Age determination and life-history characteristics of *Acanthaster planci* (L.) (Echinodermata: Asteroidea).

Thesis submitted by Richard Julian Witherington Stump

October 1994

for the degree of Doctor of Philosophy in the Department of Zoology

at James Cook University of North Queensland

STATEMENT OF ACCESS

I, the undersigned author of this work, understand that James Cook University will make this thesis available for use within the University Library and, via the Australian Digital Theses network, for use elsewhere.

I understand that, as an unpublished work, a thesis has significant protection under the Copyright Act and;

I do not wish to place any further restriction on access to this work

Signature   Date

STATEMENT ON SOURCES

Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

…………………………………………….. ………………………

(Signature) (Date)

In support of this thesis

The following publication has been derived from work connected with the production of this thesis, and a copy of the publication is included in the back of this thesis:

Stump, R.J.W. and J.S. Lucas, 1990

Linear growth in spines from *Acanthaster planci* (L.) involving growth lines and periodic pigment bands. Coral Reefs 9:149-154.

Acknowledgments

The project was funded by the Crown-Of-Thorns Research Committee (COTSREC) through the Great Barrier Reef Marine Park Authority (GBRMPA), and the Department of Industry, Technology and Commerce (DITAC). Additional funding was obtained through GBRMPA Augmentative Grants and JCUNQ Merit Research Awards (MRA). Their support is gratefully acknowledged. Considerable support came from the AIMS infrastructure, fortunately available at that time.

To my supervisor, Professor John Lucas, my thanks for his consistent guidance and support over seven years from the beginnings as a research assistant for Brett Kettle's project, and for his helpful consultations throughout the evolution and completion of this project. I would like to thank Professor Rhondda Jones (JCUNQ) for her support and allowing me to develop both her and John's ideas to investigate methods of determining age in *A. planci*. Also, belated thanks to Dr Roger Bradbury and Dr Peter Moran (AIMS), who gave me the initial opportunity in marine science in 1985, through the COTS-CCEP program, which led to this project.

Dr Peter Moran (AIMS) was instrumental in his support of the project from its early stages, providing access to valuable AIMS shiptime for the field studies and for extending the availability of benchspace and aquaria. I am especially indebted to Mr John Hardman (AIMS) who fearlessly provided essential support and access to equipment for many of the field trips, including to Lord Howe Island. Thanks to Dr Glenn De'ath (JCUNQ) who freely offered consultation and advice and helped me with the analyses, although any incorrect results are solely my own responsibility. Dr John Keesing (AIMS), Dr Russ Babcock (AIMS) and Dr Jean-Pierre Gattuso (AIMS) also assisted with shared shiptime. Dr Leon Zann (GBRMPA), Dr Brian Lassig (GBRMPA), Dr John Lawrence (USF, Florida), Professor Charles Birkeland (UOG, Guam), Professor Robin South (USP, Suva), Dr Ross Alford (JCUNQ), Dr John Glazebrook (JCUNQ) and Dr Brett Kettle, all contributed through helpful discussions and encouragement.

A large contingent of friends and willing assistants gave up their time to enable the field and laboratory work to be completed, I give thanks for their labour and patience. The bulk of an enormous pile of *A. planci* skeletal remains, approximately $1m^3$, was duly processed, sorted and measured with much perseverance by Evizel Seymour and Judy Logan. Their tireless, reliable assistance is testament to their scientific skills.

Ed Lovell and Veikila Vuki (Biological Consultants, Fiji P/L) provided excellent service and scientific support in all aspects of the project during the Suva Reef study. Fiu Manueli (IMR/USP, Fiji) and Chris Basseler (UOG Marine Laboratory, Guam) organised and provided able field support for the field collections, their humour and patience made all tasks possible. Tony McKenna took on the, at times unpleasant, task of watching over aquaria at AIMS when I was unable to travel to Cape Ferguson from town; a lesson for postgraduates attempting manipulative experiments on marine species some distance from home and university. Steve Clark (AIMS) and Fiona Alongi (GBRMPA) provided expertise in the production of the graphics and maps, their assistance is gratefully appreciated.

