



AS WE SEE IT

Use of clove oil in collecting coral reef fishes for research

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ABSTRACT: Managers need accurate and relevant information about potential adverse environmental effects of scientific collecting when considering research proposals and permits. Clove oil has recently come into use in scientific fish-collecting. While several short-term experimental studies on clove oil's effects on corals have found negative effects, these were in response to heavier dosages than are typically used by researchers to collect fishes. Thus, the available evidence suggests that the small amounts of this oil that are normally applied during such collections rarely visibly stress corals. Experiments are needed to test for negative effects of actual scientific collecting with clove oil to clarify the real-world consequences of its use on coral survivorship, growth and reproduction at ecologically significant scales. When managers are assessing proposals for research that requires collecting fish, they should place the attendant environmental costs in perspective, and weight them against the relative value of the potential research results. Coral reefs occupy enormous areas of the tropics, and corals are also common in other habitats. Coral populations are often highly dynamic, possess strong powers of regeneration, and recover from repeated effects of temporary, large-scale natural events (hurricanes, floods, volcanic eruptions, tsunamis). The relatively small numbers of researchers collecting reef fishes with clove oil do so only intermittently, in areas of a few m² per project, and at sites that are widely dispersed throughout the tropics. Any negative effects of such tiny, brief, scattered collections are inconsequential relative to the effects of acute and chronic large-scale natural and human-induced stresses on coral populations, and to the regenerative capabilities of corals.

KEY WORDS: Clove oil · Anesthetic · Coral reef fishes · Collecting · Management

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Introduction

Appreciation of the beauty and diversity of life on coral reefs has grown considerably over the past quarter century, and has penetrated so widely in human society that corals now represent iconic organisms. This view has been strengthened by growing concern over the dramatic, pan-tropical declines in coral populations that have occurred due to the chronic effects of warming-induced bleaching, coral diseases, pollution, development and overfishing (e.g. Hughes et al. 2003, Carpenter et al. 2008). One consequence is the perception that corals and coral reefs need extraordinary protective measures due to their 'fragility'. Individual

coral colonies are certainly fragile to the extent that they are easily broken and physically damaged. However, notwithstanding the human-induced global declines of coral reefs, coral populations and reefs are naturally highly dynamic entities that for eons have rebounded from the dramatic short-term effects of major natural environmental events, such as hurricanes, floods, volcanic eruptions and tsunamis (Dollar & Tribble 1993, Tomascik et al. 1996, Connell et al. 1997, Done 1997, Lugo et al. 2000, Halford et al. 2004, Bellwood et al. 2006, Game et al. 2008, Veron 2008). They also recover from short-term, human-induced major disruptions, such as those produced by atomic explosions (e.g. Richards et al. 2008).

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Increasing environmental awareness and governmental control of marine resources such as coral reefs have led managers to become more reluctant to allow research collecting of marine organisms, including coral reef fishes. However, virtually all research on the biology of fishes requires some collecting activity. Much research involves live fishes; catch-tag-release enables the tracking of individuals, while manipulation of individuals, groups and abundances in carefully designed experiments is the only scientifically valid way to determine the effects of specific processes. Fish specimens are essential for studies on biogeography, ecology (microhabitat usage, diet), demography (age, growth and longevity, and the effects of environmental variation and fishing on those demographic parameters), reproductive biology (sexual identity and condition, sex ratios, maturation, reproductive history), physiological effects of pollution, and genetic studies (e.g. barcoding) of the identification of species and the mechanisms of evolution. Augmenting this information is essential for gaining an understanding of the biology of coral reef fishes that can provide the basis for effective management and conservation. Management decisions should be based on the best data available, and research collecting is essential for expanding the scope and availability of such information (Robertson & Smith-Vaniz 2008).

