FINAL REPORT (OCTOBER 2005 – SEPTEMBER 2008):

TITLE:
Management of *Acanthaster planci* breakouts through monitoring and use of *Acanthaster* feeding attractants/deterrents.
Grant number: NA05NMF4631060

APPLICANT ORGANIZATION: The University of Guam

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PROJECT ABSTRACT:

Natural and anthropogenic disturbances of coral reef communities, such as bleaching, storms, sedimentation and mass aggregations of coral predators, have been increasing in intensity and frequency over the last several decades. This study was designed to thoroughly assess the current problem with Crown-of-Thorns starfish, *Acanthaster planci*, in Guam for the first time in 30 years. Our observations confirmed that Guam's *Acanthaster* populations represent a current threat for specific reef areas and that they might have the potential for renewed large scale mass outbreaks.
Our feeding trials identified α-linolenic acid (ALA) and Betaine as feeding cues for *Acanthaster*. Incorporation of these compounds in agar disk for use in bait stations could give local fisheries agencies new tools for the management of chronic infestations as well as potential mass outbreaks of Crown-of-Thorns starfish, by concentrating the starfish around the bait stations. This should allow a more time efficient removal of the starfish during control campaigns.

MILESTONES AND RESULTS:

1) Monitor *A. planci* populations around Guam.
During the duration of this grant we conducted a total of 73 Manta tows for surveying and tracking *Acanthaster* populations in 20 sites around Guam. Figure 1 shows the sites of the Manta tows around Guam. *Acanthaster* numbers are reported in Table 1 for each of the sites and different dates when sites were monitored repeatedly. Gun / Faifai Beach, Tanguisson, and Pago Bay were surveyed three times throughout the duration of the grant, because aggregations were frequently reported at these sites. Recently, another outbreak was surveyed in Shark's Hole (northwest of Guam). As evident by the high *Acanthaster* numbers, numerous sites around Guam reached *Acanthaster* densities of outbreak proportion, when densities reached or exceeded 30 individuals/hectare[1]. The problem was most severe during 2006 and 2007, but even in 2008 numbers reached outbreak levels at several sites, emphasizing that this is a continuous problem, with a

[1] CRC Reef Research Centre. 2003. Crown-of-thorns starfish on the Great Barrier Reef: Current state of knowledge.

need for active management of the *Acanthaster* populations to relief reefs which already have been impacted by poor land management practices, over fishing and other disturbances such a the coral killing sponge *Terpios* and the alga *Chrysocystis fragilis*..

