



Australian Government

**Great Barrier Reef
Marine Park Authority**

Crown-of-thorns starfish

CONTROL GUIDELINES





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Comments and questions regarding this document are welcome and should be addressed to:



Australian Government
Great Barrier Reef
Marine Park Authority

Great Barrier Reef Marine Park Authority
2–68 Flinders Street
(PO Box 1379)
Townsville QLD 4810, Australia

Phone: (07) 4750 0700
Fax: (07) 4772 6093
Email: info@gbmpa.gov.au
www.gbrmpa.gov.au



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Introduction

Important: Carrying out a crown-of-thorns starfish control program may involve inherent risk. A marine parks permit is required before commencing a control program in the Great Barrier Reef. The permit requires you to have public liability insurance and insurance under the *Workers Compensation and Rehabilitation Act 2003*.

The crown-of-thorns starfish (*Acanthaster planci*), or COTS, is a coral-eating starfish or sea star native to coral reefs in the Indo-Pacific region. COTS feed on the fastest growing corals such as staghorns and plate corals, allowing slow-growing corals to form colonies. This increases coral diversity. When COTS numbers are low, coral reefs can recover more readily from damage caused by COTS feeding. COTS control is not required in this situation as this is a naturally occurring event.

However, COTS densities can increase to a point where a coral reef can no longer recover from the damage caused — this is termed ‘an outbreak’. Outbreaks pose a significant threat to the health and resilience of the ecosystem. This document provides:

- information on the two endorsed methods for controlling COTS in the Great Barrier Reef, including suggestions on the equipment to use
- permit requirements
- health and safety considerations
- guidance on how to implement and conduct a COTS control program including how to effectively search and inject the starfish
- additional reading on the biology and ecology of COTS.



Further information on the management and history of COTS outbreaks on the Great Barrier Reef can be found on the Great Barrier Reef Marine Park Authority [website](#).

1. Control methods

The best practice method for undertaking COTS control is to use a modified drench gun to inject the starfish, using either a single-shot method (bile salts or household vinegar) or the multi-shot sodium bisulphate method. These injection methods minimise the risk of breaking corals, and are safer than manual removal which is not recommended due to the risk of spiking.

Although direct injection of bile salts, household vinegar or sodium bisulphate are toxic to COTS, these solutions are not known to have a residual environmental impact. Sodium bisulphate has been used in the multi-shot method in the Great Barrier Reef for more than 15 years. Comprehensive laboratory (Rivera-Posada, et. al. 2014) and field surveys were undertaken prior to the large-scale use of the single-shot bile salts in the Great Barrier Reef in 2013, and no immediate flow-on effects on reef fish, corals, and other benthic invertebrates were observed. Laboratory (Boström-Einarsson and Rivera-Posada 2016) and field impact assessments have also confirmed that injecting COTS with household vinegar has no harmful effects on non-target organisms in the surrounding environment.

1.1 Single-shot vs multi-shot methods

Single-shot injection methods are far more time efficient than the multi-shot method, especially when COTS numbers are particularly high or when control activities are carried out on a large and regular basis. Trials of the single-shot method indicate it is three times more efficient than the multi-shot method. Refer to section 2.6 on recommended injection placement as this is specific to the injection solution. The table below summarises features of the three methods.¹

	Bile salts	Household Vinegar	Sodium bisulphate
Number of injections	1	1	10-25 (depends on body size)
Injection location	middle or base of arm	base of arm	multiple across body
Dose	10 mL	20 mL	20 mL
Needle size	Veterinary (16-gauge)	Veterinary (16-gauge)	No needle required
Shelf-life in solution	~ 5 days	~ 1 year	~ 1 month
Approx. cost per COTS	\$0.03 per COTS	\$0.01 per COTS	Varies depending on body size

Videos that provide technical guidance on conducting a COTS control program are available on [the GBRMPA YouTube channel](#). The first video covers [equipment assembly and pre-dive preparations](#) (solution mixing, dive preparation) for the bile salts and sodium bisulphate methods. The second video covers [in-water search and injection techniques](#).

1.2 Single-shot method (bile salts)

Bile salts (sodium cholate $C_{24}H_{39}NaO_5$ (NaC) and sodium deoxycholate $C_{24}H_{30}NaO_4$ (NaD)) are derivatives of bile collected as a by-product from cattle during the standard abattoir process. Cattle are not killed specifically for bile salts. Bile salts are purchased as a very fine white powder and should be kept in a tightly closed container in accordance with the [material safety data sheet](#). Bile salts can be an irritant when ingested, inhaled or if contact with skin or eyes occurs. Appropriate safety equipment including protective eyewear, clothing (for example gloves) and respiratory equipment (for example, vapour and dust respirators) are recommended in accordance with the material safety data sheet².

Mixing bile salts

The solution should be prepared on land as it is difficult to get an accurate reading from the balance on a moving vessel. Weighing fine powders in a sheltered area also eliminates the risk of them blowing away. Appropriate protective gear should be worn at all times when handling bile salts, in accordance with the material safety data sheet.

¹ Current at the time of calculation (February 2017)

² Available at <http://www.sciencelab.com/msds.php?msdsId=9927340>

To be effective, the bile salts solution needs to be concentrated at 10g per litre. While onshore, bile salts powder can be pre-packed into 50g-lots in plastic zip lock bags. Once offshore, fill a five-litre bottle with freshwater (fill only to the top of the clear window on the side of the bottle to ensure an air pocket remains), and add a few drops of food colouring (preferably red). Then, use a funnel to add the pre-packed powder (50g). Close the lid, ensure the hose is blocked and shake the bottle until all powder is dissolved. Red food colouring is not harmful to the environment and helps the diver see the solution underwater. In this way the diver can see if the applicator is working correctly underwater and if the injection was successful.

Naturally occurring bacteria in the water (especially in seawater) will act to break down the bile salts, rendering the solution ineffective after five days. When bile salts have reached their expiry date, the injection solution will appear milky and opaque. If disposing of unused bile salts solution at sea, the solution should be treated and disposed of in the same way as sewage under the relevant Commonwealth and State legislation. Specifically:

- dilute the solution as much as is possible in on-board containers
- disposal to the marine environment must occur while the vessel is underway
- disposal can only start once you are more than one nautical mile (1.85 km) from the nearest reef, island, mainland or an aquaculture facility.

When injecting starfish, it is important to administer the 10 mL dose in a slow and steady flow, especially in small (less than 10 cm-diameter) starfish, otherwise much of the solution will be forced out of the body. For very large starfish (more than 40 cm in diameter) it may be necessary to administer at least two injections of the bile salts solution.

Supplier

Bile salts are a specialised product. For further information on suppliers, please contact [GBRMPA](#).

1.3 Single-shot method (household vinegar)

White household vinegar is a solution of acetic acid (CH_3COOH) and freshwater, prepared at a concentration of approximately 4 per cent (pH 1.8-2.5). Although this weak acid solution is harmless to humans when handled, it is toxic to crown-of-thorns starfish when injected into their bodies, because they are unable to regulate their internal pH.

To be effective, household vinegar must be injected using a veterinary needle in a 20 mL dose at the base of the arm. As with the other injection solutions, the addition of a few drops of food colouring to the bottle will allow divers to see the solution underwater and ensure the injection was successfully delivered.

