



# AUSTRALIAN INSTITUTE OF MARINE SCIENCE CROWN-OF-THORNS STARFISH RESEARCH STRATEGY

**Britta Schaffelke and Ken Anthony**

*Version: 3 July 2015*



**Australian Government**



**AUSTRALIAN INSTITUTE  
OF MARINE SCIENCE**

AIMS: Australia's tropical marine research agency.

---

## BACKGROUND

The Crown-of-Thorns Starfish (COTS) is a natural predator of corals in the Indo-Pacific region, including the Great Barrier Reef (GBR). COTS have been identified, together with cyclones, as a major cause of 50% decline in coral cover on the GBR observed during the last 27 years (De'ath et al. 2012). Since the 1960's, COTS populations have erupted at approximately 15-year intervals with three major outbreaks recorded and a fourth now in progress on the northern GBR. When COTS occur in plague proportions they can reduce the living coral cover on a reef to a few percent. Full recovery from such severe disturbances requires at least two decades free of all major disturbances (e.g. cyclones, coral bleaching, more COTS, e.g. Halford et al. 2004; Emslie et al. 2008). The causes and consequences of COTS outbreaks have received much research attention since the mid-1980 and a recent review by Pratchett et al. (in press) summarises the current state of knowledge.

Prediction based on GBR long-term monitoring data by AIMS shows that coral cover on the GBR would have increased since 1985, rather than declined by 50%, had there been no COTS outbreaks during that time (De'ath et al. 2012). Consequently, controlling COTS is one of the greatest immediate challenges facing managers of the GBR, and identifying management solutions to the COTS problem should be a national priority if Australia is serious about conserving this unique coral ecosystem that is recognized by World Heritage status.

In July 2012, in response to evidence of a new outbreak emerging in the northern GBR, an international workshop was held on Fitzroy Island involving 40 participants to discuss the COTS threat to the GBR and to recommend priority actions to address this threat. The workshop agreed on a consensus statement declaring "Urgent Action Required on COTS Outbreaks on the Great Barrier Reef".

The priority actions agreed at the Fitzroy workshop were: more targeted surveys to prioritise interventions, improvements of existing hand control methods, new research to find effective, safe and socially acceptable methods of population-level control, and decision support tools to optimise any and all responses. The workshop also highlighted a number of important knowledge gaps that should guide future research:

- Collate all current knowledge and facilitate improved data mining
- Develop novel proxies for monitoring COTS abundance (e.g. chemical signals; ROVs, AUVs; rapid plankton assays based on genomics)
- Understand priority sources of key nutrients in the GBR
- Update knowledge of the larval ecology of COTS, especially their response to flood plumes
- Model population dynamics to determine the cause(s) of outbreaks, and find the weakest link in their complex life cycle
- Develop a mechanistic understanding of green zone impacts on COTS
- Determine the social and economic impacts of uncontrolled outbreaks on the tourism industry

Given the growing evidence that a fourth cycle of COTS outbreaks has started in the northern GBR, a renewed strategy for COTS research at AIMS has been developed and is presented in this document. The strategy is based on an analysis of critical knowledge gaps at multiple levels (environment to cellular), and brings together the skill and experience within AIMS to address most of these gaps. The strategy provides a road map to prioritise and coordinate research within AIMS towards effective management of, and potentially solutions to, the COTS problem. It also presents research topics that AIMS wishes to undertake in close collaboration with partner institutions.

---

## RATIONALE AND SCOPE OF THE AIMS COTS RESEARCH STRATEGY

Tackling the COTS problem on the GBR requires an approach different from the one that has clearly failed the GBR over the last 30 years. As a multidisciplinary marine science institution with 40 years of experience in GBR research, AIMS is highly motivated to solve the COTS problem but knows the difficulty of finding enduring solutions. The ideas advanced below are (i) to inform the research and management community of our intentions, and (ii) to invite collaborations and partnerships with researchers and other stakeholders.

The AIMS COTS Strategy is structured around our current knowledge of what factors drive COTS outbreaks on the GBR. This provides a framework for identifying key knowledge gaps and priority research areas. The Strategy considers alternative hypotheses and assesses the role of uncertainty in COTS outbreak predictions and diagnostics. A particular objective of the Strategy is to identify processes where strong predicted or observed responses are associated with high uncertainty. These will be primary targets for intensified research.

AIMS is currently (2013/14) investing AUD 1.9million in COTS-related research and receives ~AUD 800k in funding from the Australian Government (NERP and Reef Rescue Programs). The Strategy assumes substantial additional funding matched by increased co-investment from AIMS. The COTS Research Strategy will assist in developing and prioritizing this ongoing and future research.