Clove oil, which acts as an effective and rapidly acting anesthetic on fishes (Soto & Burhanuddin 1995, Munday & Wilson 1997, Keene et al. 1998, Griffiths 2000), has come into usage in research collecting of live reef fishes in various parts of the world over the last decade (Erdmann 1999). This oil is as effective as other anesthetics that are commonly used by scientists to collect fishes in the field (Munday & Wilson 1997). Clove oil is obtained by distillation of parts of the clove plant *Eugenia caryophyllata*, with the main active ingredient (eugenol) representing ~70 to 98% of the content of the oil (Harper 2003). Accumulated experience with its usage indicates that most research collecting of live reef-fish with anesthetics can be done using this oil. In typical applications, it is thought to be minimally destructive to marine organisms, including target species (Erdmann 1999). Clove oil has other advantages, as it has a long history of safe human usage as an analgesic and antiseptic, and cloves themselves are a foodstuff. If the use of clove oil in research collecting of coral reef fishes typically has few adverse side effects, then it could replace other anesthetics that appear to be more hazardous to human users and more detrimental to both nontarget and target organisms (Erdmann 1999).

Three recent studies assessed the potentially adverse effects of clove oil use (in research collecting of reef fishes) on live corals. In this paper, we (1) sum-

marize how researchers in 17 published studies used clove oil to collect coral reef fishes, and indicate what they noticed about adverse effects of clove oil usage on corals; (2) examine the methods and conclusions of the 3 formal studies on the effects of clove oil on live corals; and (3) indicate in general terms the design features of future experiments that should provide more useful and relevant information.

Finally, we address an issue that, while important for management, was ignored by these 3 studies on the effects of clove oil on corals: How biologically significant are any adverse effects of such research collecting for the maintenance and protection of coral reefs?

Use of clove oil for sampling reef fishes

Here, we present an overview of differing patterns of use of clove-oil solution (COS) in 17 studies. A summary of each study, and any observations by its authors on adverse effects of COS use on corals, is contained in an online supplement available at www.int-res.com/articles/suppl/m401p295_app.pdf.

COS is used in several ways by researchers to collect fishes that live in close association with reef substrata. Clove oil concentrations in COS range from 2 to 28%. Sometimes, the oil is mixed with seawater (aqueous clove-oil solution, AQCOS). More typically (16 of 17 studies), it is dissolved in alcohol (alcoholic clove-oil solution, ALCOS) because it is relatively immiscible with water.

When used to catch live individual fish (or small groups of fish), COS is squirted by hand pressure from the nozzle of a soft plastic bottle containing ~500 ml of solution. Different bottle designs either maintain the concentration of the COS until it is all used, or allow it to be gradually diluted as the original contents are replaced with seawater. The objective is to briefly envelope the fish in a cloud of COS, to calm and disorient it so that it can be scooped up with an aquarium hand net (authors' pers. obs.). During this process, a small dose (typically ~10 ml) is squirted at a fish, although multiple doses scattered over a patch reef or coral colony may occasionally be needed to catch individuals of highly active, elusive species. Delivered in this way, COS disperses very rapidly in unconfined spaces. For example, Boyer et al. (2009) found that water collected within 10 cm of the site of application of relatively large quantities of AQCOS or ALCOS (120 ml) contained <1% of the delivery dose of clove oil within 5 s of application, and virtually nothing 25 s after application. Such rapid dispersion is consistent with our personal experiences using ALCOS to catch individual fishes in open water. As Boyer et al. (2009) point out, however, dispersion will be slower in more

confined spaces. The density of alcohol is ~3/4 that of seawater, which should assist dispersion from such sites.

In addition, ALCOS has been used for larger-scale collections in which small tents that are constructed either of netting or plastic sheeting were set up over a sampling site to slow the dispersion of COS and prevent the escape of fishes. In such confined-assemblage collections, COS is slowly squirted under the tent over a 5 to 10 min period, and the tent is kept in place for a further 1 to 3 min before collecting begins. Due to leakage, COS injected under a tent immediately starts to dilute and disperse, and typically disperses completely within 5 to 20 min after removal of the tent. Maximum potential initial dosages of clove oil under tents have ranged from 0.13 to 0.53 ppt in different studies (assuming that all the COS was evenly dispersed under the tent, and remained there) (see online supplement), but actual maximum dosages would be lower due to leakage, and much lower in the case of porous netting tents.

