CotSim: Scientific visualisation and gaming-simulation for the *Acanthaster* phenomenon

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Abstract

CotSim is a new type of population model for Acanthaster planci on the Great Barrier Reef (GBR). This multi-reef model simulates the population dynamics of Acanthaster on 270 reefs in the central GBR and integrates recent oceanographic modelling studies of the area. It has been designed to facilitate experimentation by non-modellers. Users can change initial conditions or any of the parameters for the underlying model, as well as editing (eg. controlling) starfish populations while the model is running. The model uses the standard graphical user interface, Microsoft Windows 3.x. Populations on reefs are viewed using simple point and click operations, and the history of Acanthaster / coral dynamics is easily accessed. Latitude versus time plots of Acanthaster populations on the GBR can also be constructed. Acanthaster dynamics are represented by a density-dependent size structured matrix model. Coral dynamics are represented by logistic equations. Spawning and fertilisation are stochastic processes quantified by user-defined parameters. The spatial structure of larval dispersal is determined by extensive oceanographic studies of the GBR. The motivation for this research was to experiment with new methods of presenting models to the scientific community. Surveys have been designed and distributed in an attempt to gather responses.

Introduction

The *Acanthaster* phenomenon (Moran 1986, Birkeland and Lucas 1990) is a potentially recurrent management problem on the Great Barrier Reef (GBR). The two documented outbreaks of the starfish have affected substantial portions of the central GBR and

there is still scientific ambivalence about whether the cause(s) of outbreaks are natural or anthropogenic. *Acanthaster* therefore remains one of the most contentious issues of GBR management (Lassig and Kelleher 1991). The significance and complexity of the *Acanthaster* phenomenon has generated a surge of public interest. The Great Barrier Reef Marine Park Authority continues to encourage this interest and understanding by presenting accessible research summaries to the public in both written/illustrated (Zann and Eager 1987, Engelhardt and Lassig 1992) and video formats (GBRMPA and AIMS 1992). This use of alternative communication media is what originally motivated this paper. Scientists working with *Acanthaster* also need to experiment with new ways of presenting information and ideas amongst themselves. Pragmatic considerations were also incorporated into this research. Increasing scientific specialisation continues to restrict accessibility of information between fields. Researchers become isolated by syntax, literature, interests and time constraints. The modelling approach (Bradbury 1990) is not immune to these symptoms. Models have to compete for the restricted attention available in the scientific and management communities (Jones 1992, Cruickshank 1992).

This paper introduces the concepts for more effective communication of the structure and results of large scale *Acanthaster* models. I will outline the background, objectives, definition and evaluation methodologies for an interactive large scale population model of *Acanthaster* on the GBR, referred to as *CotSim* (Scandol 1992).

Background

Two related bodies of thought provide the methodological basis for *CotSim:* scientific visualisation and gaming-simulation. Scientific visualisation is concerned with improving the information flow between a researcher and a computer model. Modelling is an integral, but often unrecognised, process in scientific discovery and decision making. The iterative loop of model definition, model testing/observation and then model redefinition is a basic procedure in science (Nielson 1991). However, when models are realised with computers, the rate determining step is often the ease with which a researcher can extract meaningful information from a model. Utilisation of modern computer facilities with graphical output generates images that communicate large amounts of visual information to the researcher on demand. The ability of the user to interact with the images (for example rotate them), helps to improve the communication flow between data and researcher.

In summary, scientific visualisation allows the researcher to access and display large amounts of information. Huge tables of printed results are no longer an acceptable form of output for modellers or their sponsors. Unfortunately the glamorous images of Thalmann (1990) ignore the important parallel results that less computer-resource-hungry applications can offer. The limited consistency, availability and familiarity of more powerful computers were seen as critical impediments to effective implementation of *CotSim* on these systems.

Gaming-simulation is a more abstract area, with principles not bound in computer application. Greenblat (1988) discusses the application of gaming-simulation techniques to a variety of social scenarios. However, the themes are relevant to any complex problem. The central idea is to develop an interactive system which enables users to obtain an overall perspective and to initiate their own responses. Players are

integrated into the actual realisation, their decisions determining the course of events. Application of gaming-simulation to computers is a logical application of these ideas. The contrasting roles of *Monte Carlo* simulation and gaming simulation have been addressed by Gray and Borovits (1986).

