THE EFFECTS OF CYANIDE ON HARD CORALS:
IMPLICATIONS ON CYANIDE FISHING ON CORAL REEFS
IN NORTH BORNEO

KATHERINE ATACK

A thesis submitted
in fulfilment of the requirements for the degree of
Master of Science

Institute of Biodiversity and Environmental Conservation
UNIVERSITI MALAYSIA SARAWAK
2003
Dedicated to Andrea Manica for all his help, support and encouragement.
Acknowledgments

Firstly I would like to thank the late Dr Lindsey Laird, who was my student supervisor and became a friend and mentor, for her strength and encouragement throughout the time I knew her.

I would like to thank my supervisors Dr Nick Pilcher and Prof. Steve Oakley for all their help and the chance to come and spend three fantastic years in Borneo. Also Dr Dennis Hill and Prof. Dr Fatimah Abang for their help and encouragement at this latter, but very stressful, stage of the write-up.

I would like to thank Greenforce (U.K.); especially Dave Marks, Angie MacDonald, Chris McCoulgh and the volunteers who helped in phases five and six during fieldwork set-up and collection of samples. A thank you is also due to Christina Massie and Erik Andelman for their help whilst in Kota Kinabalu, Sabah.

For the long toil of trying to find an analytical method I would like to thank J. Crabtree, and Dr Lau Seng from UNIMAS; Dr Marcel Jaspars and Dr Ian Marr from the Chemistry Department, Aberdeen University, Dr Jamie Grieves and Dr Duncan Stevens from the Forensics Department Aberdeen University Hospital; Bannet Mannipula of the Cyanide Detection Laboratory, MarineLife Alliance, Philippines; Phil Gerrard from Westlakes Scientific Consulting. Also I would like to thank Prof Ellwood for his continued advice and encouragement and Dr Greenhalgh for his chemical information.

A special thank you to all my friends who have supported me, borne with my depressions and lifted me out of them, thank you Warwick Anderson, Ch’ien Lee, Tanya Jeffrey, Rosanna Chio, Susan Wong, Glen McNair, Chong Yuh Ling, Kho Lip Khoon, Mairi MacLeod and Adrian Dowding.

And finally a big thank you to my family for all their support, patience, love and encouragement.
SECTION 1: INTRODUCTION

Chapter 1 Introduction to Coral Reefs

1.1 Coral Reef Ecology
1.1.1 General
1.1.2 Distribution of Coral Reefs
1.1.3 North Borneo Reefs

1.2 Scleractinian Corals
1.2.1 General
1.2.2 Coral Classification
1.2.3 Coral Anatomy
1.2.4 The Role of Zooxanthellae
1.2.5 Feeding Mechanisms
1.2.6 Coral Growth
1.2.7 Coral Reproduction

1.3 The Importance of Coral Reefs
1.3.1 General
1.3.2 Physical Factors
1.3.3 Biological factors
1.3.4 Tourism
1.3.5 Sustainable Fisheries
1.3.6 Natural Marine Products

1.4 Natural Threats to Coral Reefs
1.4.1 General
1.4.2 Storm Damage
1.4.3 Salinity Changes
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4.4</td>
<td>Temperature Fluctuations</td>
<td>18</td>
</tr>
<tr>
<td>1.4.5</td>
<td>Natural Predators</td>
<td>20</td>
</tr>
<tr>
<td>1.4.6</td>
<td>Coral Diseases</td>
<td>20</td>
</tr>
<tr>
<td>1.5</td>
<td>Human Threats to Coral Reefs</td>
<td>21</td>
</tr>
<tr>
<td>1.5.1</td>
<td>General</td>
<td>21</td>
</tr>
<tr>
<td>1.5.2</td>
<td>Mining and Dredging Activities</td>
<td>21</td>
</tr>
<tr>
<td>1.5.3</td>
<td>Sedimentation, Pollution and Waste</td>
<td>21</td>
</tr>
<tr>
<td>1.5.4</td>
<td>Tourism</td>
<td>22</td>
</tr>
<tr>
<td>1.6</td>
<td>Non-sustainable Fishing Practices</td>
<td>23</td>
</tr>
<tr>
<td>1.6.1</td>
<td>General</td>
<td>23</td>
</tr>
<tr>
<td>1.6.2</td>
<td>Blast or ‘Bomb’ Fishing</td>
<td>23</td>
</tr>
<tr>
<td>1.6.3</td>
<td>Chemical Fishing</td>
<td>24</td>
</tr>
</tbody>
</table>

**Chapter 2**

Introduction to Cyanide Fishing and its Relation to Coral Reefs

- 2.1 Cyanide Fishing
- 2.2 Cyanide Fishing for the Aquarium Trade
- 2.3 Cyanide Fishing for the Restaurant Trade
- 2.4 Cyanide Toxicity
- 2.5 Cyanide Fishing Techniques
- 2.6 Cyanide Fishing in North Borneo
- 2.7 Previous Studies on the Effects of Cyanide on Corals
- 2.8 Hypotheses and Aims of This Study