---

## CONCEPTUAL MODEL OF COTS ON THE GBR

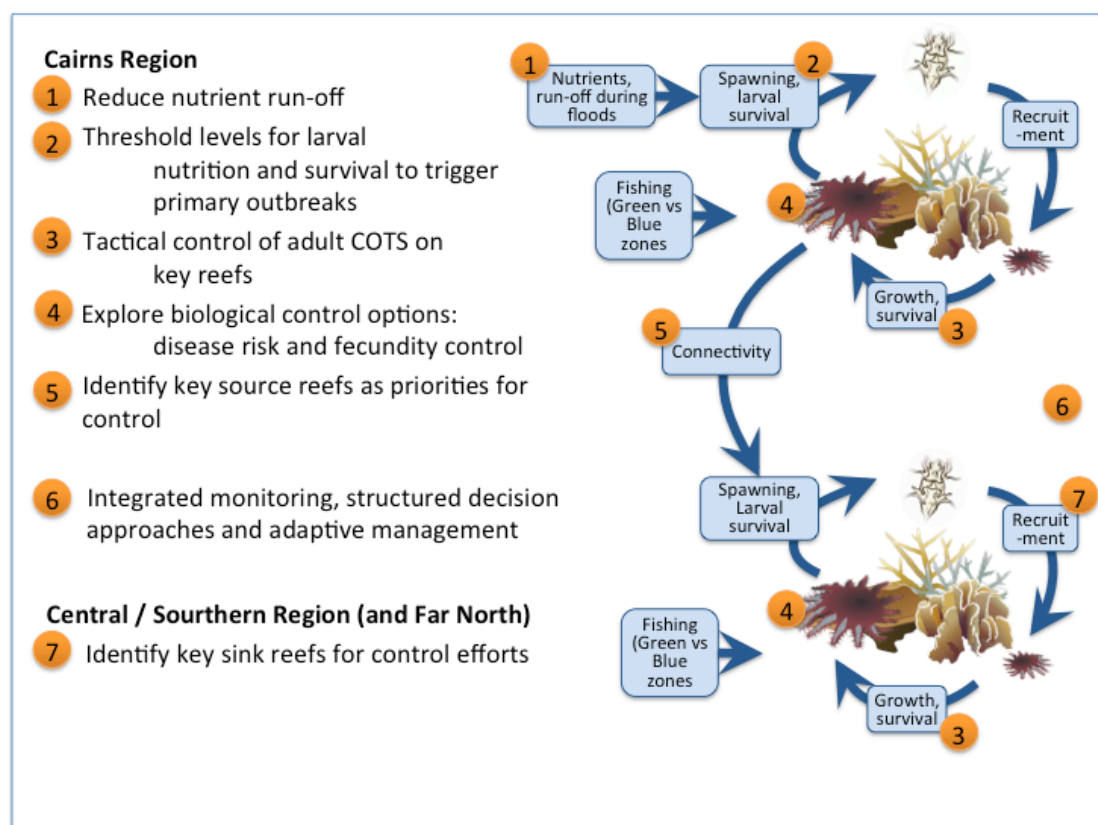
We use a diagrammatic model of the complex processes that control COTS populations on the GBR (Fig. 1) as a roadmap for our research. Within this conceptual model we populate each element with candidate hypotheses, their alternatives and uncertainty/confidence around each hypothesis.

The GBR is vulnerable to COTS outbreaks partly because of the size and connectedness of the system (Hock et al., in review; Bode, 2006). To fully understand the COTS outbreak phenomenon and to identify how best to intervene requires consideration of (a) the proximate drivers leading to the initiation of a primary outbreak – i.e. larval nutrition,



survival and recruitment, (b) demography and predator-prey relationship in the outbreak region, (c) stock-recruitment relationships of the local outbreak populations, (d) larval connectivity to reefs downstream, and points b-d considered across the network of reefs downstream.

