Collective action and lime juice fight crown-of-thorns starfish outbreaks in Vanuatu

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Introduction

Among the broad range of large-scale disturbances that affect Indo-Pacific coral reefs, the coral-eating starfish *Acanthaster planci* (crown-of-thorns starfish, COTS hereafter) is a major cause of coral reef destruction; its impact is quantitatively comparable to a cyclone. While *A. planci* generally occurs at very low densities (typically < 1 individual ha^{-1}), populations can dramatically increase during certain periods, reaching extremely high values (e.g. 538 ind. ha^{-1}; Kayal et al. 2011). These outbreaks represent one of the most significant biotic disturbances on coral reefs, causing massive and widespread coral mortality. Over a third of Indo-Pacific reefs were recently affected by severe COTS outbreaks, leading to growing concern that they are becoming more frequent and more prevalent (e.g. Brodie et al. 2005). While there is historical evidence that coral reefs can recover from COTS outbreaks, they drive even more pressure on already weakened systems (Bellwood et al. 2004; Bruno and Selig 2007; De'ath et al. 2012). The cascading effects from coral loss can severely harm the entire coral community, which raises serious concerns in areas where coastal resources (fish, invertebrates) form the basis of traditional, subsistence fishing.

Crown-of-thorns, an overlooked issue in Vanuatu

In Vanuatu, as in most Pacific countries where local people depend on coral reefs for their livelihood, COTS constitute a potential threat to food security and the lifestyle of coastal communities. While the presence of crown-of-thorns starfish has frequently been observed on the fringing reefs of many islands during the last decades, quantitative data are very scarce (Naviti and Aston 2000; Friedman et al. 2008). Large populations of

Acanthaster planci, *the crown-of-thorns starfish (Image: Pascal Dumas)*

A. planci were reported at some of the 35 sites surveyed by Done and Navin in 1989–1990. COTS outbreaks were documented in 2004 in the island of Espiritu Santo, while the reefs of Efate and the surrounding islands of Emao, Nguna, Pele, Moso and Lelepa have been successively hit since 2006. In 2008, quantitative surveys conducted by the Institute of Research for Development (IRD) reported peak densities locally, reaching up to 4,000 individuals ha^{-1} in Emao.

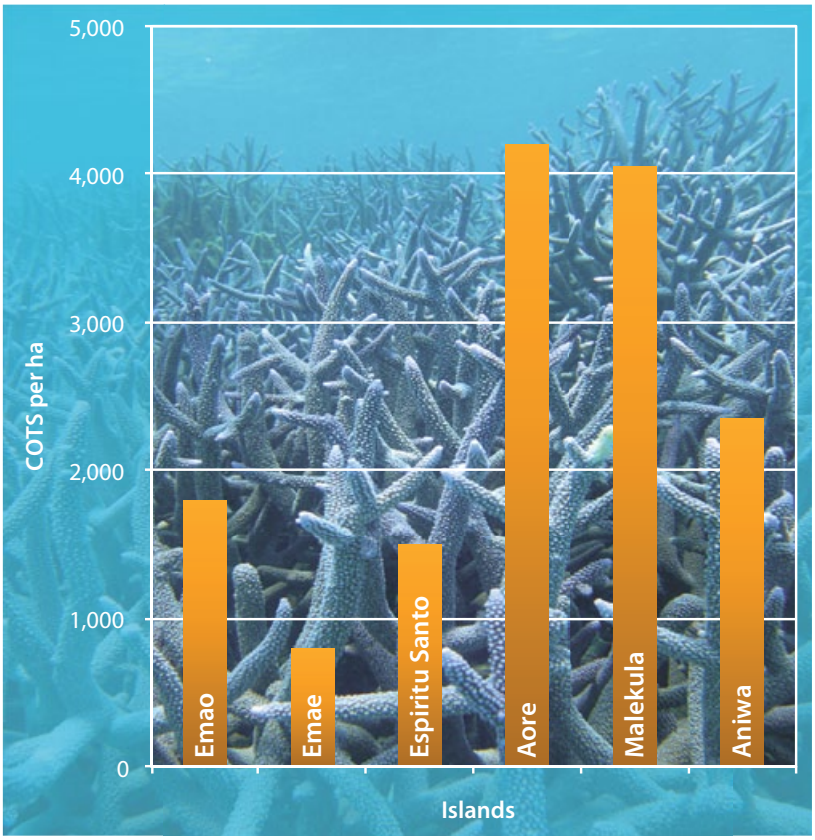

Figure 1. Peak densities of Acanthaster planci *in five islands of Vanuatu in 2014*

In 2013, alarming reports from coastal village communities, tourism professionals and NGOs raised new concerns about the geographical extension, intensity and social impacts of COTS in Vanuatu. Local scuba operators from Espiritu Santo and Efate reported increasing COTS aggregations in popular dive sites. Fishers from southern Espiritu Santo reported that, in some areas, women and children were afraid to go fishing on the reef because of very high COTS densities. In the Luganville area, there were cases of severe injury; the long, sharp spines of this species are slightly venomous and can inflict painful wounds that are slow to heal.