**SECTION 2: MATERIALS AND METHODS**

**Chapter 3**

Field Methodology

- 3.1 General
- 3.2 Experiment to Determine Cyanide Retention in Coral Tissue
- 3.3 Experiment to Determine Species Resistance to Various Cyanide Concentrations
- 3.4 Experiment to Determine the Effect of Polyp Extension/Retraction on Cyanide Absorption
- 3.5 Experiment to Determine the Effect of Multiple Cyanide Applications
- 3.6 Study Site
3.7 Materials and Preparation
3.7.1 Mortar Block Preparation
3.7.2 Selection and Collection of Coral Nubbins
3.7.3 Underwater Cementing
3.7.4 Cyanide Application
3.7.5 Nubbin Collection

3.8 Safety Aspects

Chapter 4 Laboratory Methods
4.1 General
4.2 Extraction of Cyanide from the Coral Tissue
   4.2.1 Distillation
   4.2.2 Microdiffusion
4.3 Cyanide Ion Selective Electrode
   4.3.1 General
   4.3.2 Reagents and Equipment Required
   4.3.3 Methods of Calibration
   4.3.4 Sample Analysis
   4.3.5 Problems Encountered
4.4 Colorimetric Determination Using an Iron (II) Console
   4.4.1 General
   4.4.2 Reagents and Equipment Required
   4.4.3 Analysis Preparation
   4.4.4 Sample Analysis
   4.4.5 Potential Problems with Colorimetric Determination of Cyanide Using $\text{tris}(1,10$-$\text{phenanthroline})$-iron(II)

SECTION 3: RESULTS

Chapter 5 Results
5.1 General Observational Results
5.2 The Effect of Cyanide Application on the Experiment to Determine Species Resilience to Various Cyanide Concentrations
   5.2.1 Bleaching Observations
   5.2.2 Polyp Retraction Observations
SECTION 4: DISCUSSION

Chapter 6 Discussion

6.1 General

6.2 Observational Results

6.2.1 Cyanide Bleaching Effect

6.2.2 Polyp Response to Cyanide Exposure

6.2.3 Storms and the Use of Protective Cages

6.3 Field Methods

6.3.1 General Points for all the Field Experiments

6.3.2 Experiments 3.2 and 3.3

6.3.3 Improvements to Experiments 3.2 and 3.3

6.3.4 Experiment 3.4

5.2.3 Mucus Production Observations

5.3 The Effects Of Cyanide Application on the Experiment to Determine Cyanide Retention in Coral Tissue

5.4 The Effects Of Cyanide Application on the Experiment to Determine Whether or Not Polyp Extension or Retraction is Important in Cyanide Absorption

5.5 The Effects Of Cyanide Application on the Experiment to Determine Whether or Not Cyanide Accumulates in Coral Tissue with Multiple Doses.

5.5.1 Two Three or Four Doses of Cyanide Applied at Daily Intervals

5.5.2 Two Three or Four Doses of Cyanide Applied on Alternate Day Intervals

5.5.3 Two Three or Four Doses of Cyanide Applied At Weekly Intervals

5.6 Coral Nubbin Mortality

5.6.1 Percentage Mortality in the Experiment to Determine Cyanide Retention in Coral Tissue, (3.2)

5.6.2 Percentage Mortality in the Experiment to Determine Species Resistance to Cyanide Exposure (3.3)

5.7 Analytical Results
A Time Interval Set.

A10 Observational Values for Experiment 3.2: Three-month

B Observational Values for Experiment 3.2 Over a 100-day Period

B1 Bleaching Values for Experiment 3.2 Over a 100-day Period After Cyanide Exposure

B2 Polyp Retraction Values for Experiment 3.2 Over a 100-day Period After Cyanide Exposure

B3 Mucus Production Values for Experiment 3.2 Over a 100-day Period After Cyanide Exposure

C Mortality in Experiment 3.2

D Observational Values for Experiment 3.3

D1 Observational Values for Experiment 3.3: 1.5-hours

D2 Observational Values for Experiment 3.3: Six-hours

D3 Observational Values for Experiment 3.3: 24-hours

D4 Observational Values for Experiment 3.3: Six-days

D5 Observational Values for Experiment 3.3: One-month

D6 Observational Values for Experiment 3.3: Three-month

E Observational Values for Experiment 3.3 Over a 95-day Period

E1 Bleaching Values for Experiment 3.3 Over a 95-day Period After Cyanide Exposure

E2 Polyp Retraction Values for Experiment 3.3 Over a 95-day Period After Cyanide Exposure

E3 Mucus Production Values for Experiment 3.3 Over a 95-day Period After Cyanide Exposure

F Mortality in Experiment 3.3
Observational values for Experiment 3.4

Observational values for the Retracted and Extended Polyp Tentacles during the 24-Hours After Exposure to Cyanide

Master Data Chart for Experiment 3.4

Observational Values for Experiment 3.5

Observational Values for Experiment 3.5:
- Multiple Applications on Daily Intervals
- Multiple Applications on Alternate Day Intervals
- Multiple Applications on Weekly Intervals
List of Tables