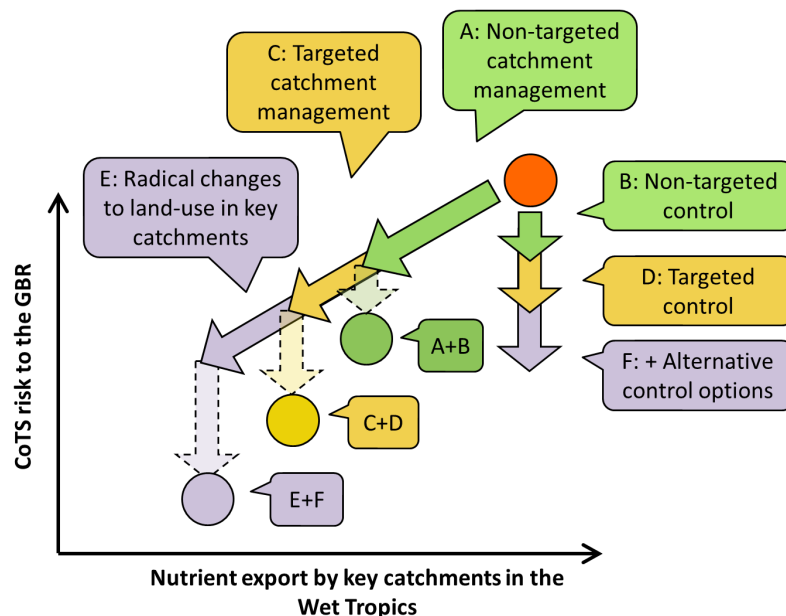
Research conducted by AIMS and collaborators suggests that phytoplankton blooms in reef waters, fuelled by the excess nutrients carried in flood plumes, can initiate COTS outbreaks on the northern GBR (Fabricius et al. 2010). The four outbreak waves in the GBR since the 1960s all followed extreme floods of the Burdekin River and the rivers along the Wet Tropics coast, in particular the Russell-Mulgrave (Furnas et al. 2013). A new outbreak is currently underway in the Cairns Region and is expected to progress southward under the influence of regional southerly currents over the next few years, progressively infesting mid-shelf reefs in the central and southern sectors of the GBR. While the nutrient-limitation hypothesis is currently the best explanation for the occurrence of COTS outbreaks, sources of nutrients other than land runoff may also be important, such as shelf-break upwelling, but these are not yet well understood. The key knowledge gap here is to develop balanced nutrient budgets at shelf-scale.



**Fig. 1.** Conceptual representation of the processes controlling COTS populations on the GBR. Numbers refer to individual projects/actions focusing on vulnerable life stages or processes. AIMS logos identify projects underway or emerging (shaded) within AIMS.

While direct impacts of climate change and water quality are important environmental concerns for the GBR, COTS outbreaks on the GBR are likely to be facilitated and exacerbated by impaired water quality, in particular in the N-GBR. Given that COTS are responsible for a large proportion of the loss of coral cover in the central and southern GBR over the past decades (De'ath et al. 2012), breaking the likely causal link between water quality and COTS primary outbreaks is a management priority (Brodie et al. 2013, Schaffelke et al. 2013). This priority is recognized by ReefPlan (Anon. 2013), which is a joint action by the Australian and Queensland Governments investing hundreds of millions of dollars to halt and reverse the decline of water quality entering the GBR lagoon from broad-scale agriculture. However, the time lag between investing in changed land-use practices and reduced incidence of COTS outbreaks may be measured by decades rather than years (Brodie et al. 2012).

Tackling the COTS problem effectively is therefore likely to involve a combination of targeted land-use management and tactical control of COTS on reefs that are either key source reefs or priority sink reefs, or both. Optimising the combination of management options through structured decision-making is a promising solution to the COTS problem now and in the future (Fig. 2), effectively using an integrated pest management approach.



**Fig. 2.** Hypothetical investment strategies and outcomes for different management alternatives to address COTS on the GBR. Investment into non-targeted catchment management (A) and non-targeted control (B) can potentially suppress COTS risk. More focused management in catchments with strong linkages to primary source reefs in the Cairns region (C) in combination with more targeted control on reefs that function as connectivity gateways (D) is likely to reduce COTS risk faster. Lastly, depending on the predicted effectiveness of actions A to D, more radical changes in land-use management (e.g. buy-back of cane farms, E) and alternative interventions such as biological control of COTS (F) can be considered.