David Hannan (Coral Sea Images) was a valued assistant in the early stages of the field study, his underwater skills are remarkable. David and I conducted a field trip to Lord Howe Island and I pay tribute to his enthusiasm, perseverance and financial help during a trip where mischievous information thwarted the best laid plans, and without his help I would have returned empty handed. I also acknowledge the assistance from the Lord Howe Island Board, the Australian National Parks and Wildlife Service (ANPWS) and Mobil Australia during the field trip. Dr John Blyth (Lord Howe Island Medical Centre) volunteered his time to help with field work and obtain further data after my visit, which was a tremendous help.

I would also like to thank: Marlene McBrien, Craig Mundy, Debbie Bass, Angus Thompson, Ian Miller, Bruce Miller-Smith, Rundi Larsen, Kirsten McAllister, Steve Lindsay, Erin Shanahan, Nina Morrisette, Carol Eberhardt, Joan Millett, David Ahearn, Ben Lees, Susie Griffiths, David and Anne Wadley, Toni Davis, Rob Rowan, Paul Chirichetti, David Welsch, Sheryl Fitzpatrick, Andrew Halford, Peter Eden, Simeon De Vow, Valonna Baker, Mark Lennard, Dave Duncan, Bill Gladstone, Udo Engelhardt, the captains and crews of the "RV Harry Messel" and "RV Lady Basten" (AIMS), QNPWS (Marine Parks) Whitsunday Group and Capricorn-Bunker Group Branches. Tony and Kathy Tubbenhauer (Burnett Heads) freely provided lodging, meals, assistance and considerable local knowledge during the Lady Musgrave Reef field trip, purely out of their interest in marine biology. They are also recognised for their contribution to marine research on the GBR for over 30 years. Thanks to my friends, Keith and Sue Harron, and Mark and Rowena Martin for their support, in every sense.

This thesis is dedicated to my parents, Gay and Dion.

Abstract

In the past, age classes in *Acanthaster planci* (L.) populations have been interpreted from modes in size frequency distributions. The relationship between size and age has continued to be used in studies despite increasing evidence of growth characteristics which are inconsistent with inherent assumptions. This approach was rationalised because the ability to determine age is fundamental to understanding the ecology and life history of this unique species, capable of developing massive outbreak populations and incurring widespread mortality of hard coral species. Therefore, the aims of the project were to develop a valid method of age determination and employ it to investigate the population dynamics, the morphometry of individual and skeletal growth and other life-history characteristics of several populations from the Western Pacific region.

Valid age determination in echinoderms has been achieved almost exclusively with echinoid species through skeletochronometric techniques. Periodic growth rings are generally found in larger skeletal elements such as test plates, since the echinoderm skeleton consists of an open tridimensional network, the calcitic stereom. However, the Asteroidea characteristically develop a skeleton of smaller ossicles which allows for a wide range of flexible movement, for locomotion, climbing and food handling. An exception is *A. planci* which has large spines that rest on pedicels, rooted in the aboral body wall, that do not restrict its habits.

The aboral spine ossicles of adult *A. planci* have a linear growth pattern unlike the mode of development previously reported for echinoids. Numerous growth lines, perpendicular to the long axis were evident in spine sections and confirmed with tetracycline staining, apparently caused by frequent growth episodes. Spine growth in adults is by elongation with addition of new stereom at the base, preserving the entire growth history. Broad pigment bands develop parallel to the growth lines and are visible on the ossicle surface after the removal of soft tissues. Therefore, it was hypothesised that spine pigment band counts (SPBC) can be used to determine age in *A. planci*, commencing after sexual maturity, in the third (2+) year. At this time,

body growth slows and spine ossicle growth changes from enlargement in three dimensions to a mode primarily of elongation. Therefore, one SPBC (light and dark band pair) = 3+ years, two SPBC = 4+ years, etc,. A biosynthetic mechanism was proposed to explain the functional role of the pigment banding process.

Field studies were conducted on Davies Reef, Central GBR, to validate the SPBC method. They consisted of mark\recapture exercises and collections of morphometric data for seasonal and longer-term growth analyses. The recapture rate for marked individuals was 3.5%. Twelve of thirteen recaptured individuals whose release periods were at least twelve months supported the validation of age classes 3+, 4+ and 5+ years. A further ten recaptures were obtained with release periods of less than twelve months, with incomplete band pair formation, also supporting the method. Further independent evidence comes from morphometric results, including: annual incremental growth in the SPBC classes; a significant increase in mean spine ossicle length over the 38 month study period; consistent estimates of the growth constant (K = 0.039mo.$^{-1}$) between the recapture and morphometric analyses; and the coincidence of the timing of the outbreak from survey results with the estimated age of the first outbreak cohort.