Table 1.3  A table of compounds taken from marine organisms and their uses. Compiled from Jaspers (1998).  Page 17
Table 3.1.1  Nubbin replicates for each of the experiments.  Page 35
Table 3.2.1  Collection schedule for blocks after cyanide application for the experiment to determine cyanide retention in coral tissue.  Page 36
Table 3.3.1  Collection schedule for blocks after cyanide application for the experiment to determine the species resistance to cyanide.  Page 38
Table 3.5.1  Dosage application timetable (A - application of cyanide, C - collection on nubbins after application).  Page 40
Table 5.2.1  Assigned bleaching values and their descriptions.  Page 65
Table 5.2.2  Assigned polyp retraction values and their respective descriptions.  Page 75
Table 5.2.3  Assigned mucus production values and their respective descriptions.  Page 81
Table 5.2.4  Observational values for the 1.5-hour time interval set, for experiment 3.3.  Page 88
Table 5.2.5  Observational values for the six-hour time interval set, for experiment 3.3.  Page 88
Table 5.2.6  Observational values for the 24-hour time interval set, for experiment 3.3.  Page 89
Table 5.2.7  Observational values for the six-day time interval set, for experiment 3.3.  Page 90
Table 5.2.8  Observational values for the one-month time interval set, for experiment 3.3.  Page 90
Table 5.2.9  Observational values for the three-month time interval set, for experiment 3.3.  Page 91
Table 5.3.1  Observational values for the O-hour time interval set, for experiment 3.2.  Page 91
Table 5.3.2  Observational values for the half-hour time interval set, for experiment 3.2.  Page 91
Table 5.3.3  Observational values for at the three-hour time interval set, for experiment 3.2.  Page 92
Table 5.3.4  Observational values for the six-hour time interval set, for experiment 3.2.  Page 92
Table 5.3.5  Observational values for the 24-hour time interval set, for experiment 3.2.  Page 92
Table 5.3.6  Observational values for the five-day time interval set, for experiment 3.2.  Page 93
Table 5.3.7  Observational values for the fifteen-day time interval set, for experiment 3.2.  Page 93
Table 5.3.8  Observational values for the one-month time interval set, for experiment 3.2.  Page 93
Table 5.3.9  Observational values for the two-month time interval set, for experiment 3.2.  Page 94
Table 5.3.10 Observational values for the three-month time interval set, for experiment 3.2.  Page 94
Table 5.4.1 Experiment 3.4: Polyps either extended or retracted at time of cyanide application and their observational values on
collection.

| Table 5.5.1 | Observational values for different cyanide treatments when two doses were applied at daily intervals, experiment 3.5. | Page 104 |
| Table 5.5.2 | Observational values for different cyanide treatments when three doses were applied at daily intervals, experiment 3.5. | Page 104 |
| Table 5.5.3 | Observational values for different cyanide treatments when four doses were applied at daily intervals, experiment 3.5. | Page 104 |
| Table 5.5.4 | Observational values for different cyanide treatments when two doses were applied at alternate day intervals, experiment 3.5. | Page 108 |
| Table 5.5.5 | Observational values for different cyanide treatments when three doses were applied at alternate day intervals, experiment 3.5. | Page 108 |
| Table 5.5.6 | Observational values for different cyanide treatments when four doses were applied at alternate day intervals, experiment 3.5. | Page 108 |
| Table 5.5.7 | Observational values for different cyanide treatments when two doses were applied at weekly intervals, experiment 3.5. | Page 112 |
| Table 5.5.8 | Observational values for different cyanide treatments when three doses were applied at weekly intervals, experiment 3.5. | Page 112 |
| Table 5.5.9 | Observational values for different cyanide treatments when four doses were applied at weekly intervals, experiment 3.5. | Page 112 |
List of Figures and Illustrations

Figure 1.1 Coral reef distribution, major ocean currents and up-welling areas. Adapted from IUCN (1994) and Sumich (1999).

Figure 1.2.1 Diagram of scleractinian coral classification, adapted from Tomascik (a) et al., (1997) and Wood, (1983).

Figure 1.2.2 Diagram of the structure of a scleractinian coral polyp, adapted from Tomascik (a) et al., (1997) and Wood, (1983).

Figure 1.2.3 Common Coral Growth Forms. Adapted from Sumich, (1999) and Humann, (1994).

Figure 1.2.4 Diagram of asexual reproduction used by most scleractinian corals to increase colony size.

Figure 3.1.1 The experimental preparation and procedure for testing the effects of cyanide on coral tissue.

Figure 3.6.1 Map of North Sabah, East Malaysia (Scale 1: 1, 900, 000).
Figure 3.6.2 Map of Pulau Banggi (Scale 1: 800, 000).
Figure 3.6.3 Map of Pulau Balak Balak and surrounding reefs (Scale 1: 100, 000).

Figure 3.7.1 Mortar Block dimensions.

Figure 3.7.2 Blocks made for collecting water samples.

Figure 3.7.3 Mortar holder assemblage.

Figure 3.7.4 Underwater mortar procedure.

Figure 3.7.5 The set layout is made up of identical groups. Each group receives one cyanide concentration. The groups contain one or more species of coral. These are laid out as simply and spatially economic as possible.

Figure 4.2.1 Distillation Apparatus Set-Up.

Figure 4.2.2 Conway Apparatus.

Figure 5.2.1 Experiment 3.3: Average assigned bleaching values for P. clavus over a 95-day period after exposure to $10^{-1}$ M cyanide. P. clavus showed signs of bleaching within six hours. Maximum bleaching was reached between two and five days before recovery began. Full recovery was obtained fifteen days after the initial cyanide exposure.