---

## RESEARCH PRIORITIES

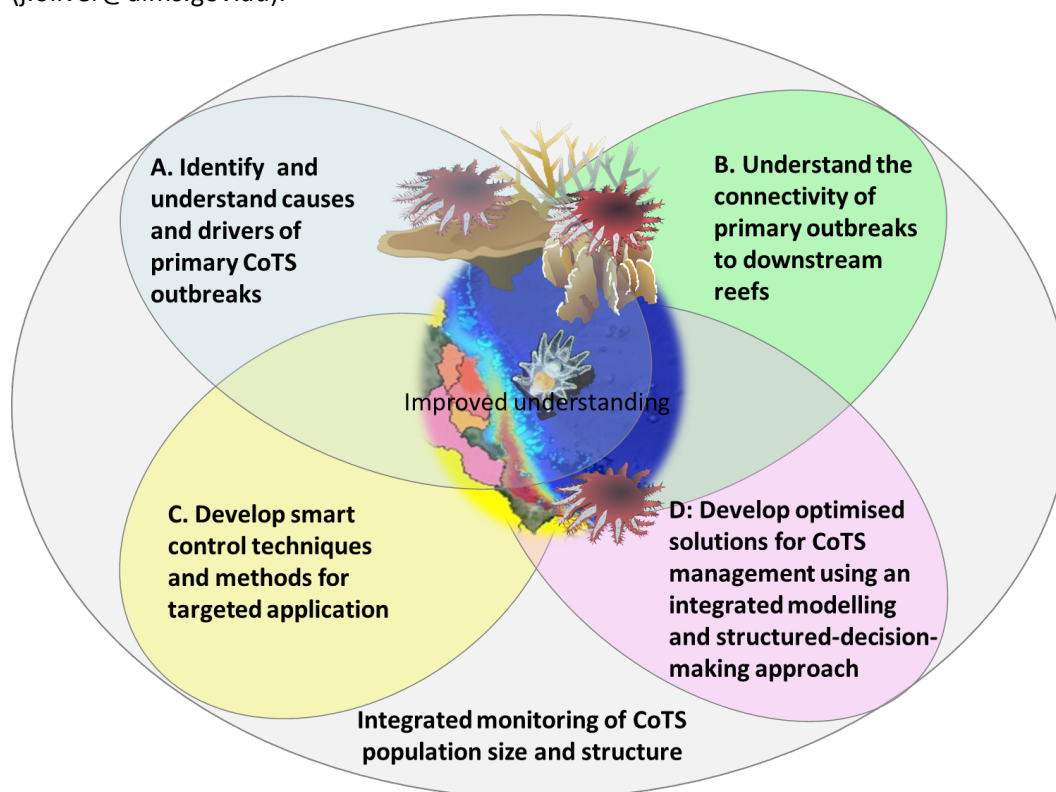
Reef Managers recognize that improving water quality will deliver many long-term benefits to the health of the GBR. However, improved targeting of water quality interventions - to reduce nutrient loads from catchments that are most likely to drive COTS outbreaks - would likely provide a more immediate and significant benefit for the GBR. R&D focused on supporting such targeting is thus a priority. A key requirement is also improved understanding (and reduced uncertainty) around of the root causes of initial COTS outbreaks and the processes involved.

Since the Fitzroy workshop (see Background), the efficiency and efficacy of the approved method for diver-based hand control of COTS has been improved radically by the introduction of more effective chemicals that have increased kill rates by almost an order of magnitude. Currently, the industry-led COTS control program is being directed to hotspots of starfish abundance by a broad-scale survey program conducted by the Field Management Program (a joint action of GBRMPA and QPWS) but this is both highly consumptive of resources and competing with other FMP priorities. Consequently, it would be beneficial to develop alternative ways to detect COTS outbreaks without deploying divers, especially if patterns could be predicted through informed and validated modelling.

Solving the COTS outbreak problem on the GBR will require a multifaceted strategy (Fig. 3) that (A) identifies root causes of primary outbreaks, (B) maps connectivity among reefs to identify larval sources, sinks, bottlenecks, and highways; (C) develops new control technologies and methods for a more targeted application and (D) develops predictive models of COTS population structure that support adaptive management.

Table 1 summarises projects aligned with this roadmap that are either underway or proposed by AIMS scientists. Potential partners interested in collaboration should send expressions of interest to the AIMS Research Director: Dr Jamie Oliver

(j.oliver@aims.gov.au).



**Fig. 3.** Overview of AIMS COTS Strategy.

**Table 1.** Priority areas for AIMS COTS research.

\* identifies research areas already underway or commencing in 2013/14.