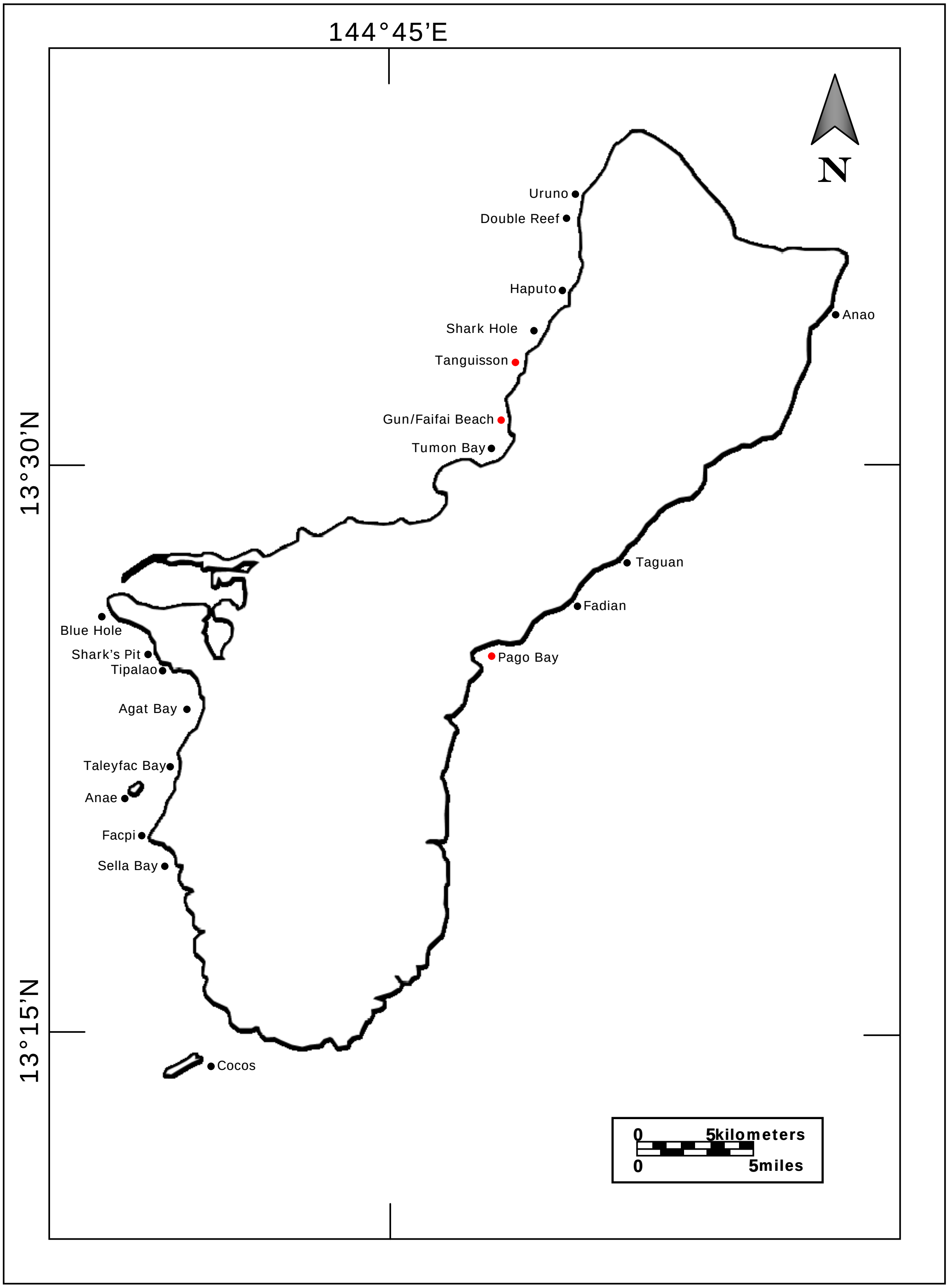

Figure 1. Manta tow survey sites.

Table 1. Number of *Acanthaster* individuals counted during manta tow surveys conducted around Guam from 2006-2008. Shallow tows were conducted in 3- to 5-m and deep tows in 9- to 12-m depth.

Site	Tow Length (m)	Number of *Acanthaster*	Month and year of survey
North of Double Reef (Shallow)	2020	193	May, 2006
North of Double Reef (Deep)	2460	184	May, 2006
Double Reef (Shallow)	1430	31	May, 2006
Double Reef (Deep)	1950	10	May, 2006
North of Haputo Point (Shallow)	2010	22	April, 2006
North of Haputo Point (Deep)	2070	159	April, 2006
Shark's Hole (Shallow)	1570	30	April, 2006
Shark's Hole (Deep)	1370	81	April, 2006
Tanguisson (Shallow)	1610	109	April, 2006
Tanguisson (Deep)	1680	339	April, 2006
Tanguisson Outbreak Site	270	1569	April, 2006
Tumon Bay (Shallow)	1570	18	April, 2006
Tumon Bay (Deep)	1760	23	April, 2006
Blue Hole (Shallow)	-	6	March, 2006
Anae Island (Shallow)	1930	15	May, 2006
Anae Island (Deep)	1960	5	May, 2006
Cocos Island (Shallow)	-	6	February, 2006
Cocos Island (Deep)	-	1	February, 2006
South of Pago Bay (Deep)	1350	291	June, 2006
Pago Bay Outbreak Site	870	1604	June, 2006
North of Pago Bay (Shallow)	1100	9	June, 2006
North of Pago Bay (Deep)	1320	323	June, 2006
North of Fadian Point (Shallow)	1460	0	October, 2006
North of Fadian Point (Deep)	1590	5	October, 2006
South of Taguan Point (Shallow)	930	0	October, 2006
South of Taguan Point (Deep)	1660	80	October, 2006
North of Taguan Point (Shallow)	2010	217	October, 2006
North of Taguan Point (Deep)	1390	146	October, 2006
South of Anao Point (Shallow)	1760	0	October, 2006
South of Anao Point (Deep)	1830	35	October, 2006
Anao Point (Shallow)	1830	0	October, 2006
Anao Point (Deep)	1400	76	October, 2006
Gun to Faifai Beach (Shallow)	-	31	August, 2007
Gun to Faifai Beach (Deep)	-	84	August, 2007
Tanguisson (Deep)	-	144	August, 2007
Pago Bay (Shallow)	-	364	September, 2007
Pago Bay (Deep)	-	105	September, 2007
Gun to Faifai Beach (Shallow)	-	208	November, 2007
Gun to Faifai Beach (Deep)	-	76	November, 2007
Pago Bay (Shallow)	-	137	January, 2008
Pago Bay (Deep)	-	44	January, 2008
Gun to Faifai Beach (Shallow)	1869	48	October, 2008
Gun to Faifai Beach (Deep)	1875	21	October, 2008
Tanguisson (Shallow)	1545	4	October, 2008
Tanguisson (Deep)	1815	143	October, 2008
South of Ague Point (Shallow)	1472	4	October, 2008
South of Ague Point (Deep)	1675	136	October, 2008
Shark's Hole (Shallow)	1307	0	October, 2008
Shark's Hole (Deep)	1410	348	October, 2008
Haputo (Shallow)	1545	27	October, 2008
Haputo (Deep)	1362	77	October, 2008