Figure 5.2.2 Experiment 3.3: Average assigned bleaching values for G. astreata over a 95-day period after exposure to $10^{-3}$ M cyanide.

Figure 5.2.3 Experiment 3.3: Average assigned bleaching values for S. pistillata over a 95-day period after exposure to $10^{-1}$ M cyanide.

Figure 5.2.4 Experiment 3.3: Average assigned bleaching values for H. rigida over a 95-day period after exposure to $10^{-2}$ M cyanide.

Figure 5.2.5 Experiment 3.3: Average assigned bleaching values for E. glabrescens over a 95-day period after exposure to $10^{-3}$ M cyanide.

Figure 5.2.6 Experiment 3.3: Comparison between species for assigned average bleaching values over a 95-day period after exposure to $10^{-3}$ M cyanide.

Figure 5.2.7 Experiment 3.3: Average assigned polyp retraction values for...
Galaxea astreata over a 95-day period after exposure to various cyanide treatments.

Figure 5.2.8 Experiment 3.3: Average assigned polyp retraction values for Euphyllia glabrescens over a 95-day period after exposure to various cyanide treatments.

Figure 5.2.9 Experiment 3.3: A comparison between species of average assigned polyp retraction values over a 95-day period after exposure to 10^{-2} M cyanide.

Figure 5.2.10 Experiment 3.3: Average assigned mucus production values for Pavona clavus over a 95-day period after exposure to various cyanide treatments.

Figure 5.2.11 Experiment 3.3: Average assigned mucus production values for Galaxea astreata over a 95-day period after exposure to various cyanide treatments.

Figure 5.2.12 Experiment 3.3: Average assigned mucus production values for Stylophora pistillata over a 95-day period after exposure to various cyanide treatments.

Figure 5.2.13 Experiment 3.3: Average assigned mucus production values for Hydnophora rigida over a 95-day period after exposure to various cyanide treatments.

Figure 5.2.14 Experiment 3.3: Average assigned mucus production values for Euphyllia glabrescens over a 95-day period after exposure to various cyanide treatments.

Figure 5.2.15 Experiment 3.3: Comparison between species of assigned average mucus production values after exposure to the same (10^{-2} M) cyanide treatment over a 95-day period.

Figure 5.3.1 Experiment 3.2: Average assigned polyp retraction values for Goniopora djiboutensis over a 100-day period after exposure to various cyanide treatments.

Figure 5.4.1 Experiment 3.4: Differences in polyp bleaching values 24-hours after 10-3 M cyanide is applied to extended and retracted Goniopora djiboutensis polyps.

Figure 5.4.2 Experiment 3.4: Differences in polyp retraction values 24-hours after 10-3 M cyanide is applied to extended and retracted Goniopora djiboutensis polyps.

Figure 5.4.3 Experiment 3.4: Differences in polyp mucus production values 24-hours after 10-3 M cyanide is applied to extended and retracted Goniopora djiboutensis polyps.

Figure 5.5.1 Experiment 3.5: Multiple cyanide applications applied two times at daily intervals, with corresponding bleaching and mucus production effects.

Figure 5.5.2 Experiment 3.5: Multiple cyanide applications applied three times at daily intervals, with corresponding bleaching and mucus production effects.

Figure 5.5.3 Experiment 3.5: Multiple cyanide applications applied four times at daily intervals, with corresponding bleaching and mucus production effects.

Figure 5.5.4 Experiment 3.5: Two multiple cyanide applications applied alternate days, with corresponding bleaching and mucus production effects.
Experiment 3.5: Three multiple cyanide applications applied alternate days, with corresponding bleaching and mucus production effects.

Experiment 3.5: Four multiple cyanide applications applied alternate days, with corresponding bleaching and mucus production effects.

Experiment 3.5: Multiple cyanide applications applied two times at weekly intervals, with corresponding bleaching and mucus production effects.

Experiment 3.5: Multiple cyanide applications applied three times at weekly intervals, with corresponding bleaching and mucus production effects.

Experiment 3.2: Percentage mortality in Acropora nobilis nubbins in the three-month time interval set.

Experiment 3.2: Percentage mortality in Pachyseris speciosa nubbins in the three-month time interval set.

Experiment 3.2: Percentage mortality of coral nubbins in the three-month time interval set.

Experiment 3.2: Total percentage mortality in coral nubbins for the three-month time interval set.

Experiment 3.2: Percentage mortality in Acropora nobilis nubbins in the two-month time interval set.

Experiment 3.2: Percentage mortality in Pachyseris speciosa nubbins in the two-month time interval set.

Experiment 3.2: Percentage mortality of coral nubbins for each cyanide treatment used, for each species tested in the two-month time interval set.

Experiment 3.2: Total percentage mortality of coral nubbins for each coral species in the two-month time interval set.

Experiment 3.2: Total percentage mortality of coral nubbins for each species used in the 15-day time interval set.

Experiment 3.2: Percentage mortality in Pavona clavus nubbins during the three-month time interval set.

Experiment 3.2: Percentage mortality in Galaxea astreata nubbins during the three-month time interval set.
nubbins during the three-month time interval set.