CotSim extracts methodologies from both these fields to define an interactive model of the large scale population dynamics for *Acanthaster* on the GBR. It was inspired by *SharkSim* of Sluczanowski (1991). This model for the South Australian Department of Fisheries has allowed effective communication between managers, scientists and the end users of the marine resources.

Objectives

CotSim has three objectives:

1. To present a non-literature-based interactive large scale population model of *Acanthaster* on the GBR to management personnel, research scientists and other individuals interested in the phenomenon.

Simulation models are dynamic. This critical aspect is lost, along with much impact, when presenting results in the scientific literature. A conventionally published model is necessarily limited in its domain. To follow conventions for probability estimation and sensitivity testing, simulations models must be very focussed. Although the importance of this formalism is not questioned, one must query what information or inspiration is sacrificed in order to satisfy statistical rigour. If new ideas are realised, then a more stringent analysis can always be performed with a carefully defined experiment. *CotSim* presents a complementary approach that may benefit research and management of the *Acanthaster* phenomenon simply by being orthogonal to other modelling approaches. Scientific visualisation and gaming-simulation are integrated into *CotSim*. Techniques have been developed to rapidly extract and graphically display large amounts of information about the status and history of *Acanthaster* populations on reefs or integrated over the GBR. The outcome of a realisation of *CotSim* is determined by the user-defined initial conditions, model definition and control efforts. These features interact with the natural stochastic processes affecting starfish populations.

2. To collect information from surveys on:

   - usage rates of *CotSim*;
   - suggested modifications to the *CotSim* model;
   - decision making using models with limited replication.

Surveys have been prepared (*Appendix A*) to attempt to obtain this information. *CotSim* has been installed at a number of test sites (*Appendix B*). The data will be collected from late August to December 1992. The results will be collated and published in Scandol (*in preparation*).

3. To provide a new communication medium for the larval dispersal studies of Dight *et al.*(1990a, b).

CotSim may enable a more developed appreciation of the somewhat abstract and easily misunderstood concepts involved in the Dight *et al.* (1990a, b) project. Improved understanding and acceptance of the models in management agencies may then result (Law and Kelton 1991). Models such as *CotSim* provide a focus for discussion (Walters 1986).

Definition and Implementation

CotSim is a multi-reef population model of *Acanthaster* for the central GBR. The basic structure is from Scandol and James (1992), but much more biological detail has been included. Each of the 270 reefs modelled has a size-classified state vector of starfish densities in starfish/hectare. Post larval development on the reef is defined by a density-dependent matrix model (Caswell 1989). Coral cover is estimated by using a logistic response (Reichelt *et al.* 1990). One or two coral types can be modelled, each with different growth rates, equilibrium densities and *Acanthaster* feeding preferences. The fertilisation model is based upon a density dependent log normal distribution. Spawning is a stochastic or deterministic process depending upon the user's choice. Inter-reef larval transport is defined by using the larval transport models of Dight *et al.* (1990a, b). These simulated dispersal events are used by selecting data from an appropriate source reef and year. Details of the use and design of *CotSim* are provided in Scandol (1992). *Appendix B* of that documentation gives a complete technical specification of the model.

The final form of *CotSim* represents a compromise between functionality and development cost. Many features were excluded simply for reasons of technical difficulty in their implementation, or the excessive computer resources required for their execution.

CotSim was written for the popular Windows 3.x (Microsoft 1992) platform for IBM compatible computers using Visual Basic 1.0 (Microsoft 1991). The benefit of using an industry standard interface such as this is that users are already familiar with the screen controls such as buttons and text boxes, and therefore the "learning curve" is not steep (Foley *et al.* 1990). *CotSim* requires the minimum of a 80286-based processor to run. However because of the extensive numerical calculations that are performed each time step, a 80386DX processor and 80387 co-processor (or faster) are recommended.

Although Visual Basic provided a simple development environment, speed and functionality were sacrificed. Using C++ and Windows development libraries would alleviate these limitations, but would have trebled development time. At the time of writing, many additions to Visual Basic are being published that would have ameliorated many these problems.