Finally, confined-assemblage collections have also been made in small tide pools that are exposed during low tide. In these studies, sufficient ALCOS was dispersed throughout a pool to provide overall clove-oil concentrations ranging from 0.01 to 0.1 ppt (see online supplement). Unlike the situation with COS applied under tents in open water, the initial concentration of COS in a tide pool was maintained for 1 to 4 h until the pools were flushed by the rising tide.

Effects of clove oil on corals

There have been 3 formal experimental studies on the effects of COS on corals: Mulochau & Durville (2004), Frisch et al. (2007), and Boyer et al. (2009). These focused primarily on the use of COS in research collecting of reef fishes (as opposed to commercial collecting of aquarium fishes) when providing a rationale for their experiments. As measures of stress on corals, the authors used loss of pigmentation leading to discoloration and bleaching (whitening), death, reductions in photosynthetic capability, and reductions in growth.

(1) Mulochau & Durville (2004) tested responses of a densely branching *Pocillopora* coral to aquarium baths of diluted ALCOS (20% clove oil, 80% ethanol). These included either (1) a single bath containing 2 ppt clove oil for each of 4 durations (1, 2.5, 5 and 10 min), or (2) 5 baths each of 0.2 ppt clove oil, each bath separated by a 3 d interval for each of the same 4 durations as in the single bath treatment. After treatment, corals were returned to flow-through aquaria and observed daily for 1 mo. For the single

bath in 2 ppt clove oil, 1 of 4 colonies discolored after 1 min immersion, 2 of 4 after 2.5 min, and all 4 after 5 min; all 4 colonies were entirely bleached after 10 min. Five baths of 0.2 ppt clove oil produced no response from corals after 1 min immersion, 1 of 4 colonies showed discoloration after 2.5 or 5 min, and 2 of 4 discolored after 10 min immersion. These color changes occurred within hours to days of the treatment, and no discolored or bleached corals recovered normal coloration during the month of post-treatment observations (T. Mulochau pers. comm., April 2009). Mulochau & Durville (2004) concluded that corals were less affected by a series of small doses of COS than by a single larger dose equal in size to the sum of the small doses.

Positive aspects of the study: entire colonies rather than fragments were used, and these were allowed a long acclimation period (8 wk prior to the start of the experiments).

Limitations on real-world relevance of study: aquarium experiments were used, which could have reduced the resistance of corals, which are known to be more stressed in aquaria than in the field (Frisch et al. 2007, Willis 2004). The level of replication was relatively low (4 coral colonies per bath, 4 controls), and results were not subjected to statistical analyses. Concentrations of clove oil that produced strong adverse reactions from corals were distinctly higher than those generally used in confined-assemblage collections in the field.

(2) Frisch et al. (2007) used both laboratory and field tests to examine responses of a finely branched *Pocillopora* species to ALCOS.

Laboratory experiments: 4 d after being broken off a colony, coral fragments were immersed in a bath of 1 of 18 exposure treatments: 0.05, 0.5 and 5 ppt clove oil (as ALCOS); 0.5, 5 or 50 ppt ethanol in seawater; plus a seawater control, with either 1, 10 or 60 min exposure during each treatment. Corals were then returned to their original recirculating aquarium and monitored for 7 d. Exposure to 0.05 ppt clove oil for 1 to 60 min had no effect on coral color; 0.5 ppt clove oil exposure for 60 min killed coral fragments within 2 d, 10 min exposure produced discoloration within 2 to 3 d, and 1 min exposure had no effect on coral color; 5 ppt clove oil exposure for 1 min or more killed all corals within 1 to 2 d. The ethanol-only treatments had no effect on coral color. Photosynthetic efficiency was reduced in all treatments except the 0.05 ppt clove oil and alcohol-only treatments.