Vinegar has a long shelf-life and does not expire. If unused solution must be discarded at sea it should be disposed of in the same way as sewage under relevant Commonwealth and State legislation. Specifically:

- dilute the solution as much as is possible in on-board containers
- disposal to the marine environment must occur while the vessel is underway
- disposal can only start once you are more than one nautical mile (1.85 km) from the nearest reef, island, mainland or an aquaculture facility.

When injecting starfish with vinegar, it is important to administer the 20 mL dose in a slow and steady flow. For large starfish, two 20 mL injections of vinegar at opposite sides of the body are recommended.

Supplier

White household vinegar can be purchased at local supermarkets.

1.4 Multi-shot method (sodium bisulphate)

Sodium bisulphate (NaHSO_4), also called dry acid, is a white powder and is commonly used in swimming pools to balance the pH of the water. It should be stored in a dry, tightly closed container in a cool, well-ventilated area in accordance with the material safety data sheet. Like bile salts, sodium bisulphate can be an irritant when ingested, inhaled or if contact with skin or eyes occurs. Appropriate safety equipment including protective eyewear, clothing (such as gloves) and respiratory equipment (for example vapour and dust respirators) should be used to limit exposure in accordance with the sodium bisulphate [material safety data sheet](#)³.

³ Available at <https://www.sciencelab.com/msds.php?msdsId=9927267>

Mixing sodium bisulphate

Sodium bisulphate needs to be mixed with freshwater until the solution becomes saturated and no more sodium bisulphate can dissolve. This occurs when the sodium bisulphate remains at the bottom of the container. The recommended dose is two cups of sodium bisulphate to five litres of freshwater, and a few drops of food colouring. Once precipitation occurs (when the sodium bisulphate will no longer dissolve and excess remains at the bottom of the container) the right concentration has been reached. Be careful not to add too much, as the undissolved sodium bisulphate can obstruct the applicator. Close the lid, block the hose and shake the bottle until all powder is dissolved.

The sodium bisulphate solution can be used for approximately one month after it has been mixed with water. If disposing of unused sodium bisulphate solution at sea, it should be treated and disposed of in the same way as sewage, under the relevant Commonwealth and State legislation. Specifically:

- dilute the solution as much as is possible in on-board containers
- disposal to the marine environment must occur while the vessel is underway
- disposal can only start once you are more than one nautical mile (1.85 km) from the nearest reef, island, mainland or an aquaculture facility.

Remember...any control of COTS requires a permit and adherence to these guidelines.

Supplier

Sodium bisulphate can be purchased from chemical suppliers or pool suppliers.

Please note: No other injection solutions are endorsed for use to control COTS in the Great Barrier Reef Marine Park.

1.5 Equipment and maintenance for single and multi-shot methods

The equipment used to inject COTS consists principally of an applicator (the gun), a five-litre plastic bottle containing the injection solution and a hook (which can be used to house the applicator when not in use). Figure 1 shows the equipment the Association of Marine Park Tourism Operators (AMPTO) control team uses to inject COTS. Alternative types of modified drench guns have also been used effectively by researchers.

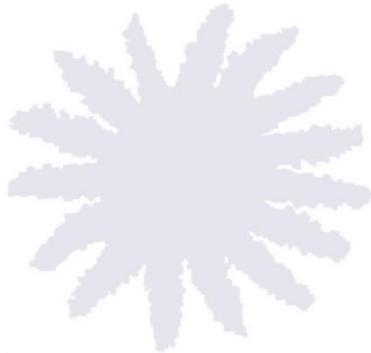


Figure 1 COTS cull kit including applicator, five litre backpack, spear and hook. © NJ Phillips

1.5.1 Applicators and their assembly

The Australian-based manufacturing company [NJ Phillips](#) has designed three purpose-built applicators for injecting COTS, and the equipment in these kits is specific to each injection chemical:

- The 10 mL bile salts applicator kit has been specifically designed by scientists, AMPTO and NJ Phillips for injecting bile salts. The kit includes a 10 mL applicator fitted with a spear that has a needle mount fitted at the tip. A veterinary needle needs to be mounted at the tip of the spear and these needles can be supplied with the kit.
- The 20 mL sodium bisulphate applicator kit can only be used for injecting sodium bisulphate. Because the solution is directly injected into the starfish through four small openings at the spear tip, the applicator does not require an additional veterinary needle.
- The 20 mL vinegar applicator kit is purpose-built for vinegar injections. The vinegar kit uses a combination of the parts used in the bile salts and sodium bisulphate kits. It includes the spear with needle mount that is used in the bile salts kit screwed into the 20 mL applicator used for sodium bisulphate. A veterinary needle needs to be mounted at the tip of the spear and these needles can be supplied with the kit.

Assembly

The assembly of these three applicators is almost identical. The main difference is that a sharp veterinary needle has to be mounted to the 10 mL bile salts and 20 mL vinegar applicators, whereas the blunt sodium bisulphate applicator already forms part of the gun.

Detailed instructions are provided with the products and there is also a [video](#) covering assembly and maintenance of the bile salts and sodium bisulphate applicators on [the GBRMPA YouTube channel](#). The vinegar applicator kit is not featured specifically in the video, although all parts that are included in the vinegar kit are shown. Pictures showing the correct assembly of applicator parts for all three kits are provided in Figure 2.