Double Reef (Shallow)	1647	154	October, 2008
Double Reef (Deep)	1750	163	October, 2008
North of Double Reef (Shallow)	1637	21	October, 2008
North of Double Reef (Deep)	1623	109	October, 2008
South of Uruno Point (Shallow)	1570	11	October, 2008
South of Uruno Point (Deep)	1600	51	October, 2008
Anae Island (Shallow)	1494	5	October, 2008
Anae Island (Deep)	1316	2	October, 2008
North of Facpi Point (Shallow)	1345	2	October, 2008
North of Facpi Point (Deep)	1598	4	October, 2008
South of Facpi Point (Shallow)	1455	1	October, 2008
South of Facpi Point (Deep)	1552	5	October, 2008
Sella Bay (Shallow)	1318	0	October, 2008
Sella Bay (Deep)	1729	15	October, 2008
Taleyfac Bay (Shallow)	-	2	October, 2008
Taleyfac Bay (Deep)	-	1	October, 2008
Agat Bay (Shallow)	-	8	October, 2008
Agat Bay (Deep)	-	17	October, 2008
Tipalao Bay (Shallow)	-	5	October, 2008
Tipalao Bay (Deep)	-	0	October, 2008
Shark's Pit (Shallow)	-	6	October, 2008
Shark's Pit (Deep)	-	5	October, 2008

2) **Design *A. planci* traps or bait stations to control their numbers on the reef.**

Identify feeding attractants for A. planci:

Feeding preference of COTS based on crude extract trials

To identify potential new feeding attractants, we tested crude extracts of two preferred corals, *Acropora surculosa* and *Montipora grisea*, and two non preferred corals, *Porites rus* and *Porites cylindrica*. Agar-based food plates with extracts (concentration based on grams crude extract per cm^2 coral surface area; dissolved in 3mL methanol) were tested against a control (with 3mL methanol) in y-chamber experiments. In short, the arms of the y-chamber contain either the control or extract agar plates and *Acanthasters* have to choose the preferred arm based on the chemical cues eluting from the plates and flowing down the arm of the chamber. COTs were significantly attracted to *A. surculosa* extracts (Figure 2; p=0.008, G-test) and *M. grisea* extracts (p=0.027, G-test), while extracts from *P. rus* and *P. cylindrica* did not attract *Acanthasters* (Figure 2). This confirmed that chemical signals play a role in the selective predation of COTS. Results were consistent with observed preference in the field.