**Figure 5.6.17** Experiment 3.3: Percentage mortality in *Hydnophora rigida* nubbins during the three-month time interval set. Page 133

**Figure 5.6.18** Experiment 3.3: Percentage mortality in *Euphylia glabrescens* nubbins during the three-month time interval set. Page 134

**Figure 5.6.19** Experiment 3.3: Percentage mortality of coral nubbins in the three-month time interval set. Page 135

**Figure 5.6.20** Experiment 3.3: Total percentage mortality of coral nubbins in the three-month time interval set. Page 136

**Figure 5.6.21** Experiment 3.3: Percentage mortality in *Pavona clavus* nubbins in the one-month time interval set. Page 137

**Figure 5.6.22** Experiment 3.3: Percentage mortality in *Galaxea astreata* nubbins during the one-month time interval set. Page 138

**Figure 5.6.23** Experiment 3.3: Percentage mortality in *Hydnophora rigida* nubbins in the three-month time interval set. Page 139

**Figure 5.6.24** Experiment 3.3: Percentage mortality in *Euphylia glabrescens* nubbins in the one-month time interval set. Page 140

**Figure 5.6.25** Experiment 3.3: Percentage mortality in coral nubbins during the one-month time interval set. Page 141

**Figure 5.6.26** Experiment 3.3: Total percentage mortality in coral nubbins during the one-month time interval set. Page 142

**Figure 5.6.27** Experiment 3.3: Percentage mortality for *Hydnophora rigida* in the six-day time interval set. Page 143

**Figure 5.6.28** Experiment 3.3: Percentage mortality in coral nubbins for the six-day time interval set. Page 144

**Figure 5.6.29** Experiment 3.3: Total percentage mortality of coral nubbins for each species used in all time interval sets throughout the experiment. Page 145

**Figure 5.6.30** Experiment 3.3: Overall average percentage mortality for different cyanide treatments for each species used throughout the experiment. Page 146
## List of Plates

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate 2.1</td>
<td>Cyanide tablet used by fishermen in Banggi, Sabah, Malaysia. Photograph by Tim Daw, 2000.</td>
<td>28</td>
</tr>
<tr>
<td>Plate 2.2</td>
<td>On the left, fisherman squirting cyanide at Grouper (<em>Epinephelus merra or hexagonatus</em>). On the right, trapping fish within the reef structure and squirting cyanide in a coral enclosed space. Photograph by Tim Daw, 2000.</td>
<td>29</td>
</tr>
<tr>
<td>Plate 3.7.1</td>
<td>Collecting a water sample. Photograph by Andrea Manica, 2000.</td>
<td>46</td>
</tr>
<tr>
<td>Plate 3.7.2</td>
<td>Coral nubbins used in cyanide tolerance trials (a). Photographs by Andrea Manica, 2000.</td>
<td>48</td>
</tr>
<tr>
<td>Plate 3.7.3</td>
<td>Coral nubbins used in cyanide tolerance trials (b). Photographs by Andrea Manica, 2000.</td>
<td>49</td>
</tr>
<tr>
<td>Plate 3.7.4</td>
<td>Cutting <em>Galaxea astreata</em> to size with a hammer and chisel. Photographs by Andrea Manica, 2000.</td>
<td>50</td>
</tr>
<tr>
<td>Plate 3.7.5</td>
<td>Inverting bag of mortar over mortar holder. Photographs by Andrea Manica, 2000.</td>
<td>52</td>
</tr>
<tr>
<td>Plate 3.7.6</td>
<td>Making sure bag is empty whilst breaking up hardening mortar and removing and unmixed cement. Photographs by Andrea Manica, 2000.</td>
<td>53</td>
</tr>
<tr>
<td>Plate 3.7.7</td>
<td>After allowing the cement too settle, mortar holder was carefully removed. Photographs by Andrea Manica, 2000.</td>
<td>53</td>
</tr>
<tr>
<td>Plate 3.7.8</td>
<td>Cage placed carefully over setting nubbins. Photographs by Andrea Manica, 2000.</td>
<td>54</td>
</tr>
<tr>
<td>Plate 3.7.9</td>
<td>Cyanide application into inverted beaker, over coral nubbins set in coral blocks. Photographs by Andrea Manica, 2000.</td>
<td>55</td>
</tr>
<tr>
<td>Plate 5.2.1</td>
<td>Control <em>Pavona clavus</em>, at left with an assigned bleaching value 0, and assigned mucus production value 1 (note polyp tentacles too small to observe polyp retraction value). Compared with <em>P. clavus</em> exposed to 10^{-2} M sodium cyanide, at right with an assigned bleaching value of 5, and an assigned mucus production value of 1. Photograph taken from study site by Andrea Manica, 2000.</td>
<td>66</td>
</tr>
<tr>
<td>Plate 5.2.2</td>
<td>Control <em>Galaxea astreata</em>, at left with an assigned bleaching value 0, an assigned mucus production value 1, and an assigned polyp retraction value of 4. Compared with <em>G. astreata</em> exposed to 10^{-2} M sodium cyanide, at right with an assigned bleaching value of 5, an assigned mucus production value of 1 and an assigned polyp retraction value of 1. Photograph taken from study site by Andrea Manica, 2000.</td>
<td>66</td>
</tr>
<tr>
<td>Plate 5.2.3</td>
<td>Control <em>Stylophora pistillata</em>, at left with an assigned bleaching value 0, and assigned mucus production value 1 (note polyp tentacles too small to observe a polyp retraction value). Compared with <em>S. pistillata</em> exposed to 10^{-2} M sodium cyanide at right, with an assigned bleaching value of 5, and an assigned mucus production value of 1. Photograph taken from study site by Andrea Manica, 2000.</td>
<td>67</td>
</tr>
</tbody>
</table>
Plate 5.2.4 Control *Hydnophora rigida*, at left with an assigned bleaching value 0, and assigned mucus production value 1 (note polyp tentacles too small to observe a polyp retraction value). Compared with *H. rigida* exposed to $10^{-2}$ M sodium cyanide at right, with an assigned bleaching value of 5, and an assigned mucus production value of 1. Photograph taken from study site by Andrea Manica, 2000.