To address this issue, a series of COTS surveys was initiated in 2014 by the IRD and the Vanuatu Fisheries Department (VFD). COTS were investigated using standardised, quantitative underwater visual census methods across Vanuatu, supplemented by semi-quantitative observations provided by local observers. The results reveal that *A. planci* is widely distributed across the whole archipelago, with densities sometimes reaching extremely high values: up to several thousand individuals per hectare, which is similar or even higher than the highest densities usually reported from coral reefs (Dumas et al. 2015; Kaku et al. 2015; Dumas et al. 2014a, b). While the definition of an outbreak is still controversial, a COTS density of 15–300 ha^{-1} has been considered in various reports to constitute an outbreak population (e.g. Pratchett et al. 2014). The high densities observed during the 2014 surveys (with peaks of 800–4,200 individuals ha^{-1}) confirmed the occurrence of severe, localised COTS outbreaks in all of the six islands investigated (Fig. 1). Despite the lack of quantitative historical data, it is possible to assume multiple and/or recurrent infestations in these areas, with populations at various stages of growth: recent primary or secondary infestations (e.g. Emao in 2013, Malekula in 2014), infestations already installed or at the declining stage (e.g. Emae, Espiritu Santo, Efate since 2004–2006).

Addressing the COTS issue in Vanuatu

Despite growing concern from a variety of stakeholders, only recently has the crown-of-thorns starfish issue gained prominence at the national level. Local tourism operators have been struggling with COTS for many years, as untreated outbreaks can seriously affect the local tourism industry, especially in Vanuatu, which has many small marine-related business activities such as fishing, diving, snorkelling tours and glass-bottom boats. The result of COTS outbreaks is that a beautiful underwater landscape is lost, and for the tourism industry, this may have a devastating impact.

Currently, COTS outbreaks can only be reduced by direct human intervention. Since 2006, several scuba operators have been monitoring and removing COTS to help prevent further spawning. They do this at their own expense, whenever possible, during their tourist dive operations. Most of these efforts target only their usual dive operation areas, so benefits are often spatially restricted by lack of resources and the distance from dive operations.

Efforts have been made by the Fisheries Department, which led to awareness campaigns around the islands from 2003 to 2011, in collaboration with several local or international NGOs. They mostly targeted rural coastal communities, schools and tourism activities, but the campaigns were not implemented in a collaborative and coordinated manner. At the village level, basic information about COTS biology and ecology was clearly lacking (e.g. feeding behaviour, reproduction cycle, larval dispersal, growth, habitat, regeneration abilities), making it very difficult for the communities to understand the issues and efficiently manage COTS outbreaks.

Community-based management of COTS outbreaks in Vanuatu

While numerous approaches have been developed over the last decades, manual collection followed by disposal ashore is the most common technique used across the Pacific to regulate COTS outbreaks, at least on a small scale (Fraser et al. 2000). The starfish are usually collected manually by local snorkelers – using simple, everyday tools such as spears, sticks, hooks, spearguns and flour bags – and then buried or burnt ashore. The efficiency of these measures is very controversial, as i) their ecological efficiency is questionable for severe outbreaks and/or large affected areas; ii) they require significant manpower, long-term commitment and they entail a high risk of injury for the participants; and iii) timing is critical, in particular with respect to the spawning period of *A. planci*, which is not consistent across the country (Fig. 2).

In Vanuatu, the affected communities usually try to manage infestations by undertaking cleaning campaigns operated on the village scale, sometimes with the help of NGOs, local sponsors and funding agencies. Unfortunately, their efficiency appears very limited, given the lack of coordination and scientific/technical basic information, as well as long-term financial support.

In 2013, a pilot participatory project developed by IRD and the Fisheries Department in the heavily affected area of Luganville (southern Espiritu Santo) demonstrated that committed communities have the capacity to efficiently reduce COT densities on their reefs (Dumas et al. 2014c). More than 3.7 tonnes of COTS were removed from a narrow fringing reef by local snorkelers and volunteers from the Vanuatu Mobile Force during a nine-day community activity, using only very basic, locally-made collection tools. After this initial work and associated awareness, the local community took over, mainly on an individual basis (i.e. fishermen or snorkelers systematically removed the specimens of COTS that they found). Six months later, the density of COTS was divided by eight, back to 'normal' levels; women and children – who used to avoid the reef flat for fear of injury – were again seen fishing and swimming in the area. This was mostly achieved by teaching the local communities good ecological practices to remove the COTS from their reefs safely and efficiently, as well as providing direct logistical support to organise clean-ups.