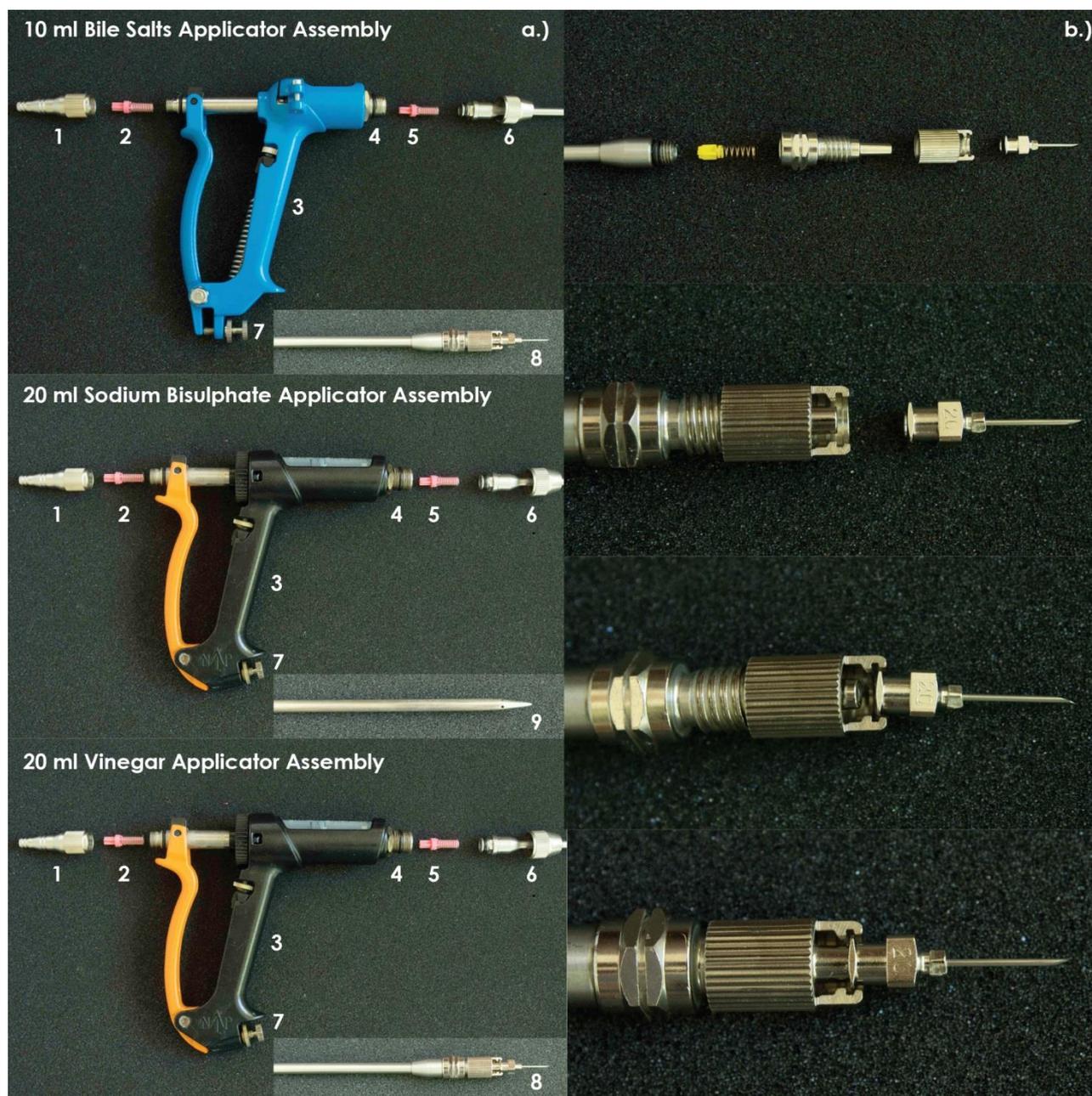


Figure 1 Assembly of the three applicators. a) 1: inlet adaptor, 2: inlet valve assembly, 3: hand piece, 4: delivery valve cage, 5: delivery valve assembly, 6: spear nut, 7: dose adjustor screw, 8: lock nut and veterinary needle, 9: tip of the spear of the sodium bisulphate applicator; b) Step-by-step sequence showing the correct assembly of the lock nut and the veterinary needle used in the bile salts and vinegar applicators. © Daniel Schultz

1.5.2 Bottle and hook

The bottle is a five-litre plastic backpack that needs to be attached to the diver in some way — how this is done is up to the control diver. One tried and tested method is to attach the bottle to the control person's weight belt with a rope. One end of the rope should be spliced to one side of the bottle; and the other end of the rope to a stainless steel clip (see Figure 3). In this way, the bottle can be easily attached and detached.

The applicator should be kept away from the body and/or placed in a protective sheath when not in use to reduce the likelihood of the diver spiking themselves or others in the water.

When filling the bottle, ensure it is not completely filled with the injection solution so that an air pocket remains. This allows the bottle to sit in an upright position when underwater. While the bottle holding the solution is interchangeable between methods, ensure the bottle is triple rinsed in fresh water between solutions to prevent cross-contamination.

If a pre-mixed solution of household vinegar is purchased for injections, it may be possible to screw this bottle directly onto the tube rather than using the five-litre plastic backpack.

To reduce impacts to corals and risks to the control diver, a hook device with a hollow handle is recommended (see example on page 5). The hook allows divers and/or snorkelers to pull COTS out from crevices without the need to touch the coral. It also provides stability when injecting and acts as a sheath for the applicator when not in use. The hook handle should be approximately 65 cm long to enable the entire spear to be housed inside the sheath.

An inexpensive hook can be made using electrical conduit, a cable tie and wire. An example of the rope attachment and hook is provided in Figure 3.



Figure 2 Hook and bottle with spliced rope and clip. © Daniel Schultz

1.5.3 Maintenance

The following steps should be carried out on the vessel after each day of diving to keep your equipment properly functioning for the longest time possible:

1. Remove the spear, needle and valve assemblies (delivery and inlet). Place all items into a container of water and vinegar (approximately one cup of vinegar to four litres of freshwater) and let it soak.
2. Flush the spear using a hose with a stream of water.
3. Leave the parts in the open air to dry.
4. Reassemble the applicator.
5. Lubricate the cylinder and piston with the lubricant provided in the kit.
6. Grease all screws and nuts.

Purchased kits and the how-to videos on [the GBRMPA YouTube channel](#) also contain detailed information on equipment maintenance.

2. Implementing a control program

2.1 Commitment, tips and training

What should be considered prior to commencing a control program?

Tourism operators, organisations or individuals who identify the need for a COTS control program at a site are encouraged to consider the following points to ensure the program is viable:

- the socio-economic and ecological value of the site
- whether a control program can be run successfully, based on the size of the site
- whether adequate resources (time, people and equipment) can be allocated.

Remember:

- Coral health surveys (Reef Health Impact Surveys (RHIS) need to be conducted regularly during and after the program to monitor success. It is recommended you use permanent reference sites so coral cover and diversity can be compared over time.
- Collecting and reporting control program data is important and an obligation under your permit.
- Cleared areas must be visited regularly (initially every four to five days) to 'mop up' starfish that were missed and any new starfish to the area.
- Effective control requires a multi-year commitment to reduce the COTS population to a level where coral reefs are able to cope and recover.

Photo by Daniel Schultz © GBRMPA



Useful information

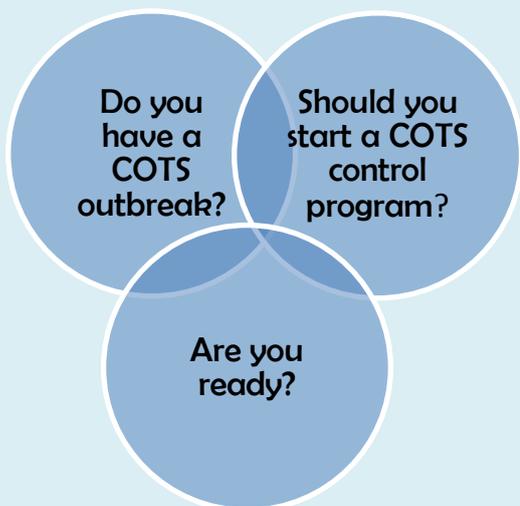
Prior to starting, ensure staff are familiar with these guidelines and trained to carry out COTS control. Experience makes a vast difference, as inexperienced divers will find less than five per cent of COTS at a site (Aiello 2006).

To eliminate duplication, conduct systematic searches and keep a large-scale map or aerial photograph recording the areas which have already been checked and the number of visits each time. Each site will require multiple searches to minimise the number of starfish missed.

Once affected sites are identified, the best method for locating and controlling individual starfish is through scuba diving or snorkelling. For the control program to be successful at managing an outbreak, all of the COTS in the affected area will need to be injected. Sites made up of patch reefs are more easily checked if several divers work around the sides of the patches at different depths.

COTS can be very cryptic and difficult to see, and tend to hide during the day time. Fresh scars on the coral clearly indicate that COTS are present, so look for these first. Efforts are best concentrated in a one-to-four-metre radius around the freshest scars, checking crevices in and under the reef. See section 2.6 for further details on searching.