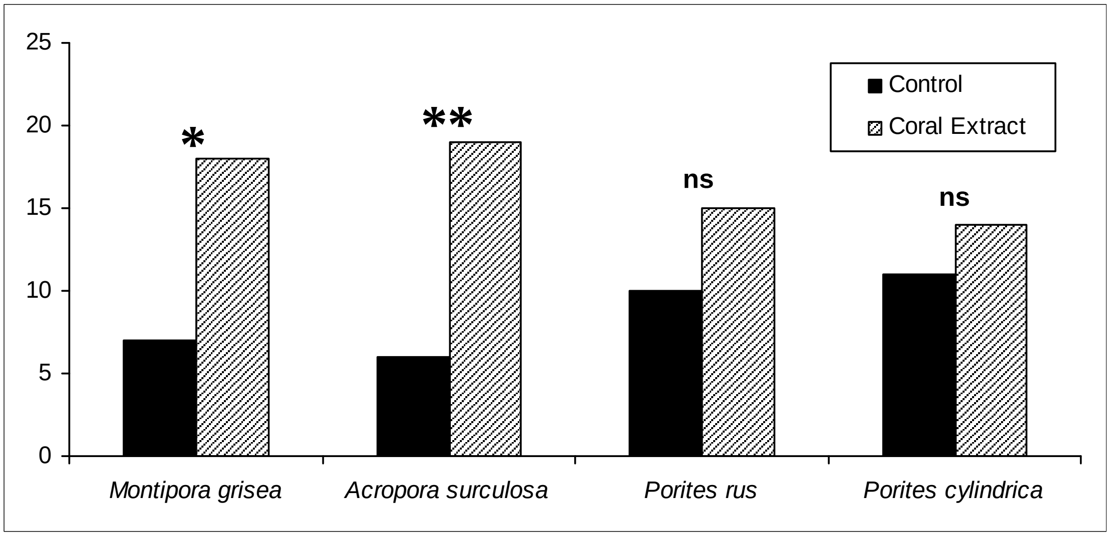

Figure 2. Y-Chamber feeding experiments with coral crude extracts. Y-axis indicates the number of COTs which chose either control or coral extracts. Statistical analyses applied G-Test for Goodness-of-Fit (differences are represented by the following markers: ***** $p<0.05$, ****** $p<0.01$, $^{\mathbf{ns}}p>0.05$; $n=25$).

Effectiveness of feeding attractant compounds

In addition to the crude extracts we also tested several pure compounds described in the literature for their role as potential feeding cues[1]. Figure 3 shows the potential of different chemical compounds for attracting COTs in y-chamber experiments. Betaine, previously described as a feeding attractant for *Acanthasters* in Japan[2], had also a pronounced effect in attracting COTs from Guam. Acrylic acid and demethyl sulfide (DMS), the break down products of Dimethylsulfoniopropionate (DMSP), which is present in most corals[3] and likely released as a feeding deterrent against possible fish predators (Schupp unpublished data), also showed an attractant effect towards COTS in y-chamber experiments. Results of G-Test for Goodness-of-Fit indicated that α-linolenic acid (ALA) and Betaine at 1% concentration were both significantly attractive to COTS, although a combination of 1% ALA and 1% Betaine was not significantly more attractive than 1% ALA only.

[2] Teruya, T., Suenaga K., Koyama T., Nakano Y., D. Uemura. 2001. J. Exp. Mar. Biol. Ecol., 266, 123-134

[3] Van Alstyne, K.L, Schupp, P., Slattery, M. 2006. Coral Reefs 25: 321–327

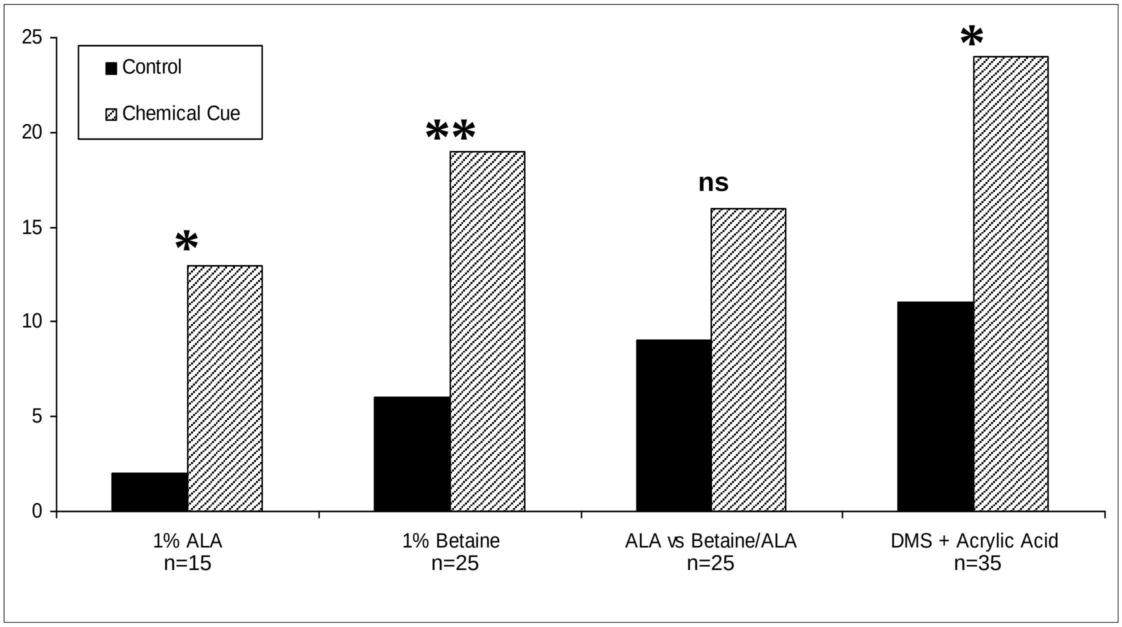

Figure 3: Y-Chamber feeding experiments with chemical compounds that are potentially attractive to COTS. Y-axis indicates the number of COTs which chose either control or chemical cues. Statistical analyses applied G-Test for Goodness-of-Fit (differences are represented by the following markers: ***p<0.05, ****p<0.01, ns p>0.05).