The project did not implement a 'bounty programme', as has been done in some countries, e.g. Japan and Australia. Under this scheme, divers are paid a fee for every COTS they remove from a reef area, which creates an incentive

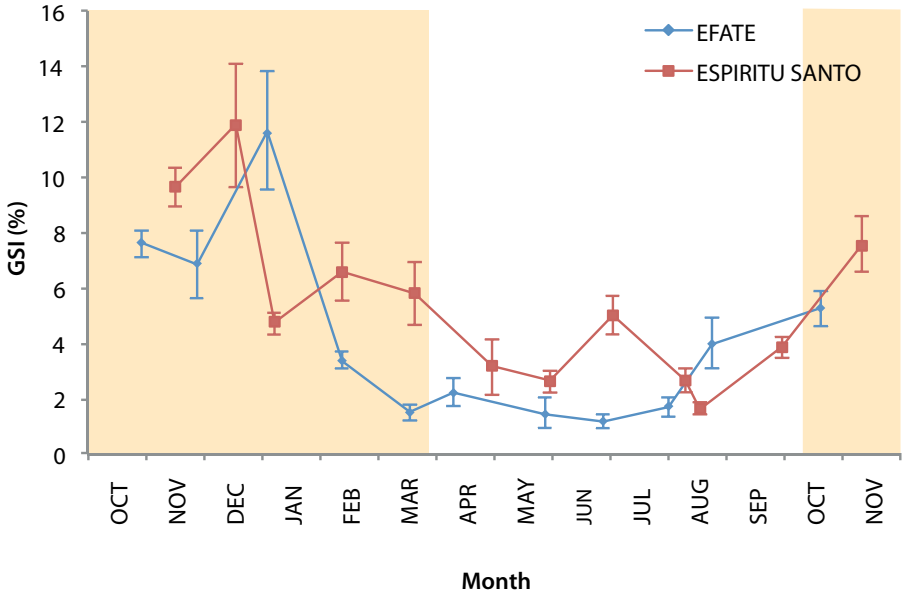

Figure 2. Spawning season (light yellow areas) of Acanthaster planci *in Vanuatu. Temporal evolution of gonado-somatic index (GSI) between October 2013 and November 2014 on Espiritu Santo and Efate.*

On this particular day, a team of more than 30 people, including members of the BanBan community and volunteers from the Vanuatu Mobile Force of Luganville, South Espiritu Santo, gathered to remove COTS from the area. (Image: Pascal Dumas)

for individuals to collect them. The main drawback is that the incentive for the collection of COTS becomes financial, and does not necessarily foster environmental concern among the local communities. Vanuatu people usually exhibit high commitment to the protection of their marine resources, so the emphasis was on environmental issues and long-term consequences of COTS outbreaks, and this motivated the participants. Despite very limited direct financial outcomes (food for all participants, closing ceremony with refreshments, and a daily fee of VUV 500 per person – ± USD 4.90 at that time), a high level of commitment was observed and the outputs were very satisfactory.

Acidic injections: a new 'cheap and natural' alternative?

Injection approaches – in which *A. planci* is injected with a variety of noxious solutions – are increasingly used as an alternative to manual methods, as they are more cost-effective than manual methods and fairly safe when handled correctly (see reviews in Rivera-Posada et al. 2012, Rivera-Posada and Pratchett 2012). However, there are drawbacks; most solutions injected over recent decades were not only noxious for COTS but for the coral community as well. For example, injections with copper sulphate were carried out in the Great Barrier Reef until it was judged too highly toxic for fish and many invertebrates (Yanong 2010).

Injections with sodium bisulphate are required at such high concentrations that they entail the risk of lowering oxygen levels in seawater (Roman and Gauzen 1993, Hoey and Chin 2004). Other chemical solutions may favour the growth of a particular type of bacterial pathogen (e.g. TCBS[1], Rivera-Posada et al. 2011), inducing disease and ultimately death in COTS, but with potential knock-on effects on the coral-associated community. Recently, single injections of 10 ml of TCBS protein ingredients (oxbile and oxgall) induced a strong immune response and death in *A. planci* with no evidence of negative effects on the coral community, so they are currently considered a promising alternative (Rivera-Posada et al. 2012, 2013). Nevertheless, the cost may be out of reach of many stakeholders; in Vanuatu, the cost of importing 250 g of oxbile or bile salts exceeds USD 900, freight cost included.

Against this backdrop, developing more cost-effective approaches is critical. In 2014, a new alternative, based on acidic injections of cheap, natural products was tested in Vanuatu by IRD and the Fisheries Department. Results from both aquaria and field experiments showed that fresh lime juice (extracted from local *Citrus arantifolia*)

[1] TCBS: thiosulfate-citrate-bile salts-sucrose agar.