Field experiments: these involved 3 treatments, 10 or 100 ml of full-strength ALCOS (100 ppt clove oil, 900 ppt ethanol), or 100 ml of 100% ethanol sprayed at close range over a period of 1 min into the center of the tight matrix of a coral colony. Corals were then moni-

tored for 63 d. Compared to the controls, exposure to either 100 ml of ethanol or 10 ml of ALCOS produced no increased discoloration, nor partial colony mortality. Exposure to 100 ml of ALCOS, however, produced discoloration in the center of the colony within 2 d, and partial mortality (a patch ~5 cm in diameter) at the point of application ~7 d later.

Positive aspects of study: weaker, shorter-duration test applications of COS in the laboratory were within the range of concentrations used in confined-assembly collections under tents (see previous section). The smaller of the 2 amounts of concentrated COS (10 ml) used in the field test was also within the range of amounts used in real-world research collecting (see previous section). Both laboratory and field experiments were reasonably well replicated ($n = 9$ treatment⁻¹ for laboratory experiments, 7 treatment⁻¹ for field experiments), and conclusions were based on statistical analyses. Field tests used whole adult coral colonies, and changes in coral status were monitored for an extended period.

Limitations on real-world relevance of study: (1) in the laboratory experiments, coral fragments were used that allowed only short acclimation periods (4 d) before treatments began. In contrast, Jones (1997) allowed 14 to 20 d for fragment acclimation in the field, by which time fragments had produced a small skirt of tissue-covered skeleton at the broken base, while Mulochau & Durville (2004) allowed 8 wk for small colonies in aquaria. (2) COS treatments that had adverse effects on corals involved substantially higher doses and levels of exposure than would normally occur in field collections of fishes.

(3) Boyer et al. (2009) tested the effects of COS on fragments of coral belonging to 1 species in each of 3 genera (*Pocillopora*, *Acropora* and *Porites*) in the field. Tips of adult colonies were attached to a concrete block, and allowed to acclimate for 1 wk prior to the experimental treatments. Four treatments were used: 3 of AQCOS (70, 140 or 280 ppt clove oil), and 1 of ALCOS (140 ppt clove oil, 760 ppt ethanol), plus a seawater control. Each exposure involved 120 ml of COS being squirted directly onto the group of 3 fragments sharing a block. These treatments were repeated 5× at weekly intervals. To measure adverse effects of COS application, these authors used (1) the proportion of weeks in which any part of a colony was discolored, and (2) the reduction in growth of these fragments measured 1 wk after the last treatment. Increased discoloration and reduced growth were found in all treatments except 70 ppt AQCOS. No coral mortality was mentioned.

Positive aspects of study: field experiments were used, and an attempt was made to control for genetic variability by using fragments from different colonies.

Corals from various genera were tested. Conclusions were based on statistical analyses.

Limitations on real-world relevance of study: only coral fragments were used (the response of a fragment may differ from that of an entire colony that has only part of its surface treated with COS); growth was measured over a very short period; a very short acclimation period was used prior to the start of the experiments; and there were low levels of replication (3 fragments species⁻¹ treatment⁻¹, plus 3 controls). In general, the levels of exposure used (large quantities of moderate to high strength COS applied at close range, with frequent reapplications) were substantially higher than those used in almost all real-world scientific collecting.

Effects of clove oil on corals vs. actual usage patterns

Most researchers collecting reef fishes with COS have used ALCOS (16 of 17 studies). Concentrations varied widely between 2 and 23% clove oil combined with 25 to 90% ethanol or, occasionally, isopropanol. Collecting with COS has involved exposure of live corals to COS in most (13 of 17) studies.