Field feeding attractant trials

We continued field experiments to identify suitable cues to attract *Acanthaster* to bait stations and also to design traps. Field experiments were conducted using agar-based food plates with 1% ALA, 2% ALA, and a control plate with the surfactant. We counted the initial number of COTs within 1-m and 3-m from the food plates. We did another count after 1 hr to see if COTs went in the 1-m or 3-m radius or out of it (Figure 4). Within the 1-m radius, there was no significant difference between the concentration treatments (p=0.16) and between sites (p=0.58). Within the 3-m radius, there was a significant difference between sites (p=0.03), although only a slight difference was seen between the ALA concentration treatments (p=0.06).

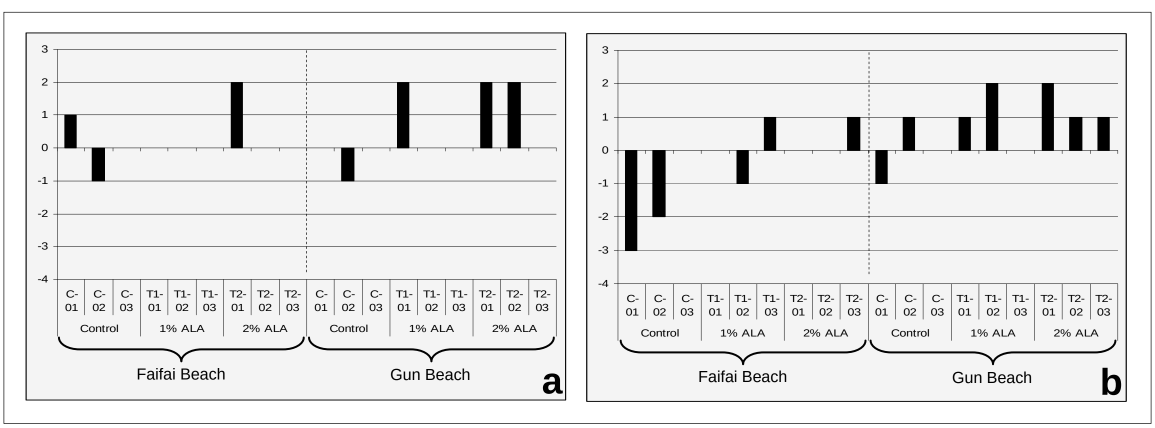

Figure 4. *(a)* Difference in the initial number of COTs and number of COTs after 1 hr within 1-m from the test feeding attractant; *(b)* difference in the initial number of COTs and number of COTs after 1 hr within 3-m from the test feeding attractant.

We also tried to increase the concentration by using 10% ALA in Faifai, but no movement was observed within 1 hr. All of the tests in Faifai were done during days with high wave action in the area. It is possible that the hydrodynamics in the area limits the contact between the feeding cue and the COTs around the area. Another factor that may play a role is the fact that COTs in the field are actively feeding during the trials, which makes it probably unlikely for it to discontinue feeding and move towards other potential food (*i.e.* ALA food plate).

In addition to our previous experiments with α-linolenic acid (ALA) we tested betaine as a feeding attractant in the field. Initial experiments used agar cubes inside mesh bags containing 1% betaine as bait stations to attract *Acanthaster*. *Acanthaster* numbers increased around the bait stations after 24h, verifying the results from our y-chamber experiments that betaine is an effective feeding cue. Figure 5 shows the results of COTs counts within 1-m and 3-m from the food plates. Results of T-Tests indicated that there were significantly more COTs within the 3-m radius of the betaine test plate after 24-hours compared to the control plates (p=0.04). However, there was no significant difference within a radius of 1-m. Results emphasize that betaine could be used as a feeding attractant to concentrate COTs at bait stations.

