Pb, and Fe) (Svecevičius, 1999); and *Danio rerio* when exposed to gradients of copper, acid mine drainage (Moreira-Santos et al., 2008) and pyrimethanil (Araújo et al., 2014) also avoided contamination. *In situ* observations have also shown a preferential fish's distribution avoiding disturbed and contaminated habitats (Saunders and Sprague, 1967; Ǻtland and Barlaup, 1995). Nevertheless, an opposite trend has also been found: higher abundance of fish larvae was recorded in disturbed and contaminated estuaries in New South Wales, Australia (McKinley et al., 2011). Furthermore, it has been shown in the laboratory that fish may prefer contaminated zones in order to avoid other more repulsive and metabolically expensive stimulus (Harper et al., 2009). In general, the presence of contaminants, the ability of fish to detect and avoid them, the presence of other attractive factors, and the cost-benefit relationship of remaining in a habitat seem altogether to determine habitat selection at a wide extent.

It is known that contaminants can interfere in the feeding activity of fish by limiting or preventing their displacement to forage (locomotor damage) or by impairing them to sense the presence of food (sensory damage); i.e., confronted with a sensory damage, fish are not able to choose the less repulsive stimulus, usually because their sensory mechanisms stopped working appropriately (Lemly and Smith, 1985; Atchison et al., 1987; Baatrup, 1991; Hansen et al., 1999a; Scott and Sloman, 2004; Tierney et al., 2010). Generally, the approach in which fish ecotoxicological tests are used in environmental risk assessments consists in forcedly exposing organisms to one concentration of contaminants or samples with no chance to move towards uncontaminated zones. Although such forced exposure approach is important for establishing the concentration-response relationship and simulating closed systems with homogeneous contamination, it is not completely reliable for conditions where a contamination gradient is formed and the contact with the contaminant could be sporadic and gradient-dependent. Additionally, if the surrogate of a more real scenario is desirable, then the analysis of the avoidance response to contamination in a univariate stress condition is limited and lacks relevance (Schmitt-Jansen et al., 2008), as many other factors can be critical and more decisive for habitat selection than contamination (McNicol et al., 1999; Harper et al., 2009). Under real conditions, neither organisms are necessarily forcedly exposed to contaminants, behaving like passive uptakers, nor is food necessarily uniformly distributed and more abundant in pristine habitats. This means that fish may have to face a conflict between attractiveness of food and repulsion of a contaminant (Pedder and Maly, 1985). Therefore, if, on one hand, the requisite to feed is vital, and, on the other hand, the avoidance from contaminants prevents sublethal and even lethal effects, then the main question driving the present study was: does a higher availability of food in contaminated areas interfere in the avoidance from contaminants regardless of the contamination its level? Tilapia fry were exposed to two different effluent samples from a tuna fish processing plant. Fish were placed in a free-choice non-forced exposure system with a contamination gradient. The avoidance from contamination was tested with the two effluents, both in the absence and presence of food to verify how fish behave when facing the two conflicting stimulus.

2. Materials and methods

2.1. Test organisms

Tilapia fry (*Oreochromis* sp.; 2.5–3.0 cm total length and 0.5–0.8 g wet weight; n = 10) used in the experiments were provided by a fish farm (Estación Piscícola Cacharí, Subsecretaría de Acuacultura del Ecuador, Guayaquil, Ecuador). Organisms were maintained in the laboratory in dechlorinated tap water (culture water), with continuous aeration at a temperature of 26 °C and fed daily with fish food (Piscis T-450, 45% protein, floated flaks; GISIS, Durán, Ecuador) for one week before experiments. Two days before experiments, fish were maintained under starvation to stimulate future foraging.

2.2. Effluents

Effluent samples were taken from a tuna fish processing plant at Manta city, Ecuador. The tuna fish processing plant used a dissolved air flotation system and aerobic treatment by activated sludge to treat the effluent. Initially, the effluent was stored in a tank where greases and suspended solids are removed by a trap. Afterwards, the effluent was sieved (1.0 mm) and sent to a dissolved air flotation system to remove solids and oils. After this process, the effluent was stored for 7 days in a tank. At this point, this raw effluent (RE) was sampled for testing. Subsequently, RE was sent to a biological treatment tank with activated sludge. A sample of this effluent (TE) was also taken. Samples of RE and TE were maintained for two days at 4 °C before testing. A range of six dilutions (3, 6, 12, 25, 50, and 100%) of each effluent was prepared by diluting the 100% sample with the fish culture water. A control containing only culture water was also used in the experiments. Due to a