During individual-fish collections, concentrated COS was delivered in small quantities (≤ 10 ml) at any particular point on a coral. Large doses (~100 ml) of concentrated COS were applied to a small cluster of coral polyps in only 1 case (Shima et al. 2008, see online supplement), and repeat treatments of groups of polyps at short intervals occurred (infrequently) only in Shima et al. (2008).

Corals can display obvious visible signs of stress in response to COS application. With increasingly stronger concentrations or duration of exposure, these include partial discoloration, complete discoloration (bleaching), and death. Discoloration, bleaching and death can occur within 1 to 2 d of exposure to high levels of COS, although partial mortality of colonies may be somewhat delayed. The skeleton of dead corals is white and remains so for weeks before being overgrown by algae. Discolored, bleached and dead coral colonies are readily visible to field researchers, often from a distance (authors' pers. obs.). Entire colonies can display such signs when treated with COS baths in the laboratory. In contrast, any such signs in field collections are limited to the small parts of colonies that are directly exposed to COS during targeted collecting of individual fish.

While the 3 experimental studies clearly demonstrate that large doses of COS at high concentrations and delivered at close range have strong adverse effects on corals, the concentrations and dosages that produced these results are rarely used in research collecting of reef fishes. While a large amount (100 ml) of

strong COS applied to a coral colony in the field can produce lasting damage (partial mortality), the area of such damage is very small (~5 cm in diameter), and limited to the point of application. Observations by researchers indicate that corals occasionally display minor signs of stress (localized, temporary discoloration) in response to the small doses of high-strength COS typically used when collecting individual, unconfined fish in the field. However, single applications of small amounts (10 ml) of 100 ppt ALCOS into the center of finely branched coral colonies and even repeated doses of large amounts (120 ml) of 70 ppt AQCOS may produce no obvious signs of stress in corals.

The rapidity with which high-strength COS normally dissipates in open water reduces the potential for adverse impacts on corals during collections of individual fish. Repeated exposure of small parts of coral colonies to COS occurs most often in experimental studies (5 of those analyzed here) that involve the capture of inquiline fishes that associate closely with, and depend strongly on live corals. However, there was little evidence of adverse reactions by corals in these studies and the occasional reactions were slight and temporary. Researchers have a strong vested interest in minimizing COS use to avoid any coral damage that would jeopardize the integrity of experiments with such inquiline fishes.

In confined-assemblage collections under porous tents in open water, corals can be exposed to COS for between 1 and ~15 min. Initial potential concentrations of COS (which would rapidly decline due to leakage and dispersion) are ~1 to 5% of those used when catching individual fish using squirt bottles. Exposures to similar concentrations of COS for similar durations in aquaria (with no increasing dilution, unlike the field situation) produce little or no obvious coral damage.

COS concentrations used in tide-pool collections are very low, and are lower than those used under tents in open water. However, exposure times in tide pools, where there is no immediate onset of a decline in concentration, can be for several hours. Effects of such treatment regimes on corals remain unknown.

When delivered in large quantities at close range, concentrated ALCOS produces a stronger adverse reaction from corals than AQCOS containing the same percentage of clove oil. Moreover, a large dose of ALCOS at close range produces a much stronger adverse reaction than a similar sized dose of high strength ethanol. Exposure of corals to laboratory baths of 5% ethanol in seawater for 60 min can produce less obvious stress than weaker baths of ALCOS. These results indicate that the dissolution of clove oil in alcohol renders the oil more toxic to corals. However, even if ALCOS is more toxic than

AQCOS containing the same concentration of clove oil, there may be no net advantage to using AQCOS if its immiscibility with water means that larger quantities are needed per fish.

The total amount of substratum that was exposed to COS during any study involving collection of fishes was typically small: an average of 9 m² (range 0 to 17 m²) of live coral in each of 7 studies in which COS was used to catch unconfined fish; 3 to 5 m³ of pool in each of 3 tide-pool studies; and 33.3 m² (range 10.1 to 86.5 m²) of various substrata in 5 confined-aggregation studies in open water. Because other substrata as well as corals were sampled in both types of confined-aggregation collections, the actual areas of live coral that were exposed to COS could have been much smaller than these values.