Results and Application

During testing *CotSim* has generated a huge variety of replicates. Many of these give confidence that the system is capable of reproducing the gross features of observed large scale *Acanthaster* populations for the GBR. These features include: (*1*) the southerly movement of populations via larval dispersal, (*2*) the suggested 10 - 20 year interval between outbreaks.

Figure 1 is a plot of outbreak latitude versus time for a typical *CotSim* replicate. The previous points are illustrated.

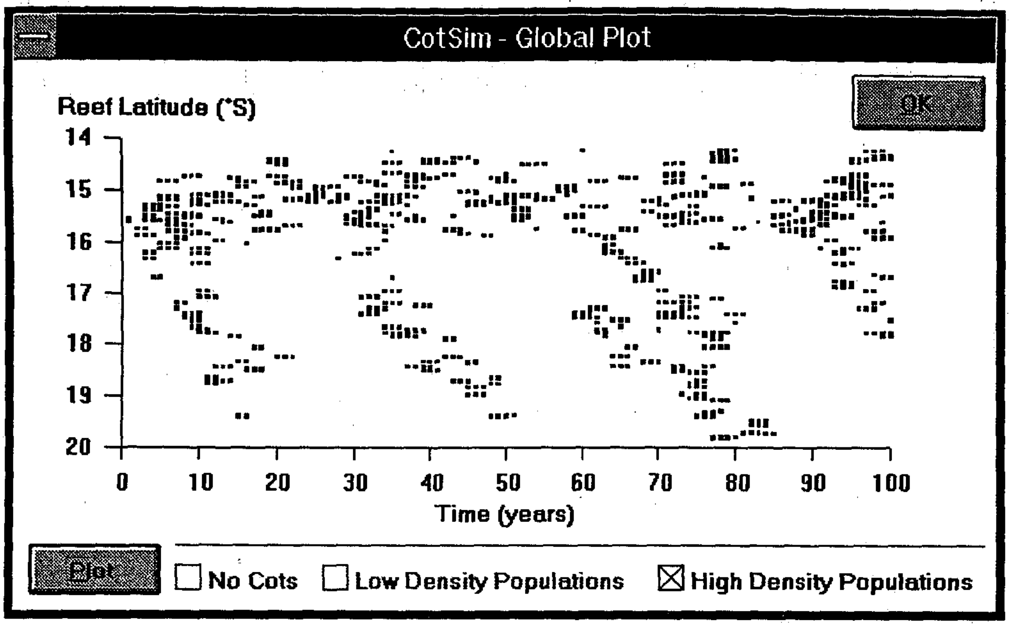

Figure 1: A typical *CotSim* global plot: latitude of reefs with outbreaks vs time. There are no explicit rules for the usage of *CotSim*. The system was not designed for formal experimentation, but exploration of ideas. The following list is a subset of the types of investigation that could be completed with *CotSim*.

- How much variation exists in five different replicates of the system (using the same parameters)?
- What difference in a replicate occurs if started with medium rather than high density populations?
- What initial model definitions give the best qualitative agreement with the field observations? How robust is this answer?
- Does the location of a reef affect the recruitment patterns of *Acanthaster*?
- What is the effect of self-seeding of reefs?
- How difficult would it be to control an outbreak?

CotSim will not answer these questions, merely allow users to explore the ideas. Sample problems for *CotSim* users are suggested in the survey (*Appendix A*).

Discussion

Models have great potential for the construction and explanation of ideas. To realise that potential, we must explore new methods of definition, interpretation and implementation. *CotSim* has introduced concepts from scientific visualisation and gaming-simulation to the *Acanthaster* debate. By monitoring response it is hoped that the role of these techniques can be assessed accurately enough so that integration into future modelling programs can be facilitated. Response will be measured with simple survey techniques. The results of this study will be the first measure of attitude to *Acanthaster* modelling that has been undertaken.

The *CotSim* model won't generate results that are "statistically significant", but may, as a consequence of its design, give some users a better understanding of complex concepts (such as inter-year recruitment variation). Modelling studies can have quite different applications. Some models may provide "intuitive" information, others "statistically significant" information. Both of these may be required for the effective integration of modelling into management strategies.