A COTS control program is a multi-year commitment requiring finances and trained personnel. Contact GBRMPA for further information on training providers.

Checklist — before commencing a COTS control program (adapted from Aiello 2006)**DO YOU HAVE A COTS OUTBREAK?**

- Have you seen COTS scars at your site?
- Are COTS out in the open during the day?
- Are COTS clumping together in groups of more than two or three?
- Are you finding small and large COTS?
- Is there more than one COTS during a 20-minute swim?

SHOULD YOU START A COTS CONTROL PROGRAM?

- Do you have the capacity to support an ongoing program?
- Have you identified the most important site/s for protection?
- Do you have regular (weekly) access to your site/s?

ARE YOU READY?

- Do you have a permit to control COTS?
- Have participants been trained and read these guidelines?
- Do you have a detailed map of your site?
- Do you have the necessary equipment?
- Have you chosen your control method?

2.2 Permits and reporting

Permits to undertake COTS control can be obtained from GBRMPA. The name of the permission is '*A program to take animals or plants that pose a threat*'. Information on how to apply is on the [GBRMPA website](#). It should be noted that the standard application process may take at least two months.

A return of zero is an important result and it also needs to be recorded.

Please note: Undertaking a crown-of-thorns starfish control program may involve inherent risk. Permittees will be required to obtain appropriate insurance to cover their program and all participants, and indemnify GBRMPA.

As part of permit requirements, you need to submit your COTS cull data to GBRMPA in the format of the approved form, which is an Excel spreadsheet. The approved form

will be provided to you to record this information on every COTS control dive. It is important this data is accurate as it is used by GBRMPA and the Queensland Parks and Wildlife Service for management purposes. Reporting requirements are included in permit conditions

2.3 Health and safety

COTS have hundreds of long needle-like toxic spines covering their bodies and arms, presenting a health threat to people who interact with them. Individuals undertaking COTS control activities need to take suitable precautions to avoid being spiked and should be instructed on the appropriate first aid treatment.

Most injuries to humans from COTS occur on the hands and feet. Symptoms range from intense pain (which may last several hours), through to nausea and vomiting. Frequently, the area around the puncture turns a dark blue and begins to swell. The swelling may persist for a number of days. Where the victim has suffered multiple wounds, the whole limb may stiffen and swell. In these cases, the patient may experience numbness around the wound(s) and the swollen area may become extremely itchy. Some victims may also respond in an allergic manner (Moran 1988). Persons affected by a spiking should immediately advise their supervisor and/or others on the control team and, if necessary, seek medical assistance.

Precautions should always be taken to minimise the risk of contact with COTS spines, particularly as the toxins can bio-accumulate. Ideally, divers should cover their skin as much as possible by wearing full wetsuits, gloves, booties, hoods and face masks. AMPTO has been undertaking a COTS control program for many years and, as a precaution, will not allow control divers to participate in the program if they have been spiked twice.

It is not known what effect injections of bile salts, vinegar or sodium bisulphate would have on humans, so ensure the spear tips and needles are covered when not in use, especially during entry and exit from the water.

2.4 Outbreaks and outbreak indicators

COTS are natural inhabitants on coral reefs, typically occurring at very low densities (less than one starfish per hectare) (Moran 1986; Baird et al. 2013). A COTS outbreak occurs when their density is at a point where their feeding rate exceeds the typical long-term average growth rate of coral (Fabricius 2013).

COTS outbreaks represent the most significant biological disturbance on tropical coral reefs throughout much of the Indo-Pacific region. For example, on the Great Barrier Reef it is estimated that of the 50 per cent decline in live coral cover over the past 27 years, approximately 42 per cent of that loss was due to COTS (De'ath et al. 2012).

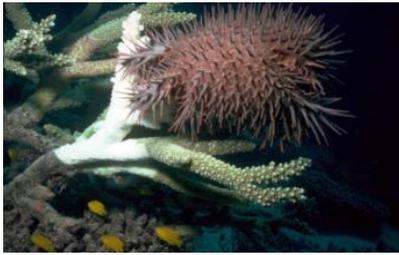
There have been four major outbreaks on the Great Barrier Reef since the 1960s (each starting in the 1960s, late 1970s, early 1990s and 2010) and the time between the start of each outbreak has been 15–17 years. The fourth and current outbreak began in 2010.

Densities

Keesing and Lucas (1992) estimated 10 to 15 COTS per hectare could be sustained in areas with 20 to 50 per cent coral cover. Generally, if you see more than 15 starfish per hectare (that is, two starfish per 20-minute swim) then the density has reached an outbreak level.

For management purposes, GBRMPA considers a catch per unit effort of 0.05 (the number of COTS killed per minute) as an active outbreak when coral cover is below 40 per cent. When coral cover is above 40 per cent, a catch per unit effort of 0.1 is considered an outbreak. Control efforts should endeavour to keep COTS below this threshold. An example on how to calculate catch per unit effort is included in Section 2.5.

The following signs indicate a COTS outbreak has begun or is underway at a reef, and that control measures might be appropriate:



1. There are COTS feeding scars (bare coral skeleton with all the tissue removed). Fresh scars will appear snow white in colour, with details of the skeletal structure of the coral still visible.



2. COTS of different size are present, including juveniles (size of your hand) and adults (larger than the size of your hand).



3. Generally, when snorkelling or diving, more than one COTS is sighted every 20 minutes.



4. COTS are aggregating in large numbers.

2.5 Planning and executing your dive

Dive brief

When planning a control dive, pre-define the area that you want to cover. Tools such as maps, Google Earth spatial outputs and a portable handheld global positioning system (GPS) can be useful for this, to allow quantitative comparisons over time. In general, divers should be able to cover a distance of approximately 400 metres in a 40-minute dive, however this may vary, depending on factors such as COTS density, weather and tidal conditions, and sea state. It is important to

The bottle combined with the weight belt can be cumbersome and heavy. Assistance should be given to support the diver/snorkeler exit from the water.

note entry and exit points of each dive with a GPS to avoid overlapping surveyed areas and to accurately record areas where COTS control has occurred. It is best not to revisit the same area within three to four days, so as to allow enough time for fresh scarring to fade. This will prevent divers searching for COTS that have already been injected.

Before entering the water, ensure all participants are aware of the approved dive plan. To avoid COTS being injected twice by different divers and to maximise the area being covered on each dive, it is imperative that divers swim next to each other, keeping a horizontal line, approximately five metres apart. This is especially important when using the applicators fitted with veterinary needles, as the injection scar is so small that it becomes difficult to differentiate between injected and non-injected COTS. When COTS numbers are particularly high, turn COTS over after they are injected to avoid this issue.

In most cases, COTS start moving and retreating into crevices once injected. As a result, an increase in activity indicates a starfish has been injected. However, un-injected COTS have also been observed to start moving once adjacent starfish have been injected.

Dive entry

Steps to take once the injection solution has been prepared on board the vessel:

1. The control diver should attach the bottle of solution to their weight belt (or preferred alternative position). Ensure enough weight is carried, as the bottle increases overall buoyancy.
2. Attach the hose to the applicator.
3. Place the applicator into the hook or some other protective sheath to ensure it is kept away from the body.
4. Enter the water, ensuring a firm hold on the applicator and hook.
5. Once underwater, prime the applicator (squeeze it several times under the water) until the cylinder is full with solution and contains no air bubbles.