Plate 5.2.5 *Euphyllia glabrescens* exposed to $10^{-2}$ M sodium cyanide, at left with an assigned bleaching value of 5, an assigned mucus production value of 1 and an assigned polyp retraction value of 1. Compared with control *E. glabrescens* at right, with an assigned bleaching value 0, an assigned mucus production value 1, and assigned polyp retraction value of 4. Photograph taken from study site by Andrea Manica, 2000.

Plate 5.2.6 *Euphyllia glabrescens* nubbins 48 hours after exposure to $10^{-2}$ M cyanide. With an assigned bleaching value 5, an assigned mucus production value 1, and assigned polyp retraction value 1. Photograph from study site by Andrea Manica, 2000.

Plate 5.2.7 *Galaxea astreata* polyps before, 48 and 72 hours after exposure to $10^{-2}$ M cyanide. Photograph’s from study site taken by Andrea Manica, 2000.
List of Abbreviations

IMA - International MarineLife Alliance
LFFFT - Live Reef Fish Food Trade
M - Molar (moles per litre)
ppm - parts per million
ppt - part per thousand
TRF - Tropical Rain Forest
°C - degrees Celsius
NaCN - sodium cyanide
pers. comm. - personal communications
pers. obs. - personal observations
BBD - black band disease
ISE - Ion Selective Electrode
ISA - Ionic strength adjuster
HCN - hydrogen cyanide
NaOH - sodium hydroxide
MV - millivolt
μg - micrograms
mg - milligrams
psu - measure of spectrophotometric absorbance.

Specialised Nomenclature

Ahermatypic - Scleractinian corals without the symbiotic zooxanthellae algae.
Argonite - Similar to calcium, a compound that many corals use in their skeletons.
Axialplanula corralite - A new corallite forming at the tip of a branch on a mature colony.
Autotrophic - Energy source is sunlight.
Block - Mortar block with nubbin replicates attached (usually three).
Branching - A type of coral growth form.
Coelenteron - The body cavity or ‘sack’ of the polyp animal.
Coenosarc - Area between corallites.
Columnar - A type of coral growth form.
Cnidarian - Taxonomic phylum of animals with the stinging nematocyst cells.
Ectoderm - Out layer of cells of the polyp body wall (or epidermis).
Encrusting - A type of coral growth form.
Endoderm - Inner layer of cells of the polyp body wall (or gastrodermis).
Extratentacular Fission - New corallite develops in the coenosarc between polyps.
Foliosc - A type of coral growth form.
Gametogenesis - The formation of gametes in the mature polyp individual.
Gonochoric - Are either male or female.
Group - Sample of species at any one concentration.
Hermaphroditic - Have both male and female reproductive parts.
Hermatypic - Scleractinian corals with the symbiont zooxanthellae algae.
Heterotrophic - Require organic material for energy.
In situ - In place of origin.
Intratentacular fission - New mouth develops inside the original tentacle ring.
Massive - A type of coral growth form.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medusoid</td>
<td>The same as jellyfish. Corals are only medusiod in their planula stage before settlement.</td>
</tr>
<tr>
<td>Mesenterial</td>
<td>The cellular material between the ectoderm and endoderm.</td>
</tr>
<tr>
<td>Mesoglea</td>
<td>The area between the ectoderm and endoderm.</td>
</tr>
<tr>
<td>Nematocysts</td>
<td>Stinging cells used for defence and predation.</td>
</tr>
<tr>
<td>Nubbin</td>
<td>3-4 inch piece of coral used as a sample replicate.</td>
</tr>
<tr>
<td>Pelagics</td>
<td>Describes the area in the mid ocean between benthic (bottom) and the surface.</td>
</tr>
<tr>
<td>Phytoplankton</td>
<td>The microscopic animal found near the sea-surface.</td>
</tr>
<tr>
<td>Planulae</td>
<td>The stage between fertilised egg and advanced larval stage before settlement.</td>
</tr>
<tr>
<td>Sample</td>
<td>The blocks (between 3 and 5) that receive the same treatment.</td>
</tr>
<tr>
<td>Scleractinian</td>
<td>The taxonomic order of corals that produce a calcareous skeleton that forms the structure of most tropical reefs.</td>
</tr>
<tr>
<td>Sedentary</td>
<td>Once settled lives in one place until it dies.</td>
</tr>
<tr>
<td>Set</td>
<td>A number of groups (including control) at any time interval.</td>
</tr>
<tr>
<td>Time Interval Set</td>
<td>Time between cyanide application and nubbin collection.</td>
</tr>
<tr>
<td>Viviporous</td>
<td>Internal fertilisation and brooding of the fertilised ova or planula within the polpy.</td>
</tr>
</tbody>
</table>
Abstract

There are many threats such as over-exploitation, pollution, urban and industrial development and destructive fishing practices, which are damaging and destroying a large majority of the world’s reefs. Cyanide fishing is used extensively throughout Southeast Asia for both the aquarium trade and increasingly for the live reef fish food trade (LRFFT). The use of cyanide has been proven to be harmful to smaller fish, other reef fauna, and it causes corals to bleach and die at concentrations much lower than used by the fishermen.