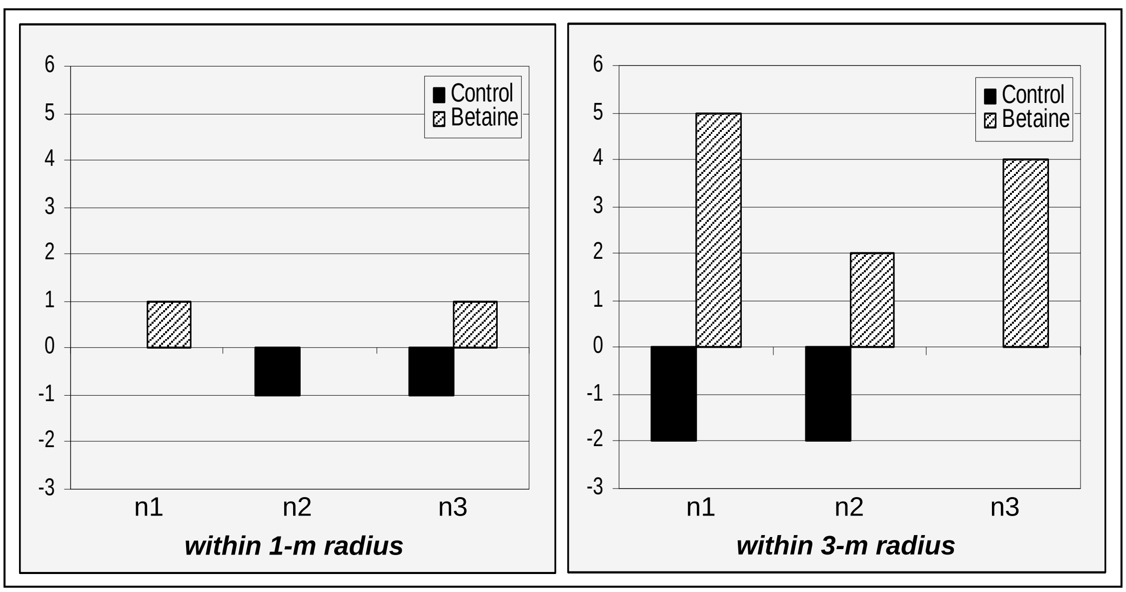

Figure 5: Differences in the initial number of COTs and number of COTs after 24 hours within a 1-m and 3-m radius from the betaine test plate. Numbers on the y-axis indicate the number of COTs which moved in (positive) or out (negative) the 1m and 3m radius.

We conducted another field experiment to determine the effectiveness of betaine as an attractant at higher concentrations. Betaine was incorporated in agar blocks at concentrations of 10% per wet weight. A series of agar blocks containing betaine (treatment) or just agar (controls) were put out on the reef in mesh bags tied to the substratum in about 7- to 10-m depth. *Acanthaster* numbers were counted in a 1m radius

(figure 6) and 3m radius (figure 7) around the control and treatments blocks upon deployment, one hour after deployment, 6 hours after deployment at night and 24h later (next morning).
Results revealed a significant increase of *Acanthaster* numbers around agar cubes containing betaine (Figure 5 and 6), making betaine a possible feeding attractant to be used by managers from marine resource agencies to attract *Acanthaster* to specific reef sites for removal during chronic infestations or acute outbreaks.

