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The effects of clove oil on coral: An experimental evaluation using *Pocillopora damicornis* (Linnaeus)

Ashley J. Frisch [a,*], Karin E. Ulstrup [b,c], Jean-Paul A. Hobbs [a]

[a] *School of Marine and Tropical Biology, and ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Qld 4811, Australia*

[b] *Institute for Water and Environmental Resource Management and Department of Environmental Science, University of Technology, Sydney, PO Box 123, Broadway, NSW 2007, Australia*

[c] *Australian Institute of Marine Science, PMB No. 3, Townsville MC, QLD 4810, Australia*

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Abstract

Clove oil solution (10% clove oil, 90% ethanol) is an anaesthetic that is widely used to catch demersal fish on coral reefs. This study assessed the effects of clove oil solution on colonies of *Pocillopora damicornis*, a cosmopolitan reef coral. In the laboratory, low concentrations (0.5 ppt) of clove oil solution had no effect on coral colour or photosynthetic efficiency, irrespective of exposure time (1–60 min). Corals treated with high concentrations (50 ppt) of clove oil solution died immediately, including those that were exposed briefly (1 min). Intermediate concentrations (5 ppt) of clove oil solution produced variable results: a 1 min exposure had no effect, a 10 min exposure caused bleaching and reduced photosynthetic efficiency, and a 60 min exposure caused total mortality. To validate these observations, clove oil solution was applied to corals *in situ*. Sixty-three days after application, corals treated with 10 ml of clove oil solution appeared to be unaffected. It was concluded that (1) limited amounts of clove oil solution are unlikely to harm this coral, and (2) clove oil solution may represent an 'eco-friendly' alternative to cyanide for use in the live reef-fish trade.

Keywords: Anaesthetic; Clove oil; Coral; Eugenol; Live reef-fish trade; *Pocillopora damicornis*

1. Introduction

Many of the world's coral reefs are found in developing nations where reef fisheries are heavily relied upon as a source of food and income (McManus, 1997; Wilkinson, 2004). Over recent decades however, stocks of many reef fishes have become severely depleted, such that traditional fishing methods are no longer effective or profitable (Jackson et al., 2001; Wilkinson, 2004). Faced with few alternatives, many fishers resort to destructive fishing practices (Pauly, 1994). This is particularly evident in the South–East Asian live reef-fish trade, where the depletion of fish stocks across vast areas has led to the broadscale misuse of cyanide (Johannes and Riepen, 1995; McManus, 1997).

Cyanide fishing began in the Philippines in the early 1960s, and has since spread to at least 15 other countries (Rubec, 1986; McManus, 1997). The technique itself involves the dissolution of sodium cyanide tablets in water (30–120 g l^{-1}), which is subsequently 'squirted' across benthic coral communities using small plastic bottles (Johannes and Riepen, 1995; Pet, 1997). Fish that are exposed to the milky solution are rapidly asphyxiated,

* Corresponding author. Tel.: +61 7 47816273; fax: +61 7 47251570.
E-mail address: ashley.frisch@jcu.edu.au (A.J. Frisch).

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and can be easily captured as they sluggishly emerge from their coral shelters. Even when transferred to clean seawater, captured fish suffer a suite of physiological disruptions, and as many as 80% die as a consequence (Rubec et al., 2001). By far the most serious aspect of cyanide fishing, however, is its effects on corals, the principal reef builders.

The administration of 5.2 g l^{-1} of cyanide for 10 min killed corals within 7 d (Jones and Steven, 1997). Lower concentrations resulted in the loss of zooxanthellae and impaired photosynthetic capacity, which may cause corals to die over a longer period of time (Jones and Steven, 1997; Jones and Hoegh-Guldberg, 1999; Jones et al., 1999; Cervino et al., 2003). By all accounts, cyanide exposure reduces the quality and quantity of reef habitat (Rubec, 1986; Johannes and Riepen, 1995; McManus et al., 1997; Barber and Pratt, 1998). For this reason, cyanide fishing is regarded as one of the greatest direct threats to the sustainability of coral reefs (McManus, 1997; Wilkinson, 2004).