The potential role of gaming-simulation in *Acanthaster* management is unexplored. These techniques are ideal for dealing with decision systems where parties may have conflicting or contradictory points of view (Gray & Borovits 1986). The management of the *Acanthaster* phenomenon involves physical and biological scientists, industries with large vested interests, media representatives, and an interested general public. Management personnel must deal with these parties by guiding research and justifying their actions (including inaction) to this varied audience. Workshops could be designed to enable such players to simulate their reactions to a third outbreak, and how those actions might effect the outbreak scenario. These sorts of management games may be capable of producing important results. For example, the tourist industry representatives may realise that extensive lobbying for starfish controls may simply create unnecessary concern about the outbreak. Tourism receipts may be adversely affected by this publicity and the control efforts may be worthless and expensive because outbreaks were discovered too late. Simulations of this type could also be used to test the effectiveness of contingency plans (Lassig *et al., in press*).

In management, decisions are inevitable. If experimentation is not possible, deductive inferences are made about the possible outcomes of decisions, using underlying assumptions. If these underlying assumptions are presented clearly, they will be discussed and evaluated critically. Modelling in this general sense is unavoidable, so we should do so openly (Walters 1986). The *CotSim* project attempts to meet this criterion.

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References

Birkeland C and Lucas JS (1990)
Acanthaster planci: Major management problem of coral reefs.
CRC Press, Boca Raton, 257 pp.

Bradbury RH (ed.) (1990)
Acanthaster and the coral reef: a theoretical perspective.
Lecture notes in biomathematics 88, Springer Verlag, New York.

Caswell H (1989)
Matrix population models construction, analysis, and interpretation.
Sinauer, Sunderland.

Cruickshank D (1992)
S.A.V.E. (Scientific Analysis for Visualisation of the Environment)
IRIS Universe 19: 10-13

Dight IJ, Bode L and James MK (1990a)
Modelling the larval dispersal of *Acanthaster planci*: I Large scale hydrodynamics, Cairns Section, Great Barrier Reef Marine Park.
Coral Reefs 9: 115-123

Dight IJ, James MK and Bode L (1990b)
Modelling the larval dispersal of *Acanthaster planci*: II Patterns of reef connectivity.
Coral Reefs 9: 125-134

Engelhardt U and Lassig B (eds.) (1992)
Crown-of-thorns starfish - Research Update 1991/92.
Great Barrier Reef Marine Park Authority, 19 pp.

Foley JD, van Dam A, Feiner SK and Hughes JF (1990)
Computer graphics - principles and practice.
Addison-Wesley, New York.

GBRMPA and AIMS (1992)
The crown-of-thorns phenomenon.
Video, available from GBRMPA, Townsville.

Gray P and Borovits I (1986)
The contrasting roles of *Monte Carlo* simulation and gaming in decision support systems.
Simulation 47(6): 233-239

Greenblat CS (1988)
Designing games and simulations - an illustrated handbook.
Sage Publications, Newbury Park.

Jones B 1992)
Enstein is our only icon.
New Scientist 1822: 46 (Australian edition only)

Lassig BR and Kelleher G (1991)
Crown-of-thorns starfish on the Great Barrier Reef.
in: Environmental Research in Australia, Australian Government Publishing Service, Canberra, pp 39-62.

Lassig BR, Gladstone W, Moran P and Engelhardt U (*in press*)
A crown-of-thorns starfish contingency plan.
Proc. 7th Int. Coral Reef Symp., Guam.

Law AM and Kelton WD (1991)
Simulation modelling and analysis.
McGraw-Hill, New York.

Microsoft (1991)
Microsoft Visual Basic 1.0 - Programming system for Windows.
Microsoft Corporation, Redmond.

Microsoft (1992)
Microsoft Windows operating system Version 3.1.
Microsoft Corporation, Redmond.

Moran PJ (1986)
The *Acanthaster* phenomenon.
Oceanogr. Mar. Biol. Ann. Rev. 24: 379-480

Nielson GM (1991)
Visualisation in scientific and engineering computation.
Computer 9: 58-66

Reichelt RE, Greve W, Bradbury RH and Moran PJ (1990)
Acanthaster planci outbreak initiation: a starfish-coral site model.
Ecological Modelling 49: 153-177

Scandol JP (1992)
CotSim: An interactive model of *Acanthaster planci* for the Great Barrier Reef.
Department of Civil and Systems Engineering, James Cook University.

