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Chemical shark repellent: Myth or fact? The effect of a shark necromone on shark feeding behavior

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ABSTRACT

Since 1942, the search for an effective chemical shark repellent has been ongoing research concern in the United States. A long-standing anecdote that sharks avoid areas containing decomposing shark tissue has initiated new interest in identifying trace chemical alarm signals produced during decomposition (necromones). A commercially-sourced shark necromone produced from putrefied shark tissue was evaluated over a five-year period in South Bimini, Bahamas. Competitively-feeding populations of Caribbean reef sharks (*Carcharhinus perezi*) and blacknose sharks (*Carcharhinus acronotus*) were exposed to necromones using pressurized aerosol canisters at the surface. Shark density estimations were made at the initial, 1 min and 5 min intervals after preliminary exposure along with continuous exposure of feeding stimulus. In both species, an unambiguous halt in feeding behavior was observed within 1 min after exposure of the necromone. For aerosol delivery, a 150 mL dose of the necromone from a single aerosol canister is able to halt all feeding activity in a combined population of *C. perezi* and *C. acronotus*. Shark necromones induced a spectacular alarm response in interacting sharks resulting in a temporary evacuation of an area containing feeding stimuli. Additionally, sharks were not deterred by alternative treatment presentations of 10% weight percent (w/w) aqueous urea, 10% w/w oleic acid in ethanol, or water buffered to pH 8.5. Habituation to the necromone was not observed for repeated tests at the same location. In all experiments, the presence of a shark necromone did not produce a similar aversion response for teleosts as observed in *C. perezi* or *C. acronotus*; however, anecdotal observations demonstrate that teleosts increased their feeding rate in the presence of the necromone. Experimental controls using denatured ethanol or water confirmed that feeding sharks were not deterred by bubbles, sound, or the solvents used to extract the necromones. Comprehensive two-dimensional gas chromatography coupled to time-of-flight mass spectrometry indicates that the necromone is a complex solution rich in amino acids and putrefaction products. Experiments demonstrate that the key chemical component responsible for the alarm response is within these amino acids and/or putrefaction products, but further experimentation is needed to more accurately identify the active ingredient. Shark necromones hold particular promise for use in shark bycatch reduction and conservation. The existence of a putative chemical shark repellent has been confirmed.

1. Introduction

The term semiochemical broadly describes molecules used for animal communication, resulting in specific behaviors such as orientation, survival, and reproduction (Law and Regnier, 1971). In terrestrial organisms, notably insects, semiochemicals are volatile and have a molecular weight between 80 and 300 (Wilson and Bossert, 1963). Semiochemicals that induce repellent behavior are particularly interesting for pest management and bycatch reduction practices. Certain semiochemicals, such as the odor emitted by dead conspecifics, trigger strong avoidance behaviors. For example,

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the unsaturated fatty acids, oleic acid (one double bond) and linoleic acid (two double bonds) induce necrophoric corpse removal in ants and bees (Wilson et al., 1958; Akino and Yamaoka, 1996). In cockroaches and termites, blood, intact corpses, and alcohol extracts of conspecifics are also repellent, and these samples contain the common oleic and linoleic acid moieties (Rollo et al., 1994, 1995). In the aquatic environment, isopods also share oleic and linoleic acid as necrophoric behavior-inducing semiochemicals (Yao et al., 2009). These phenomena also exist in vertebrates. For example, the sea lamprey, an ancient cartilaginous fish, is also chemically aware of its dead and will avoid odors emitted by dead conspecifics (Wagner et al., 2011).

Based largely on anecdotal information, the existence of a novel alarm cue has been speculated for sharks. Commercial fishermen have long purported that shark fishing dramatically decreased in areas where decomposing shark tissue was present (Baldridge, 1990). Development of the Shark Chaser, a time-release chemical shark repellent, focused on the acetate anion (from ammonium acetate). The acetate anion was the major constituent identified in decomposing shark tissue. The existence of a true shark repellent semiochemical was first considered by Rasmussen and Schmidt (1992). The findings from this study suggested that sharks may be chemically aware of the presence of potential danger through the sensing of bodily secretions from predators. Rasmussen and Schmidt (1992) hypothesized that lemon sharks (*Negaprion brevirostris*), especially juveniles, inherently recognize chemical exudates produced by the American crocodile (*Crocodylus acutus*), a known predator of these shallow water coastal sharks. The concentrations needed to produce aversive responses in lemon sharks ranged from 10^{-7} to 10^{-9} M, which was near the functional limit of shark chemoreceptors (Hodgson and Mathewson, 1978). Both Rasmussen and Schmidt (1992) and Sisneros (2001) proposed that semiochemicals exist in extremely low concentrations within decaying shark flesh and act as alarm substances for other sharks in the proximity. Since these signals are produced following death and decomposition, they are broadly described in this study as “necromones”.