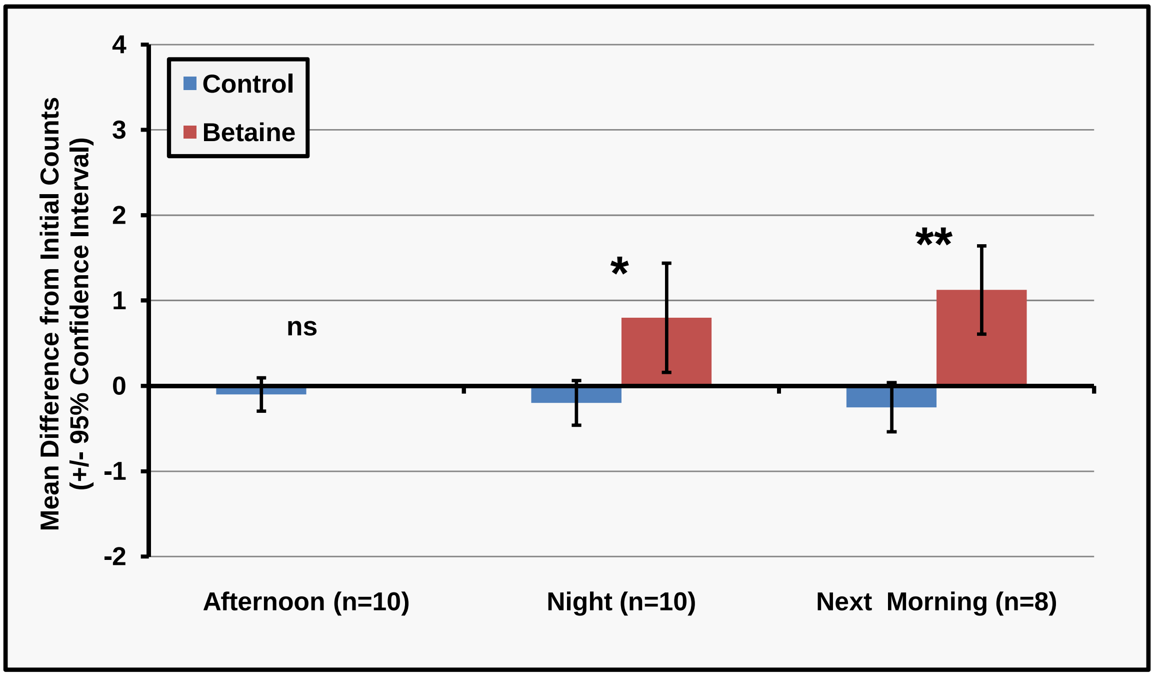

Figure 6: Number of *Acanthaster* within a 1 m radius at different time intervals following baiting with control (agar only) or treatment (agar and 10% betaine) agar blocks. Mann-Whiney U Test: *$p<0.05$; **$p<0.01$; $^{ns}p>0.05$.

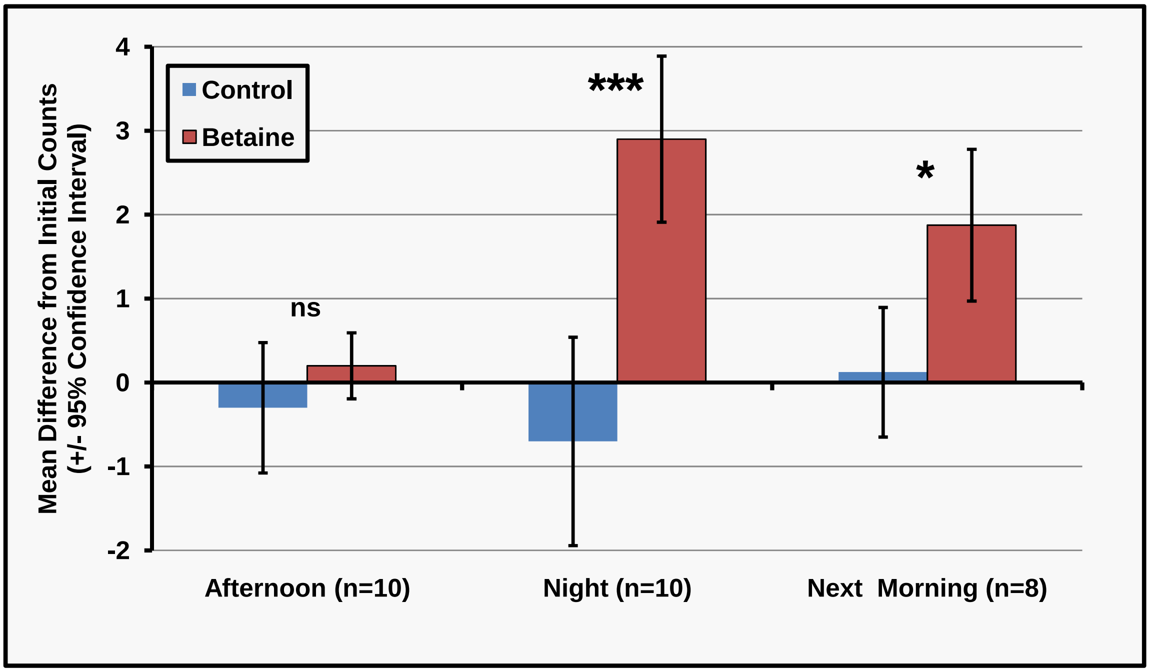

Figure 7: Number of *Acanthaster* within a 3 m radius at different time intervals following baiting with control (agar only) or treatment (agar and 10% betaine) agar blocks. Mann-Whiney U Test: *p<0.05; ***p<0.001; ^{ns}p>0.05.

Trapping experiments

We also conducted experiments to trap COTs using the above mentioned feeding cues. We modified a 3 x 3 x 6 feet fish trap for the *Acanthaster* experiment by attaching Plexiglas panels on each trap opening to allow the starfish to easily walk up the "ramp" and into the trap. We increased the betaine concentration to 10% to attract COTs from further away. The trap was deployed in 5m of depth overnight at a site with moderate COTs numbers and checked 24h later. No COTs were found within the trap and only a few were found around the trap. One possible explanation is that weather conditions were not optimal with a 2-3 foot swell which might have negatively affected the release of the cue. Given the moderate effect of traps in attracting COTs at low cue concentration one could speculate, that traps might not be effective in catching COTs, since the COTs might travel from further away towards the trap, but might start feeding on corals around the trap, rather then trying to get inside the trap to the cue source. Therefore using bait stations to concentrate COTs and removal of them by divers might be a more successful approach and should be further investigated.