As an alternative to cyanide, Erdmann (1999) suggested the use of clove oil. This is a heterogeneous distillate made from the crushed buds of the terrestrial plant *Eugenia aromatica* (Soto and Burhanuddin, 1995). It has been manufactured in Indonesia for centuries, where it is commonly used as a topical anaesthetic for minor ailments such as tooth-ache (Soto and Burhanuddin, 1995). Clove oil is also an extremely efficacious fish anaesthetic, known to cause rapid and calm immobilization (Munday and Wilson, 1997; Keene et al., 1998). For this reason, clove oil is used to sedate fish during transport or surgery (Taylor and Roberts, 1999; Cooke et al., 2004), and to capture coral-dwelling reef fish, both for research and the aquarium trade (Erdmann, 1999; Ackerman and Bellwood, 2002). In the latter case, clove oil is applied to coral colonies in much the same way as cyanide, except that it is mixed with ethanol (1:9) instead of water. The active ingredient of clove oil is thought to be eugenol (4-allyl-2-methoxyphenol), which comprises 70–95% of the commercially available product (Erdmann, 1999; Harper, 2003). The remaining 5–30% is comprised of eugenol acetate and kariofilen-5 (Soto and Burhanuddin, 1995).

The use of clove oil on coral reefs began in the mid-1990s (Munday and Wilson, 1997). It is now used in many parts of the world (*e.g.* Erdmann, 1999; Whiteman and Cote, 2004; Arvedlund et al., 2006), including Australia's Great Barrier Reef (GBR). In fact, the Great Barrier Reef Marine Park Authority (GBRMPA) currently administers 40 research permits which allow for the use of clove oil on the GBR. Given that some of these permits are issued to whole institutions (*e.g.* universities), there may be hundreds to thousands of clove oil users in Australia alone. Surprisingly, however, the effects of clove oil on coral have never been investigated.

Previous work indicates that corals exposed to toxic substances exhibit a variety of responses. In the most severe cases, colonies may experience total or partial mortality, depending on the proportion of polyps that die (Loya and Rinkevich, 1980; Pastorok and Bilyard, 1985). Sub-lethal effects typically include bleaching (loss of zooxanthellae and [or] their pigments) or reduced photosynthetic efficiency, both of which may reduce growth, reproductive output and long-term survival (Szmant and Gassman, 1990; Jones et al., 1999; Cervino et al., 2003; Siebeck et al., 2006). In order to regulate the future use of clove oil, and to promote its use as an 'eco-friendly' alternative to cyanide (Erdmann, 1999), management agencies need to be sure that clove oil has no (or minimal) effects on corals. The aim of this study, therefore, was to assess the effects of clove oil on a common and cosmopolitan reef coral, *Pocillopora damicornis* (Linnaeus). This species forms an integral part of coral reef ecosystems in the Indo-Pacific region (Done, 1982; Veron, 1986), and is known to provide essential habitat for a range of fishes and invertebrates (Austin et al., 1980; Pratchett, 2001).

To investigate both short- and long-term effects, experimental trials were conducted in a controlled laboratory environment as well as in the field. Since the dose and exposure time of clove oil to which corals are exposed during fishing activities is highly variable (due to differences in water currents, turbulence and susceptibility of target fish species), clove oil was applied in three different concentrations for three different periods of time. In each case, an attempt was made to simulate typical fish-catching operations, and the choice of minimum and maximum doses (0.5 and 50 ppt, respectively) was based on the amount of clove oil required to induce slow *versus* immediate anaesthetisation in a range of fish species (Soto and Burhanuddin, 1995; Munday and Wilson, 1997; Keene et al., 1998; Taylor and Roberts, 1999). After clove oil application, the health and photosynthetic efficiency of treated corals was assessed by measuring tissue colour (degree of bleaching) (Siebeck et al., 2006), chlorophyll *a* fluorescence (Schreiber, 2004), and the extent of mortality.

2. Materials and methods

2.1. Aquarium experiment

Twelve colonies of *P. damicornis* were collected from the fringing reef (depth 2–4 m) at Orpheus Island (18° 30′ S, 146° 29′ E) on 8th April, 2006 and transported