This study was conducted off the island of Pulau Banggi on the northeastern coast of Sabah, East Malaysia. Eight coral species were used; Acropora nobilis, Goniopora dijiboutensis, Pachyseris speciosa, Pavona clavus, Stylophora pistillata, Galaxea astreata, Hydnophora rigida and Euphyllia glabrescens. These species were exposed to various concentrations of sodium cyanide for 15 minutes: in situ. They were then left to recover over different intervals of time of up to three months before they were collected and stored for later analysis.

All the species exposed to $10^{-2}$ M cyanide bleached, confirming laboratory tests from previous studies. Difference in species resistance to cyanide was evident with mortality values ranging from 100% for H. rigida to 0% for S. pistillata over the three-month period when exposed to $10^{-2}$ M NaCN. There was a significant increase in mortality in G. astreata and E. glabrescens due to algal encroachment: three to nine weeks after $10^{-2}$ M NaCN exposure, even through the corals had appeared to be recovering. This negates the theory that suggests that if death has not occurred within a week or two then the coral has completely recovered. Cyanide at concentrations of $10^{-3}$ M NaCN causes extensive bleaching, polyp retraction and an increase in mucus production, but demonstrates a species specific resistance to cyanide. It is clear that the concentrations of cyanide, which the corals are receiving from cyanide fishing, are highly toxic. These results lead to further questions about the long-term effects of cyanide on coral health and recovery.

Abstrak


Kajian ini telah dijalankan di sekitar Pulau Banggi yang terletak di timur laut Sabah, Malaysia Timur. Lapan spesis terumbu karang telah digunakan iaitu; Acropora nobilis, Goniopora dijiboutensis, Pachyseris speciosa, Pavona clavus, Stylophora pistillata, Galaxea astreata, Hydnophora rigida dan Euphyllia glabrescens. Spesis_spesis ini didedahkan kepada pelbagai tahap kepekaan natrium sianida selama 15 minit secara "in situ". Ia kemudiannya diibaikan supaya pulih dalam selang masa yang berbeza sehingga 3 bulan sebelum dikutip dan disimpan untuk kajian analisis.
Kesemua spesis yang didedahkan kepada $10^{-2} M$ sianida mengalami pelunturan dan ini menyokong keputusan kajian makmal sebelum ini. Perbezaan daya ketahanan terhadap sianida dalam pelbagai spesis yang didedahkan kepada $10^{-2} M$ NaCN selama 3 bulan adalah ketara dengan kadar kematian di antara 100% untuk *H. rigida* ke 0% untuk *S. pistillata*. Walaupun *G. astreata* dan *E. Glabescens* kelihatan semakin pulih, peningkatan yang nyata dapat dikesan bagi kadar kematian kerana lapisan alga yang merebak selama 3 minggu 9 minggu sebaik saja ia terdedah kepada $10^{-2} M$ NaCN. Ini telah menafikan teori yang menyatakan bahawa terumbu mampu pulih sepenuhnya sekiranya kematian terumbu tidak berlaku dalam tempoh masa 1 atau 2 minggu. Sianida di tahap kepekatan $10^{-2} M$ NaCN dapat mengakibatkan pelunturan yang meluas, penarikan semula polip dan peningkatan penghasilan mukus. Namun, ia menghasilkan satu daya ketahanan khusus spesis terhadap sianida. Maka, terbukti bahawa konsentrasi sianida dalam terumbu yang diperolehi melalui perikanan teknik sianida adalah amat toksik. Keputusan ini telah mengemukakan persoalan seterusnya mengenai kesan jangka panjang sianida terhadap kesehatan dan pemulihan terumbu.
SECTION 1: INTRODUCTION
CHAPTER 1: INTRODUCTION TO CORAL REEFS

1.1 Coral Reef Ecology

1.1.1 General

Coral reefs are one of the world’s most diverse and productive natural ecosystems, regarded as the ocean’s equivalent to tropical rainforests. A healthy coral reef is one of the most amazing and beautiful sights on this planet. Coral reefs also provide local human communities with their main source of protein, and also supply many markets worldwide with fish and other reef delicacies. It is the corals that have been the basis of coral reef ecosystems for at least the last 200 million years, building entire reefs, islands and the massive expansive reefs such as the Great Barrier Reef (Hoegh-Guldberg, 1999). Unfortunately, coral reefs, in common with tropical rainforests, are in serious jeopardy. Over-exploitation and destructive collection methods are the main causes of decline in both these once vast ecosystems. In particular coral reefs are under threat from rising sea temperatures, pollution, over-exploitation and destructive fishing practices such as cyanide fishing (Cervino et al., in press; Cesar, 1996; Cesar, 2000; Johannes & Riepen, 1995; Jones & Steven, 1997; McManus, Nanola & Reyes, 1997; Pastorok & Bilyard, 1985; Rubec et al., in press; Simpson, 2001)

Coral reefs are known to support: hundreds of thousands of marine animal species (Hoegh-Guldberg, 1999; International-Marinlife-Alliance, 2001; UNEP/IUCN, 1988). They are highly complex and diverse, and scientists have only just scratched the surface in understanding and documenting the many relationships and processes that are so important to the mechanisms of reef development and sustainability.