Scandol JP (*in preparation*)
Metapopulation models of *Acanthaster planci* for the central Great Barrier Reef: an analysis of design, interpretation and role in management.
PhD Thesis, James Cook University, Townsville.

Scandol JP and James MK (1992)
Hydrodynamics and larval dispersal: a population model of *Acanthaster planci* on the Great Barrier Reef.
Aust. J. Mar. Freshwater Res. 43(3): 583-596

Sluczanowski PR (1991)
Computer graphics models of fisheries.
National Agricultural and Resources Outlook Conference 1991, ABARE, Canberra, (paper available from the author at the South Australian Department of Fisheries).

Thalmann D (ed.) (1990)
Scientific visualization and graphics simulation.
John Wiley & Sons, Chichester.

Walters C (1986)
Adaptive management of renewable resources.
MacMillan, New York.

Zann L and Eager E (eds.) (1987)
The crown of thorns starfish.
(Special Feature of Australian Science Mag) Great Barrier Reef Marine Park Authority, Townsville.

Appendix A: *CotSim* User Survey

CotSim Questionnaire

1 Please indicate which area best describes your occupation
(tick one only)
- ◻ secondary school student
- ◻ undergraduate
- ◻ postgraduate
- ◻ teaching/tutoring
- ◻ researcher
- ◻ management
- ◻ other (please specify) ________

2 How do you consider your knowledge of Crown-of-thorns starfish on the Great Barrier Reef
(tick one only)
- ◻ non existent
- ◻ general media reports only
- ◻ basic understanding
- ◻ good understanding
- ◻ other (please specify) ________

3 What is your experience of ecological models
(tick one only)
- ◻ never seen or read about any
- ◻ read books or papers
- ◻ developed own ecological models
- ◻ other (please specify) ________

4 What is your attitude to ecological models
(tick as many responses as required)
- ◻ don't have one
- ◻ of no use
- ◻ of scientific use
- ◻ useful for public communication
- ◻ other (please specify) ________

5 Did you find *CotSim*
(tick one only)
- ◻ confusing
- ◻ entertaining
- ◻ boring
- ◻ interesting
- ◻ too difficult to use (please go to Question 6)
- ◻ other (please specify) ________

If the answer to question (5) was: "too difficult too use" then please answer the next question (6), otherwise please answer the rest of the questions starting at question (7).

6 *CotSim* was too difficult because
(tick one only)
- ◻ don't understand computers
- ◻ don't understand anything about Crown-of-thorns on the Great Barrier Reef
- ◻ interface did not make sense
- ◻ other (please specify) ________

Thanks for completing this survey. Please turn to the end of the questionnaire.

CotSim Questionnaire 1

7 Please indicate the approximate amount of time you spent using *CotSim* (including units), ________

was this,
(tick one only)
- ◻ much less than expected
- ◻ less than expected
- ◻ about the same as expected
- ◻ more than expected
- ◻ much more than expected
- ◻ other (please specify) ________

8 Is the interface for *CotSim*
(tick one only)
- ◻ too detailed
- ◻ about right
- ◻ not detailed enough
- ◻ other (please specify) ________

9 Is the underlying model for *CotSim*
(tick one only)
- ◻ too detailed
- ◻ about right
- ◻ not detailed enough
- ◻ other (please specify) ________

10 What is the least believable aspect of the *CotSim* model?
(tick as many responses as required)
- ◻ the representation of starfish populations on the reef
- ◻ the starfish growth model
- ◻ the coral model
- ◻ the spawning model
- ◻ the fertilisation model
- ◻ the dispersal model

continued next column

continued from question 10
- ◻ the definition of initial populations
- ◻ other (please specify) ________

11 What are the most believable aspects of the *CotSim* model?
(tick as many responses as required)
- ◻ the representation of starfish populations on the reef
- ◻ the starfish growth model
- ◻ the coral model
- ◻ the spawning model
- ◻ the fertilisation model
- ◻ the dispersal model
- ◻ the definition of initial populations
- ◻ other (please specify) ________

12 After your experience with *CotSim* do you:
(tick one only)
- ◻ know more about the Crown-of-thorns phenomenon
- ◻ know the same amount the Crown-of-thorns phenomenon
- ◻ know less about the Crown-of-thorns phenomenon
- ◻ other (please specify) ________