Real-world experiments on the effects of clove oil are essential

With the aim of minimizing possible adverse responses of corals and other organisms to COS usage, field experiments should be made to establish (1) minimum concentrations of clove oil (and alcohol) for effective collecting of live unconfined fishes in the field; (2) minimum dosages (concentration × duration of exposure) for effective confined-aggregation collections in open water; and (3) minimum dosages (concentration × duration) for effective collections in tide pools. The only situation in which aquarium experiments might be substituted would be in determining dosages for tide-pool collections (cf. Griffiths 2000). Concentrations and dosages that are used to collect live unconfined fish will likely vary, with small, slow species that are strongly attached to small areas requiring less and weaker COS than larger, more agile and mobile species. Usage of these minimum concentrations and dosages should be adopted as 'best practice', based on knowledge of the behavioral characteristics and relative mobility of the target species and the objectives of the research.

Existing experimental studies do not provide a sufficient understanding of the effects of field usage of COS on live corals, mainly because they did not accurately simulate the range of modes of actual field usage, and because they were of short duration. The primary focus of future assessments of damage potential should be on field experiments. These should examine the effects of ALCOS and AQCOS on a variety of indicators of coral stress (discoloration, bleaching, and partial and/or complete mortality), as well as growth and reproduction. As there can be substantial seasonal fluctuations in the densities of zooxanthellae and pigments in hard corals that are not visibly dis-

cernible by divers (Fitt et al. 2000), assessments of stress and recovery could also include direct measurements of these densities and of changes in photosynthetic capability (cf. Frisch et al. 2007). Assessments of stress effects must be done at ecologically significant time scales, e.g. seasonal or annual, to gauge the extent of long-term stress and the capacity of corals to recover from any negative effects of COS exposure. Field tests are necessary because laboratory conditions may impose hidden stresses that are not evident in control corals but strengthen adverse reactions of corals exposed to COS. Experiments should primarily use entire adult colonies rather than colony fragments, because (1) unexposed parts of an entire colony may enhance recovery from negative effects that are experienced by a small proportion of the colony, and (2) fragments are unlikely to represent useable habitat for fishes. Any use of fragments must allow adequate acclimation time before treatments are administered. The point at which growth has visibly resumed and is readily discernible (~15 to 20 d, cf. Jones 1997) may be appropriate. Species of corals that harbor inquiline fishes and are most likely to be collected with COS are most appropriate for tests of adverse COS effects, particularly repetitive treatments. As responses to stresses such as elevated water temperatures that produce bleaching vary among coral species (e.g. Huerkamp et al. 2001), variation among coral species in responses to COS applications should be expected. Separate tests need to be made using the 3 modes of COS application used in field collections: (a) highly targeted collecting of live, unconfined fish using brief exposures to small amounts of high-strength COS; more sustained exposure to low strength COS used for confined-assembly collections, including (b) nondiluting baths in tide pools, and (c) diluting baths under tents in open water.

Any laboratory experiments to assess the effects of COS on coral physiology must accurately simulate one or more of the 3 modes of COS use noted in the previous paragraph. Results from one mode of use cannot be assumed to be valid for another.

Is scientific collecting a significant problem for management?

As increasing attention by managers becomes focused on research collecting on coral reefs, it becomes essential to ask whether the adverse effects of COS use in field studies of coral reef fishes represent a biologically significant problem for individual corals exposed to COS, and for the health and maintenance of coral populations and coral reefs.

The 3 experimental studies on the effects of COS on corals implied that there is a potentially significant problem with such COS usage because it has come into common use among reef-fish biologists in many parts of the world. Frisch et al. (2007, p. 102), for example, stated that '... there may be hundreds to thousands of clove-oil users in Australia alone'. There is no evidence from the number of publications produced over the last decade of such a level of activity. There simply are not that many coral-reef fish biologists (scientists and graduate students) who are currently active in Australia, and most of them are not using COS to collect reef fishes.