Dive exit

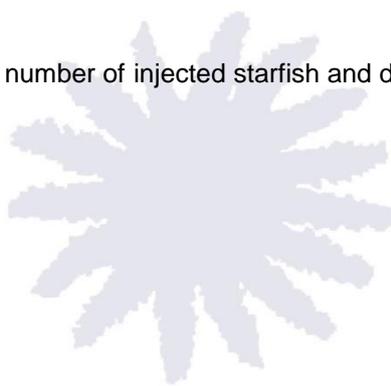
Follow these steps at the end of the dive, when you are ready to ascend:

1. Remove the hose from the applicator.
2. Tie a knot into the hose (this prevents seawater from compromising the solution).
3. Place the applicator into the hook.
4. Pump the trigger until the coloured solution is flushed out.
5. On board the vessel, record details of the cull efforts, in accordance with permit reporting requirements.
6. Maintain the equipment as outlined in Section 1.2.3.

What is catch per unit effort and how do I calculate it?

The catch per unit of effort is calculated by adding up the total number of injected starfish and dividing the figure by the total dive minutes. See example below.

<i>COTS control dives on Roxy's reef — Site 1 — 17/05/14</i>		
Dive Number	Total dive minutes (all divers)	Total number of starfish injected (all divers)
1	240	55
2	440	121
3	160	99
4	320	420
TOTAL	1160	750



Catch per unit effort is $750/1160 = 0.65$ (rounded up to two decimal places)

2.6 Searching and injecting

Search techniques

An [in-water video](#) detailing all technical aspects of this section can be viewed on [the GBRMPA YouTube channel](#).

To increase your success rate, look for the scars not the animals!

As mentioned previously, it is important that all participants keep to the pre-defined plan, swimming in a line next to each other and not behind each other.

COTS are generally cryptic during the day, making them difficult to find. Their spines and colour can match their surroundings perfectly, especially when hiding at the bases of staghorn corals.

When searching for COTS, it is more efficient to search for feeding scars (see Figure 7) than the COTS themselves:

- Fresh scarring is bright white and the fine detail of the coral skeleton is still visible. When scarring is just a few hours old, you may be able to see thin threads of mucus still attached to the coral. In general, COTS can be found within five metres of the scar. Look around, especially in crevices, underneath plate corals and at the bases of staghorn corals.
- Older scarring appears yellowish-brown in colour, as it has been overgrown by algae. In general, the older the scarring, the darker the colour and the harder to distinguish the details of the coral skeleton. When you see old COTS scarring, try to find more recent scarring in the surrounding area. If there is no fresh scarring, it is likely the COTS have already left the area.

The stomach of a COTS is about the size of its central disc, so the size of the scar is a good indication of the size of the COTS present. Large areas of scarring may indicate more than one COTS is present.

COTS scarring may be confused with *Drupella* snail scarring, diseases (for example, white syndromes and brown band disease) and/or coral bleaching. However, they may also be simultaneously present on diseased corals or corals which are infested with *Drupella*. For more information on how to differentiate between *Drupella* scarring, diseases and coral bleaching, see Beeden et al. (2008).

Injecting COTS

The placement and number of injections depend on the injection solution used.

- Bile salts require a single-shot injection. However, two injections are needed for COTS larger than 40 cm. The injection is best placed at the base of the arm. If this can't be reached, the injection can be made elsewhere, however it will take longer for the starfish to die. For juveniles, the injection is best placed in the central disc. Trials have indicated some starfish can expel the solution when injected into the central disc.
- Household vinegar requires a single-shot injection, or two injections for COTS larger than 40 cm. The injection should be placed at the base of the arm. Effectiveness may decrease when injections are placed in the central disc or middle of the arm.
- Sodium bisulphate: Multiple injections need to be placed in the central disc of the starfish, spaced at approximately 3 to 4 cm from each other. If you can't access the entire central disc, try to bring the COTS out in the open with your hook. Otherwise, try to inject it in as many different places as possible. When COTS are less than 8 cm in size it may be easier to directly collect them with tweezers or tongs for later disposal. This is not recommended for starfish greater than 8 cm in diameter. For COTS that are the size of a dinner plate (about 25–30cm) you will need to perform 12–15 injections; those larger than a dinner plate will need at least 15 injections, and up to 25 if particularly large.

When injecting a starfish always ensure the needle does not go through the starfish. You should also take care to pull the trigger gently to allow the full dosage to be injected into the starfish's body. Once injected, starfish generally die within 24 to 48 hours. Starfish injected with sodium bisulphate tend to decompose more quickly than those injected with bile salts or vinegar.

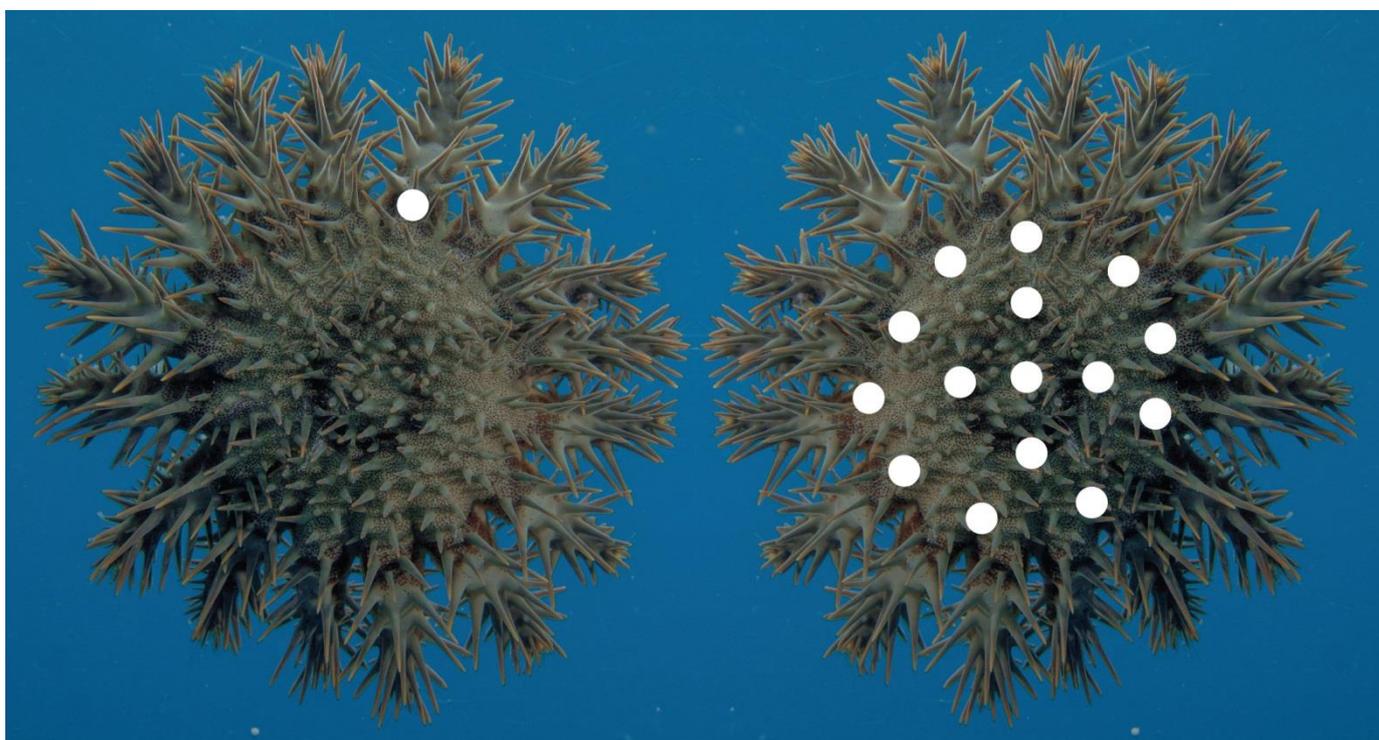


Figure 3 Injection placement (white dot/s) for use of bile salts and vinegar (left) and sodium bisulphate (right). © Daniel Schultz

3. Biology and ecology

COTS occur naturally throughout the Indo-Pacific region. Like all starfish, sea urchins, sea cucumbers, feather stars and brittle stars, they belong to the phylum Echinodermata (from Greek: *echinos* meaning hedgehog and *derma* meaning skin).