Research area	Approach	Outcomes
<b>Causes and drivers of outbreaks</b>		
Broad-scale reef monitoring including COTS*	AIMS LTMP	Situational awareness and record of COTS impacts on reefs
Quantify COTS larvae in plankton*	Genetic marker development, in situ sampling	Rapid assessment of plankton samples for presence of COTS larvae
Larval development and survival*	Process studies, SeaSim experiments	Link food and environment with COTS larval survival
Flood plume studies	In situ, SeaSim experiments	Link flood plumes with COTS larval survival
<b>Control measures</b>		
COTS population size estimates*	In situ surveys, statistical analyses and modelling	Assess efficacy of manual control options
COTS (coral, feeding scars) detection in benthos	Innovative robotics and object recognition techniques	Rapid mapping of COTS densities in areas deeper than safe for sustained diving (>10 m)
COTS attractants/repellents*	COTS genome sequencing, Analyses of secretome, SeaSim studies of COTS behaviour	New control techniques
Integrated biological control*	COTS-specific pathogens tested	New control techniques

	experimentally under stringent control, identifying vulnerable COTS life stages for potential biological control	
<b>Downstream risks</b>		
Modelling of GBR reef connectivity*	Modelling, local/regional scale	Linking land-use to COTS outbreak risk. Identify high-risk reefs
<b>Management and investment strategies</b>		
Integrating research, monitoring, and management through optimization*	Spatial structured decision-making and adaptive management	Supporting evidence-based decision-making on intervention/investment priorities.



---

## REFERENCES

Anon. (2013) Reef Water Quality Protection Plan 2013. Securing the health and resilience of the Great Barrier Reef World Heritage Area and adjacent catchments. The State of Queensland. Reef Water Quality Protection Plan Secretariat, Brisbane. 34 p. Available at [www.reefplan.qld.gov.au](http://www.reefplan.qld.gov.au)

Bode M, Bode L, Armsworth PR (2006) Larval dispersal reveals regional sources and sinks in the Great Barrier Reef. *Marine Ecology Progress Series* 308:17-25

Brodie JE, Kroon FJ, Schaffelke B, Wolanski EC, Lewis SE, Devlin MJ, Bohnet IC, Bainbridge ZT, Waterhouse J, Davis AM (2012) Terrestrial pollutant runoff to the Great Barrier Reef: An update of issues, priorities and management responses. *Marine Pollution Bulletin* 65:81-100

Brodie J, Waterhouse J, Schaffelke B, Kroon F, Thorburn P, Rolfe J, Johnson J, Fabricius K, Lewis S, Devlin M, Warne M, McKenzie L (2013) 2013 Scientific Consensus Statement. Land use impacts on Great Barrier Reef water quality and ecosystem condition. The State of Queensland, Reef Water Quality Protection Plan Secretariat. Available at [www.reefplan.qld.gov.au](http://www.reefplan.qld.gov.au)

De'ath G, Fabricius KE, Sweatman H, Puotinen M (2012) The 27-year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings of the National Academy of Sciences* 109:17995-17999

Emslie, M. J., A. J. Cheal, et al. (2008). "Recovery from disturbance of coral and reef fish communities on the Great Barrier Reef, Australia." *Marine Ecology Progress Series* 371: 177-190.

Fabricius K, Okaji K, De'ath G (2010) Three lines of evidence to link outbreaks of the crown-of-thorns seastar *Acanthaster planci* to the release of larval food limitation. *Coral Reefs* 29:593-605

Furnas, M., Brinkman, R., Fabricius, K., Tonin, H., Schaffelke, B., 2013. Chapter 1: Linkages between river runoff, phytoplankton blooms and primary outbreaks of crown-of-thorns starfish in the Northern GBR. In: *Assessment of the relative risk of water quality to ecosystems of the Great Barrier Reef: Supporting Studies*. Report to the Department of the Environment and Heritage Protection, Queensland Government, Brisbane. TropWATER Report 13/30, Townsville, Australia.

Halford, A.; Cheal, A.J.; Ryan, D.; Williams, D.McB. (2004) Resilience to large-scale disturbance in coral reef and fish assemblages on the Great Barrier Reef, *Ecology and Society*, 85: 1892-1905

Hock K, Wolff NH, Condie SA, Anthony KRN, Mumby PJ (in press) Connectivity networks reveal outbreak patterns in crown-of-thorns starfish on the Great Barrier Reef. *Nature Communications*

Pratchett M, Caballes C, Rivera-Posada J, Sweatman HPA (in press) Limits to the understanding and managing outbreaks of the crown-of-thorns starfish (*Acanthaster* spp.). *Oceanography and Marine Biology: an Annual Review*.

Schaffelke B, Anthony K, Blake J, Brodie J, Collier C, Devlin M, Fabricius K, Martin K, McKenzie L, Negri A, Ronan M, Thompson A, Warne M (2013). Supporting evidence to *Scientific consensus statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition. Chapter 1, Marine and Coastal ecosystem impacts*, Reef Water Quality Protection Plan Secretariat, Brisbane. Available at: [www.reefplan.qld.gov.au](http://www.reefplan.qld.gov.au)