13 Do you think that ecological models are:
(tick as many responses as required)
- ◻ important for scientific research
- ◻ unimportant for scientific research
- ◻ a waste of time and money
- ◻ toys but not real research
- ◻ important in ecosystem management
- ◻ unimportant for ecosystem management
- ◻ other (please specify) ________

2 *CotSim* Questionnaire

14 Do you think easy to use interfaces for ecological models are:
(tick one only)
- ◻ a waste of time and money
- ◻ not necessary
- ◻ useful but not critical
- ◻ important
- ◻ absolutely critical
- ◻ other (please specify) ________

15 What features or processes would you like to see added to a future version of *CotSim*?

16 Please write any other comments here.

Thank you for taking the time to fill in the *CotSim* questionnaire. Your response will help in the understanding of the role of these population models in scientific research programs.

The following questions are real research problems that could be explored with *CotSim*. If you would like to try this exercise please note your answers in the spaces provided.

Please use the parameter file "survq.cot" and initial reef file "survq.irf" and don't alter these files. This will enable different people to have comparable responses.

Q1 How would you define a Crown-of-thorns outbreak?
(tick one only)
- ◻ a certain proportion of reefs with high density populations of Crown-of-thorns
- ◻ coral cover being substantially reduced by Crown-of-thorns on a certain proportion of reefs
- ◻ reefs of commercial tourist value having their coral cover substantially reduced by Crown-of-thorns
- ◻ other (please specify) ________

Q2 How easy is it to generate Crown-of-thorns outbreaks with *CotSim*?
(tick one only)
- ◻ impossible
- ◻ difficult
- ◻ moderate
- ◻ easy
- ◻ trivial
- ◻ other (please specify) ________

CotSim Questionnaire 3

Q3 How would you describe the repetitive pattern of Crown-of-thorns outbreaks?
(tick one only)
- ◻ cyclical (fixed and predictable period between outbreaks)
- ◻ outbreaks occur randomly in time
- ◻ impossible to say
- ◻ other (please specify) ________

Q4 Are all outbreaks the same?
- ◻ yes
- ◻ maybe
- ◻ no
- ◻ impossible to say
- ◻ other (please specify) ________

Q5 Can the slower growing corals survive the effect of these types of Crown-of-thorns outbreaks?
- ◻ yes
- ◻ maybe
- ◻ no
- ◻ impossible to say
- ◻ other (please specify) ________

Q6 How easy is it to stop a Crown-of-thorns outbreak on the Great Barrier Reef?
(tick one only)
- ◻ always impossible
- ◻ possible if less than five reefs populated
- ◻ possible if less than ten reefs populated
- ◻ possible if less than twenty reefs populated
- ◻ always possible
- ◻ other (please specify) ________

Q7 If you did not have access to the information about Crown-of-thorns on the *CotSim* reef maps, how would you detect an outbreak ?
(Try this by turning off all Crown-of-thorns population markers for the maps.)
(tick one answer only)
- ◻ sample reefs on the GBR randomly
- ◻ sample reefs which are of commercial tourist value
- ◻ sample reefs which had previously suffered an outbreak
- ◻ sample reefs in certain reef sectors (maps) only (if this is your selection please note which sectors here)
- ◻ other (please specify) ________

Q8 How many replicate simulations did you examine when trying to answer these questions?

If you would like to be sent a summary of the results of this survey, please provide your name and address below, and then return the completed survey. If you would like this information but would prefer your survey response to remain anonymous then please return your request for the results and address separately.

Please post or fax completed questionnaires to:

James Scandol
Department of Civil & Systems Engineering
James Cook University
Townsville 4811
phone (077) 81 5079 / 73 1001
fax (077) 75 1184

4 *CotSim* Questionnaire

Appendix B: List of test sites for *CotSim*

Institution	Expected Number of Respondents
Department of Zoology James Cook University	10
Department of Marine Biology James Cook University	10
Great Barrier Reef Marine Park Authority	5
Australian Institute of Marine Science	10
Department of Civil & Systems Engineering James Cook University	5
Department of Zoology University of Queensland	5
UOG Marine Laboratory University of Guam	5
South Australian Department of Fisheries	3
School of Biological Sciences The University of Sydney	5
School of Resource Science and Management The University of New England	3