3.1 Anatomy

COTS are multi-coloured and can range in colour from purplish-blue with red tipped spines, to green with yellow-tipped spines. Adults have a varying number of arms (generally 14–18; and up to 21) and may shed arms when stressed. They can also lose them to predators, however they are able to regrow arms in about six months (Moran 1988).

The mouth of the starfish is located on the lower side of the body in the centre of the disc. Grooves radiate from the central disc to the tip of each arm. Within each groove there are two rows of retractable tube feet (see Figure 5). Mobile spines run along the edges of the grooves.

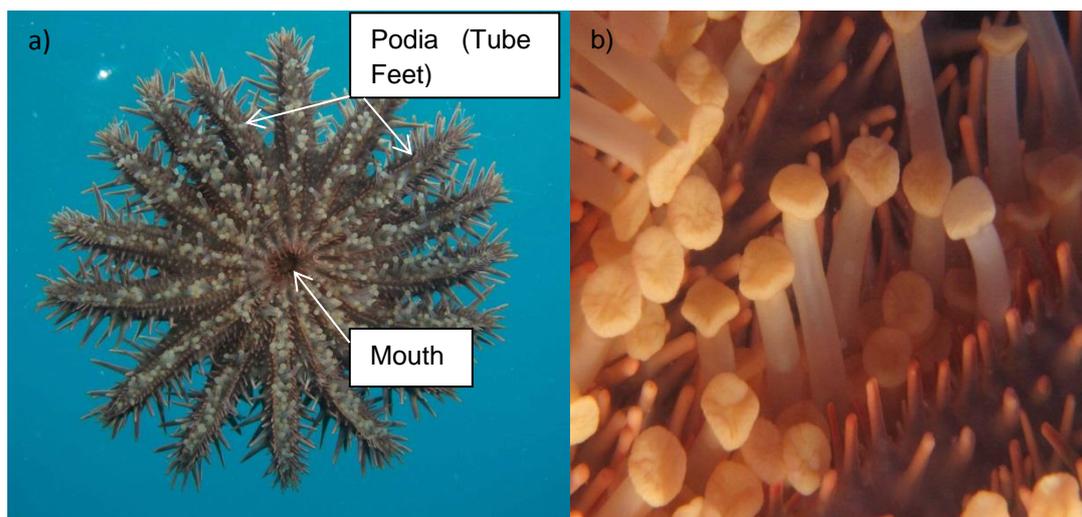


Figure 4 a) oral side © Daniel Schultz; b) close-up of feet © Jennifer Wilmes

Although COTS normally range in size from 25 to 35 cm in diameter, individuals as large as 80 cm have been found. As with most echinoderms, the size is determined by what they eat, food availability and their population levels (Moran 1988).

3.2 Habitat

COTS seem to prefer to live in sheltered areas such as lagoons, and in deeper water along reef fronts. They generally avoid shallow water on the tops of reefs where the water conditions are likely to be more turbulent. Occasionally they may feed in these areas, particularly when the weather is calm (Moran 1988). During major outbreaks it is important to search all habitat types.

3.3 Predators

While large individuals appear to escape predation due to their long spines and body size, the cryptic behavior of small individuals during the day suggests predation may be higher in juveniles (Birkeland and Lucas 1990).

The predators most commonly observed to feed on COTS are: triton's trumpet, the starry and white spotted puffer fish, two species of triggerfish (titan triggerfish and yellow margin triggerfish), the harlequin shrimp and the lined fireworm (see some examples in Figure 6). Each has been recorded to feed on juveniles and small adults (Moran 1988).

The role of these predators in regulating COTS populations is not well understood (Pratchett *et al.* 2014), however evidence suggests that reefs where predators of COTS are protected in no-take marine reserves are less prone to COTS outbreaks (Sweetman 2008).

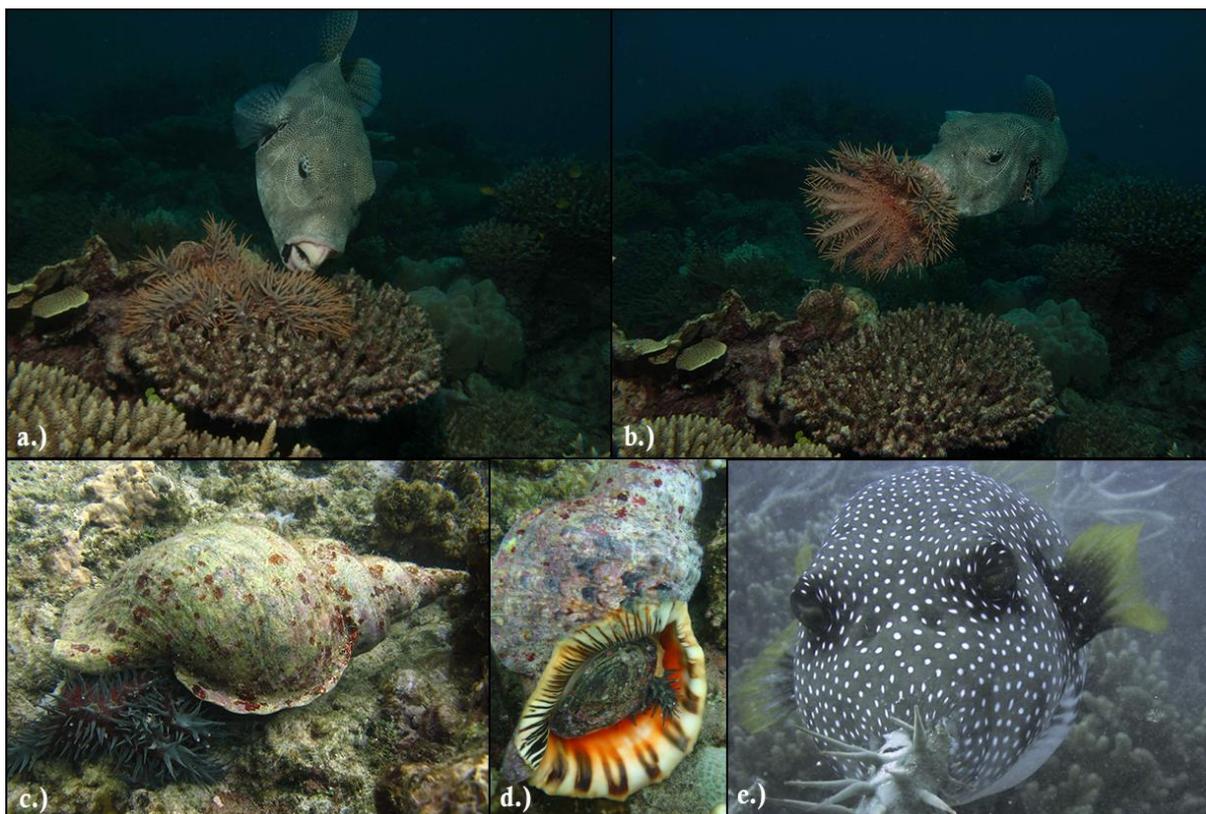


Figure 5 COTS predators a) and b) starry pufferfish, c) and d) triton's trumpet, e) white-spotted pufferfish. © Daniel Schultz