We were able to obtain information on 15 studies (that produced 31 publications) conducted since 2000 that involved the use of COS to collect coral reef fishes, plus 2 that collected reef fishes in other habitats (an average of <2 publications yr⁻¹). Searches of Biological Abstracts, Zoological Record, the Web of Science and Google Scholar using key words such as 'clove oil' and 'fish', identified less than a quarter of these publications. This number is an underestimate of the actual number of studies because some studies might not have recorded their use of COS and others that involve COS usage might not have been published. Thus, we assume that there might be 50 to 100 studies yr⁻¹ worldwide that involve the use of COS to collect tropical reef fishes, which would mean that publications enable detection of only ~2 to 3% of the actual usage.

The potential effects of such a level of research activity (~50 to 100 studies yr⁻¹) on corals can be placed in perspective as follows: first, the total area of live coral tissue subjected to COS exposure during any single study would be very small, i.e. <10 m² on average, for a total of ~500 to 1000 m² yr⁻¹ (~40 to 80% of the surface area of an Olympic swimming pool) worldwide. This amount stands in stark contrast to the 285 000 km² occupied by structural coral reefs worldwide (Spalding et al. 2001). Further, large areas of shallow tropical habitats that lack coral reefs support dispersed coral growths. For example, while there are only ~25 km² of structural coral reefs in the tropical eastern Pacific, Glynn & Ault (2000) noted that the region includes ~15 000 km² of shoreline habitats that are capable of supporting reef development, and where scattered coral growths commonly occur (D. R. Robertson pers. obs.). Although this region may be an extreme example, it clearly demonstrates that corals are common organisms not only on structural coral reefs but also in other habitats. Even assuming an average coral cover of only 10% on a structural coral reef, sampling of reef fishes with COS would expose <<0.000005% of the world's coral populations to COS during any year.

Second, there is simply no comparison between the scales of any brief effects produced by COS-based

field research and that of major damage produced either by acute natural events such as floods, storms, hurricanes, volcanic eruptions, and tsunamis or by large-scale, long-term and increasing negative human impacts brought about by global warming, pollution, coastal development, anchor damage, recreational SCUBA diving, and overfishing. Such acute natural events affect corals and coral reefs on the scale of 10s to 1000s of km², while long-term, human-induced stresses affect corals and coral reefs virtually throughout the entire tropics.

Finally, the scale of research collecting of coral reef fishes needs to be placed in perspective relative to the scale of other human extractive usage of tropical reef fishes. This includes commercial and recreational fishing, and the collection of live fishes for both the live food-fish and ornamental aquarium-fish trades. Methodologically, scientific collecting of live reef-fishes resembles commercial live-fish collecting. However, such commercial fishing involves many thousands of collectors and millions of individual fish (Wood 2001, Sadovy et al. 2003), and individual commercial collectors are much more continuously active throughout the year than most researchers. Hence, the scale of this commercial activity and its attendant environmental effects are vastly greater than those of scientific collecting.

All this readily available information demonstrates that any negative effects of tiny, brief research collections using COS are inconsequential relative to the capacity of coral populations and coral reefs to recover from temporary environmental stress, especially when compared to the effects of large-scale natural and human-induced events on coral populations. However, in defending research collecting and the use of clove oil for collecting coral reef fishes, we emphatically are not advocating that the environmental effects of such an activity be ignored, or that such collecting be allowed anywhere at any time. Proposals for such activities should be assessed individually based on their merits, and particularly sensitive sites obviously should not be open to collecting. Rather, we urge managers to recognize and take into account the minuscule environmental effects of individual research projects that involve collecting of coral reef fishes, and to allow limited levels of this activity when it has sound scientific or management goals.

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