Removal of Acanthaster starfish

We performed a total of 10 starfish removal dives to collect starfish for our experiments or to relieve heavily and affected reef sites (Table 2). Dives were planned in close collaboration with the Guam Department of Agriculture and Wildlife Resources (DAWR). A total of 1094 starfish were removed during the duration of this grant.

Table 2: Number of *Acanthaster* removed from selected reefs around Guam.

Site	Number of COTS Removed	Month & Year of Removal
Tanguisson	89	April, 2006
Tanguisson	133	May, 2006
North of Double Reef	120	May, 2006
South of Pago Bay	71	June, 2006
North of Taguan Point	80	October, 2006
Pago Bay	93	November, 2007
Gun Beach	159	February, 2008
Faifai Beach	182	June, 2008
Shark's Hole	55	October, 2008
Shark's Hole	112	December, 2008
TOTAL COTS Removed	**1094**	**April, 2006 - December, 2008**

Public awareness:

Posters were distributed to major dive shops on Guam to urge divers and dive guides to notify us if they see potential COTs population outbreaks (Figure 8). An email address (acanthaster.uog@gmail.com) was also created for this purpose. An electronic copy of this poster was also e-mailed to partners and people involved in coral reef management around Guam. Several concerned recipients have expressed their willingness to support this drive and pledged to report sightings of COTs aggregations around the island and elsewhere.

We had several reported sightings as a result of this outreach activity, which were verified by Manta tows. A few sightings let to above mentioned *Acanthaster* removal dives.

Figure 8. Poster distributed to major dive shops and e-mailed to partners and reef managers.

RECOMMENDATION TO MANAGERS:

Based on our results in the y-chambers and the filed experiments I would recommend to use betaine as feeding attractant to concentrate *Acanthaster* starfish around bait stations for time efficient removal of the starfish. Betaine is a salt that can easily be shipped, stored and safely handled. It is also cheap enough to allow its use in larger quantities. Larger field experiments to try the use of betaine in bait stations in different habitats and under different current conditions and over prolonged times should be conducted, before the procedures is recommended to fisheries agencies for cost-effective *Acanthaster* management. This would also allow to assess if other species would be attracted as well to these bait stations when they are used in larger quantities (we did not observe any "by-catch during our experiments).

PROBLEMS:

Several factors contributed to the delay and resulting no-cost extensions of the project:

1) A tropical storm, which later turned into a typhoon, wiped out the seawater pumps. This caused serious delay (months) in our ability to conduct the Y-chamber experiments.
2) Another problem we encountered were problems with our boats causing cancellations in scheduled field trips for days and in one instance for several moths. This was due to the financially strained situation at the UOG, which delayed repairs or the purchase of new motors. We hope that the creation of a research office at UOG will enable us to use funds in a timely manner to avoid such down times in field experiments.

PUBLICATIONS:

Burdick, D., V. Brown, Caballes, C.F., J. Asher, M. Gawel, L. Goldman, A. Hall, J. Kenyon, T. Leberer, E. Lundblad, J. McIlwain, J. Miller, D. Minton, M. Nadon, N. Pioppi, L. Raymundo, B. Richards, R. Schroeder, P. Schupp, E. Smith, and B. Zgliczynski. 2008. Status of the Coral Reef Ecosystems of Guam. Bureau of Statistics and Plans, Guam Coastal Management Program. iv + 76 pp.

Caballes, C.F. and Schupp, P.J. renewed localized outbreaks of the crown-of-thorn starfish *Acanthaster planci* around Guam, Northern Marianas Islands. *Coral Reefs*, in preparation

Caballes, C.F. and Schupp, P.J. Use of feeding attractants as a new management tool for chronic and acute outbreaks of the crown-of-thorn starfish *Acanthaster planci*. *Coral Reefs*, in preparation

PRESENTATIONS:

Caballes, C.F. and Schupp, P.J. Monitoring of Crown-of-Thorns Seastars (*Acanthaster planci*) Around Guam and the Role of Chemical Signals in their Feeding Behavior. Guam Coral Reef Symposium, T. Stell Newman Visitors Center, Guam, April 2008

Caballes, C.F. and Schupp, P.J. The role of chemical signals in the feeding behavior of the crown-of-thorn seastar *Acanthaster planci*. *11th International Coral Reef Symposium*, Fort Lauderdale, Florida, USA, July 2008