3.4 Feeding behaviour and preferences

COTS are well known for their ability to alter coral community structure by preferentially feeding on certain species of hard corals (scleractinian corals). Adults almost exclusively feed on scleractinian corals (90–95 per cent). The main non-scleractinian food items are soft corals, zoanthids and coralline algae. Non-coral prey is taken in, thereby increasing abundance in areas of low coral availability (Keesing 1990).

To feed, COTS turn their stomach outwards through their mouths, spreading it over the surface of the coral using their tube feet. After about four to six hours of feeding, the starfish moves on, leaving behind a white feeding scar of exposed coral skeleton (Fabricius 2013).

Figure 7 shows a number of new (bright white) and old (yellow-brown) COTS feeding scars on a variety of corals.

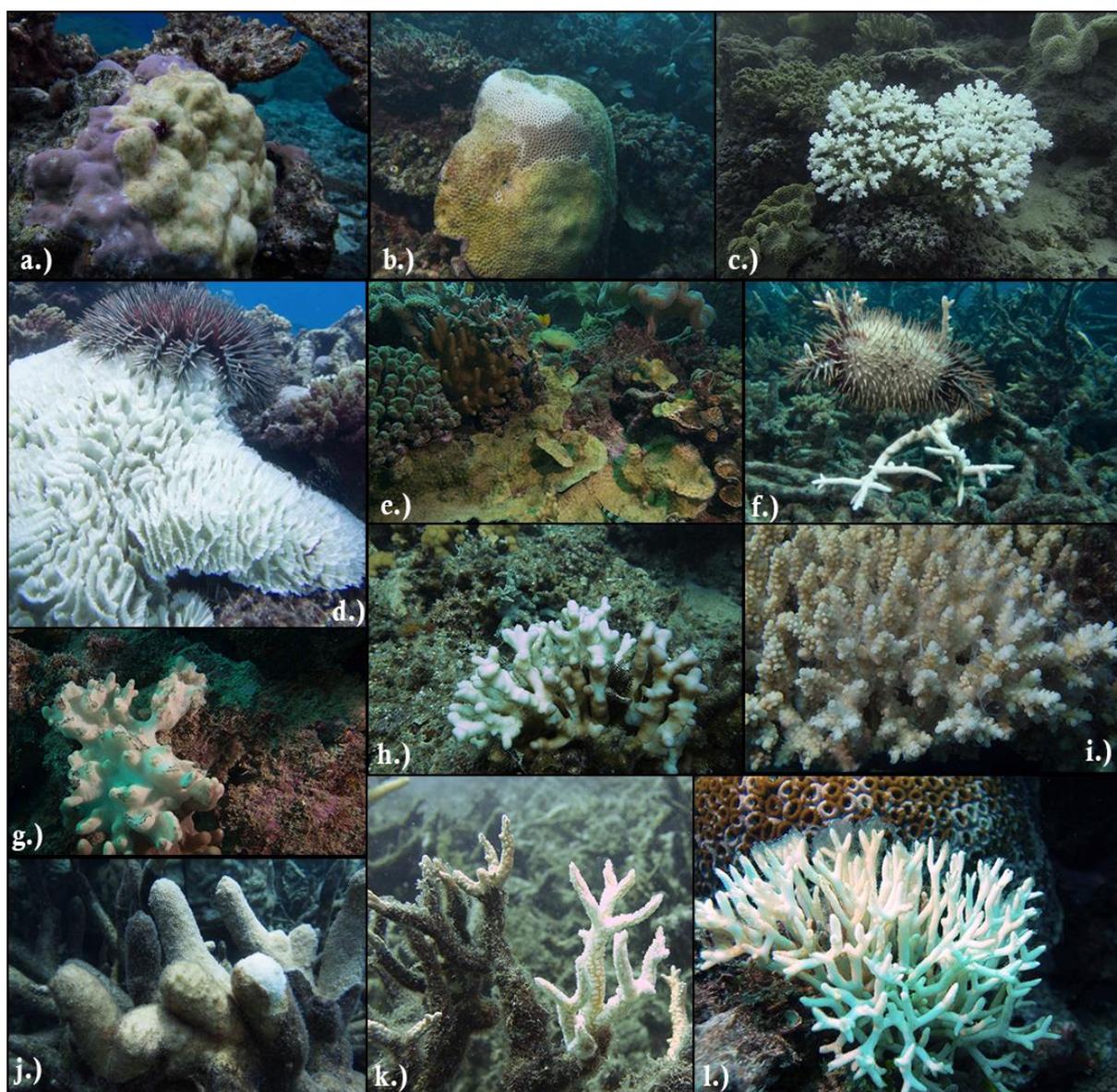


Figure 6 Old and fresh feeding scars on different species of coral. Old and fresh COTS feeding scars on: a) *Porites sp.*, b) *Goniastrea sp.*, c) *Pocillopora sp.*, d) *Pectinia sp.*, e) *Echinopora sp.*, f) *Acropora sp.*, g) Soft coral, h) *Stylophora sp.*, i) *Acropora sp.* with thin threads of COTS mucus, j) *Isopora sp.*, k) *Hydnophora sp.*, l) *Seriatopora sp.* © Daniel Schultz.

During the planktonic life stage, COTS larvae feed on phytoplankton. Once larvae settle, they change into juvenile starfish and start feeding on crustose coralline algae (the pinkish cement-looking cover on coral rubble/rocks). About four to six months after spawning, the starfish gradually starts feeding on scleractinian corals (refer to Figure 8).