1.1.2 Distribution of Coral Reefs

Coral reefs are generally found in the tropical latitudes (between 30° North and South of the equator) of the oceans, where sea temperatures are warm, and waters are clear of sediment and have consistently low nutrient levels (Johnston, 1986; Nybakken, 1993; Searle, 1980; Sumich, 1999; Tomascik et al., 1997(a)). Some of the most diverse marine flora and fauna are found in Southeast Asia where approximately 30 % of the world’s reefs are found (Barber & Pratt, 1997; Tomascik et al., 1997(a)). The Indo-Pacific, with a coral triangle around Borneo, the Philippines and New Guinea) and Caribbean bio-geographic regions are the two main centres of coral diversity and coral reef development. The Caribbean is a smaller area and less diverse with 65 species of scleractinian corals compared to 450 species of scleractinian corals in the Indo-Pacific, diversity declines outwards from these hotspots (Almada-Villela et al., 1996; Tomascik et al., 1997(a); Wood, 1983).

Coral reef distribution around the tropics and sub-tropics is partly dependant on warm sea waters where temperatures remain at an average between 18 and 32°C (Searle, 1980; Sorokin, 1989; Tomascik et al., 1997(a); Veron, 1986; Wilkinson & Buddemeier, 1994; Wood, 1983). Correspondingly in areas where temperatures fluctuate below this range, either due to seasonal cooling or up-welling (where coldwater is pushed or pulled to the surface from deep ocean currents), reef development is inhibited. Reef development can be
found in subtropical latitudes where tropical warm water currents move into higher latitudes, or conversely, development may be retarded in tropical latitudes where coldwater currents or up-welling occurs (Tomascik et al., 1997(a)). Figure 1.1 illustrates many of the oceanic factors that affect coral reef distribution such as cold and warm water currents, up-welling and the general 20 °C isotherm range.

In general, excluding up-welling areas, the Coriolis Effect (the spin of the earth which causes the currents to flow clockwise in the northern hemisphere and counter-clockwise in the southern hemisphere) causes profuse coral growth and diversity on the eastern shores with warm water currents, while the cooler water currents on the western coasts show a lower coral species diversity (Nybakken, 1993; Sumich, 1999; Wood, 1983).

Reefs found off eastern coastlines and in subtropical waters include examples such as the Atlantic Ocean’s largest reef, the Belize Barrier Reef in Central America. Sub-tropically there are the Bermudan coral reefs (32.3° N), which are dependent on the warm Gulf Stream, whereas the tropical western coast of Africa has no coral reefs. The Eastern Indian Ocean is famous for the Arabian and Red Sea reefs as well as those on the east coast of North Africa (Sheppard, Price & Roberts, 1992). The central Indian Ocean has no coral reefs due to poor bottom topography for settlement as well as cold up-welling. The Western Pacific Ocean, where coral reefs thrive around the Northern Philippines, Ryukyu Islands and Southern Japan (Taheyama) (Japan 35° N) are dominated be the warm western boundary Kuroshio Current, which keeps sea surface temperature an average 28°C with little seasonal variation (Tomascik et al., 1997(a); Veron, 1992). Lord Howe Island, off the East coast of Australia, at 31.5° S has coral reefs due to the warm East Australian current. The cold ocean Benguela and Peru (also known as Humboldt) currents prevent coral reef development off the coasts of Southwest Africa and South America respectively. The Galapagos Islands lying on the equator have no coral reefs due to strong up-welling (Tomascik et al., 1997(a)).

A coral reef can be defined in terms of its overall structure; there are fringing reefs, patch reefs, barrier reefs and atolls. Most coral reefs are fringing reefs, where the reef develops adjacent to the coastline. Patch reefs are isolated and discontinuous patches of fringing reefs. Barrier reefs are found further away from the coast but have grown as the seabed has fallen. And atolls are circular reefs that have risen from deep-sea platforms such as submerged volcanic seamounts (Cesar, 2000).

Due to the requirements of coral for warm and clear waters, coral reefs are generally found between 2 and 25 m depth. In areas where there is a high sediment load, coral is confined to shallower water around 10m or less. Whereas in clearer waters, coral is found to depths of 50 to 70 m (Nybakken, 1993; Sumich, 1999) and has been known to grow to depths of 100m (Sorokin, 1989; Tomascik et al., 1997(a)). There are exceptions to these rules, and some corals are found in deep waters for example Lophilia pertusa. This species exists in large strands at depths of 150 m off the Shetland and Hebrides in Scotland (Wilson, 1979), and some azooxanthellate (corals without symbiotic zooxanthellae algae) corals have been reported to grow as deep as 2800 m off the eastern Atlantic (Tomascik et al., 1997(a)).