Through preliminary field and laboratory experimentation, evidence exists for the efficacy of a shark necromone since a private corporation first publicized the efficacy of a putative shark necromone (National Geographic News, 2004). The present study aims to replicate the preliminary work done in 2004 to determine the efficacy of the semiochemicals on two species of shark, *Cacharhinus perezi* and *Carcharhinus acronotus*. We hypothesize that the putative shark necromone will induce a “schreckreaction-like” response in sharks similar to that evoked by Schreckstoff in ostariophysian fish (von Frisch, 1938), whereby chemically stimulated sharks will rapidly cease feeding and disperse from the treated site.

2. Materials and methods

2.1. Aerosol canister preparation

All shark repellent aerosol canisters were obtained from Repel Sharks, LLC (Charlestown, Nevis) and were supplied in nominal 177 mL steel aerosol canisters. According to the manufacturer, the model RS-IM-S canister is charged with 150 mL of necromone and pressurized to 150psig with argon gas. The necromone mixture, labeled “CP/BCOMP/BGCOMP”, is a composite mixture of extractions from putrefied blue shark (*Prionace glauca*), *C. perezi*, and Galapagos shark (*Carcharhinus galapagensis*) tissue. The canisters are positively buoyant and therefore have a lead metal band near the canister top (i.e. content ejection point) to ensure the can is slightly negatively buoyant and inverted in the water after deployment. This arrangement allows a rapid evacuation of canister contents and the minimization of gas bubble release. The canister is designed to fully evacuate within 60 s, producing a plume in the water column as the can gradually rises to the surface. All aerosols were stored at ambient temperature and out of direct sunlight until testing, per the manufacturer’s instructions.

The concentration of the stock necromone was consistent for all field experiments because a single batch (lot CP/BCOMP/BGCOMP) was purchased from the supplier and all canisters had a uniform fill volume. The dried solids basis of the necromone extract was approximately 3%w/w. At the time of the field tests, the necromone active or its physical state were not elucidated, therefore the precise concentration of the necromone active at the time of delivery was unknown.

Control canisters contained 150 mL of either water or denatured ethanol (EtOH). Denatured ethanol was chosen to establish that the necromone solvent system alone was not repellent. Deionized water was chosen to establish that the ejection of fluid and argon gas from the canister and the accompanying sound and motion was not repellent.

2.2. Preliminary treatments

Additional canisters were obtained for a preliminary evaluation of the efficacy of necromone components. The necromone solution, as obtained directly from the aerosol canister, has an average pH of 8.5 at room temperature. A corresponding buffer solution (pH 8.5) was selected to establish that the slightly more basic pH of the necromone than seawater (pH 8.1) was not repellent. A 10% w/w aqueous urea solution and a 10%w/w oleic acid solution in ethanol samples were chosen as both urea and oleic acid were identified in the necromone using instrumental analysis. Oleic acid is essentially insoluble in water and its high viscosity at room temperature presents a challenge for aerosol delivery. A 10%w/w solution in ethanol was selected to reduce viscosity and aid in the dispersion of oleic acid droplets in water.

2.3. Study location

This study was conducted at South Bimini, Bahamas, in association with the Bimini Biological Field Station. More specifically, all experimental trials were conducted at a shallow reef location, known as Triangle Rocks (25°37′58.29″N, 79°18′52.48″W). The site affords large populations of adult *C. perezi* and adult *C. acronotus* throughout much of the year. Visual observations of sharks are easily made at this site due to its 6 m depth, sandy substrate, and excellent water visibility. Tests were conducted under Bahamas Government research permits, held by the Bimini Biological Field Station BBFS (2005–2009) and SharkDefense (2010). The BBFS supplied boats, bait, photography, and supervision for the experiments.

2.4. Field trials

Following anchorage at the Triangle Rocks site, sharks were stimulated into competitive feeding behavior at the surface with the use of chum and small pieces of locally captured fish. An actively feeding population was typically established within 10 min at the surface using this method. Feeding stimuli were continuously added to the test site during an experimental trial. Once sharks were actively feeding at the surface, researchers estimated shark density by determining the number of sharks feeding on the chum. If the feeding population remained intact after 5 min, the experimental trial commenced. Researchers randomly selected a can to deploy, either a control or treatment canister. If treatment canisters were selected first and sharks were repelled, the researchers returned to the test site later in the day following a tide change to