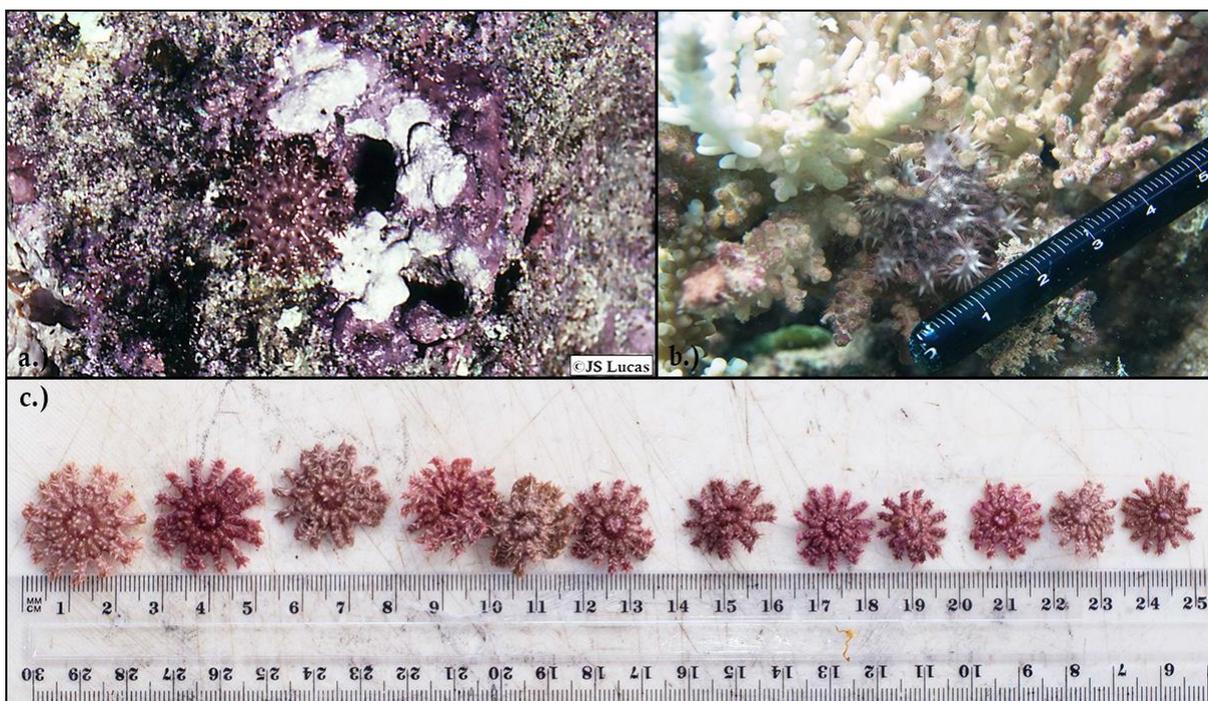


Figure 7 a) Juvenile COTS feeding on crustose coralline algae © JS Lucas, b) Juvenile COTS feeding on coral (*Acropora* sp.) © Daniel Schultz, c) COTS juveniles found feeding on coral © Daniel Schultz

Small adult starfish (less than 20 cm) are highly cryptic during the day, emerging to feed only at night. Large starfish (40 cm or greater) feed during the day and show little tendency for cryptic behavior (Moran 1988) (Keesing 1990). Intermediate-sized starfish show a varied response suggesting they have a transition period (Keesing 1990). Keesing (1990) has suggested the observed behavior has evolved as a predator avoidance strategy, with large starfish achieving a refuge through their size.

COTS feeding rates are dependent on starfish size and season. Rates are greatest before the summer spawning season. Keesing (1990) calculated the average feeding rate in winter as 66 cm² coral per day (for COTS 20–39 cm), and 478 cm² coral per day in summer (COTS at 40 cm or more). The reduced feeding rates in winter are thought to be related to water temperature.

3.5 Reproduction and lifecycle

COTS reproduce sexually. During spawning, females shed eggs into the water column; sperm released from nearby males then fertilise the eggs. Both male and female starfish normally adopt a bell-shaped posture during spawning (Moran 1988).

Fertilisation may be synchronised among small aggregated groups of starfish. A chemical compound (pheromone) has been isolated from spawning females; this is thought to induce males close by to release sperm. Synchronisation and aggregation of spawning starfish are likely to be extremely important in promoting increased fertilisation of eggs and settlement of large numbers of larvae. Scientific studies have found disproportionate increases in fertility as the size of COTS increases. A large female starfish (about 40 cm in diameter) may produce up to 65 million eggs per season (Conand 1984, Kettle and Lucas 1987), while starfish less than 30 cm in size may produce 0.5–2.5 million eggs per year (Kettle and Lucas 1987).

Consequently, a very small increase in the survival rate of larvae (for example two per cent) can result in a big increase in the adult population (for example, two per cent of 60 million equals 1.2 million adults) (Moran 1988). Of note though is the high mortality of juvenile COTS, thought to be approximately 99.3 per cent for those aged 8–23 months (Zann *et al.* 1987), and approximately 75 per cent for starfish aged 22–34 months (Doherty & Davidson 1988).

The spawning season for COTS on the Great Barrier Reef is from October to February (with a peak in December) when warm water temperatures coincide with a high probability of monsoonal rainfall. It is not known whether the individual starfish spawn at regular intervals, or only once during this period (Pratchett *et al.* 2014). To improve management responses, GBRMPA is working with researchers to determine this and other knowledge gaps.

A diagrammatic representation of the COTS life cycle is shown below in Figure 9.

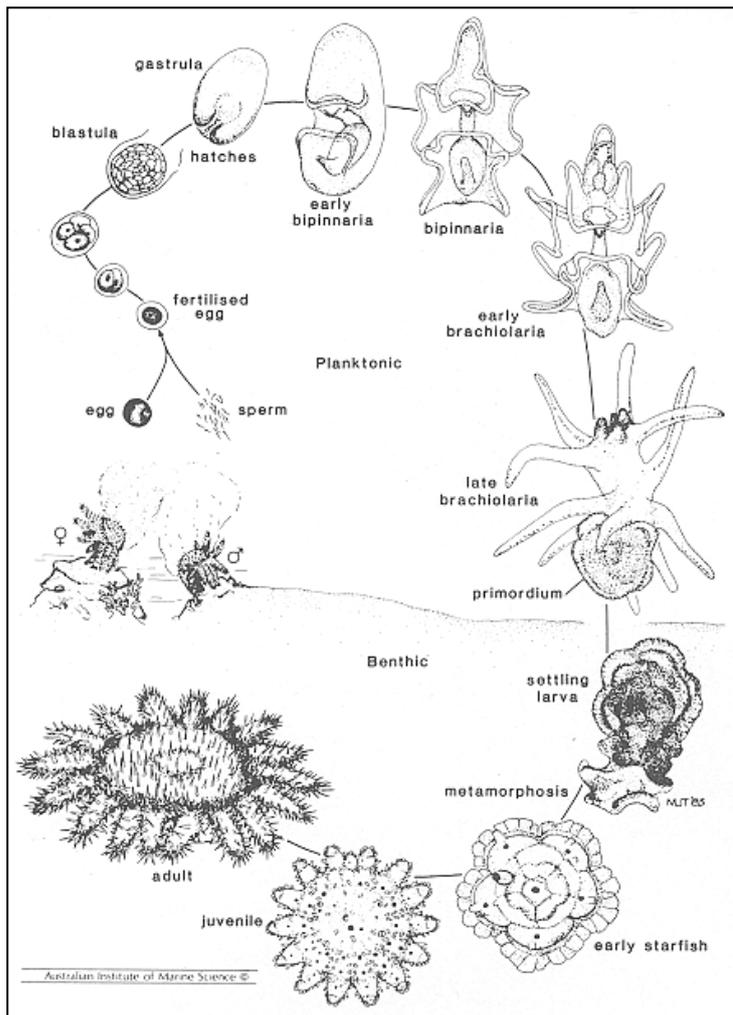


Figure 8 Diagrammatic representation of the life cycle of the crown-of-thorns starfish (as illustrated in Moran 1988).

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