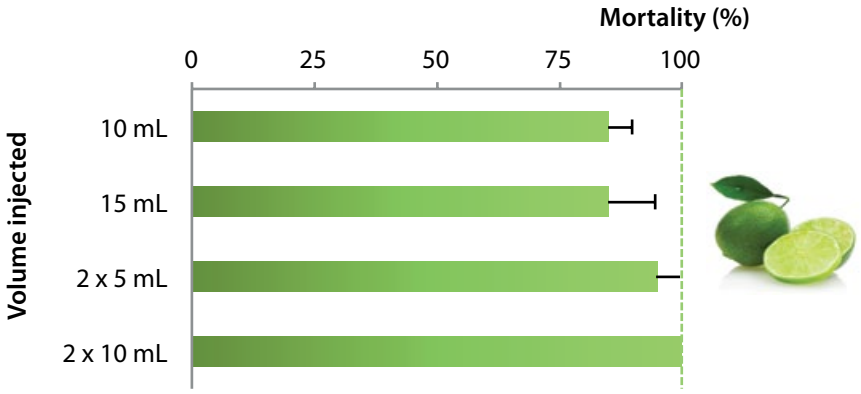

Figure 3. Effects of lime juice injections on Acanthaster planci. *Mean per cent mortality ± STE.*

and white spirit vinegar offer an option to control COTS outbreaks. They were found to induce high mortality, even with small volumes: 10-20 mL injected per starfish induced death in 89% and 97% of the injected specimens after an average of 34.3 hours, using lime juice, and 29.8 hours, using vinegar. Highest efficiency was reached with double shots of 10 mL each in two different areas of the body; 100% mortality occurred within 12–24 hours, which is similar or shorter than with other current injection methods (Fig. 3). With this new method, 10–20 L of lime juice or vinegar could kill up to a thousand COTS at a cost of less than USD 0.05 per specimen; and no permits or special handling procedures are required. Contagion to either conspecifics or a variety of other reef species was not observed. Based on these results, acidic injections of lime juice and vinegar offer great advantages when compared to current best practices and constitute a cheap and natural option for all countries affected by COTS, including Vanuatu.

Conclusion

The fact is that numerous coastal areas in Vanuatu are currently experiencing COTS outbreaks, the management of which is almost totally ineffective, leading to massive destruction of coral reefs and resources. While removal methods are only short-term responses to a complex phenomenon whose ultimate causes are not fully understood, their efficiency is increasingly recognised as a good protection for isolated or individual reefs (Bos et al. 2013). In the social and economic context of Vanuatu, the most promising approach in the long term is likely to be the use of cheap, low-tech removal techniques, relying on the strong commitment of the coastal communities through participatory, coordinated approaches. More effective control of COTS outbreaks will require that the lessons learnt at local (villages, communities) level be applied on a larger scale – a considerable challenge.

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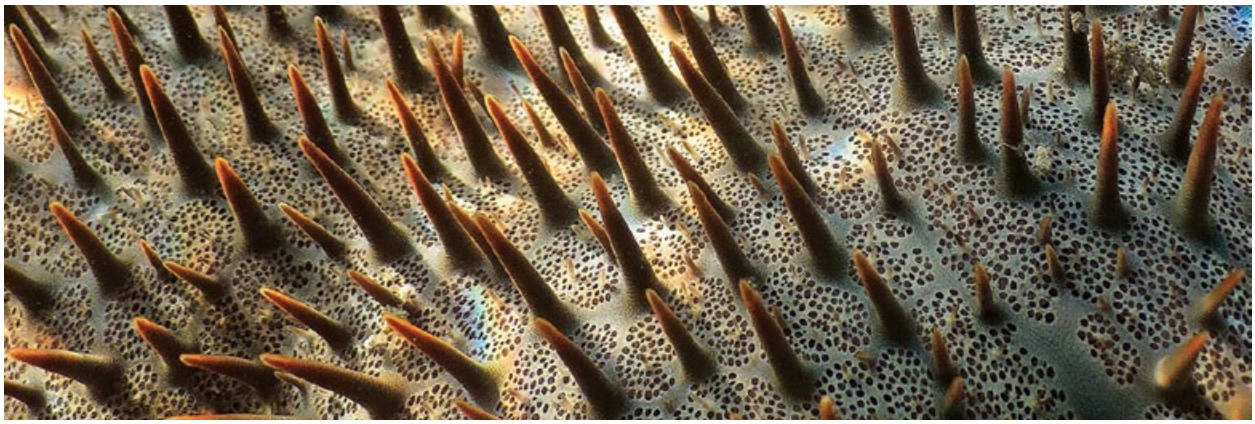

Wounds inflicted by COTS spines can be very painful. (Image: Pascal Dumas)

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