The outbreak population density on Davies Reef was approximately 420ha.$^{-1}$. This is at the lower end of the scale of outbreak sizes, and consisted of four principal cohorts, estimated to have settled between 1983 and 1986. A significant reduction in population size over the study period, following a profound decline in coral cover, was caused by high mortality rates in the post-outbreak cohorts. Lower mean asymptotic body sizes in each successive cohort occurred as a response to the increasingly limited resources.

A. planci can grow to well over 60cm in diameter and 4kg in wet weight, but more often exhibits lower ranges, well below maximum attainable size. The mode of growth varies between habitat-dependent, asymptotic growth (determinate) and plastic asymptotic growth (indeterminate). Therefore, determinate growth occurs when constraints are imposed on an underlying potential for indeterminate growth. Further physiological studies are required to describe precisely how *A. planci* reach very large body sizes under solely intrinsic resource limitation.

Sexually dimorphic characteristics were found in the Davies Reef outbreak population, where male starfish had lower gonad weights, and longer lifespans, promoting high fertilization rates during the decline phase of outbreaks. Higher estimated reproductive effort and a seasonal oscillation in whole body diameter of 2 to 3cm occurred in the post-outbreak cohorts. Therefore, larger body sizes in the pre-outbreak cohorts allowed for storage of relatively greater energy reserves to offset fluctuations in body size and the energetic demands of reproduction, promoting iteroparity and longevity. When resources became limited in higher densities, body reserves were drawn upon more heavily in order to support the increased reproductive effort causing resorption of body wall and skeletal tissues, resulting in shrinkage and presumably reduced lifespan.

Among the Western Pacific populations studied (Suva Reef, Guam and Davies Reef) reproductive tactics were described as "big-bang iteroparity" (Davies Reef and Suva Reef), approaching semelparity in higher density outbreaks, and iteroparous with a lower reproductive output (Guam). A life-history strategy of phenotypically polymorphic bet-hedging is proposed for *A. planci*, which varies according to sex, population density, the pattern of mortality from *stress* (decreased production), and *disturbance* (loss of biomass). Therefore, *A. planci* owes its success to the ability to vary its channelling of resources into the various functions of growth, somatic maintenance, protection and reproduction. To maintain this variable strategy between iteroparity and semelparity implies that periodic outbreaks of *A. planci* occur within regions under natural conditions. The immediate concerns of management agencies regarding the prediction of outbreaks should focus on the dynamics of expanding populations i.e. those leading to primary outbreaks. These issues can only be addressed through the implementation of long-term population studies, including the assessment of age structure, particularly in areas where primary outbreaks are suspected to occur.

TABLE OF CONTENTS

CHAPTER 2

VALIDATION STUDY OF THE SPINE PIGMENT BAND COUNT (SPBC) METHOD OF AGE DETERMINATION FOR *A. planci.*

CHAPTER 3

THE DAVIES REEF POPULATION STUDY OF *A.planci.*

CHAPTER 4

COMPARATIVE MORPHOMETRIC STUDY OF *A. planci* POPULATIONS FROM THE WESTERN PACIFIC REGION

CHAPTER 5

REPRODUCTIVE MORPHOMETRY OF *A. planci* FROM THE WESTERN PACIFIC REGION

List of Tables

CHAPTER 1.

CHAPTER 3

CHAPTER 5

List of Figures

(f) Adult aboral spine ossicle in longitudinal section showing detail of the intersection between the spine apex and shaft. The medulla (m) develops from the spine apex. The cortex (c) develops and expands from the remanent juvenile spine margins. (bar = 0.5mm)

(g) Spine and pedicel ossicles from a juvenile *A. planci* reared in the laboratory (BD = 12cm) and an adult *A. planci* (BD = cm) collected from Davies Reef, Central GBR. The spear-like spine apex has developed prior to the spine shaft in the older specimen. (bar = 10mm)

(h) Aboral spines from one *A. planci* recaptured after 6 months on Davies Reef, Central GBR (October, 1988 to April, 1989 (A)). Pigment bands are matched between the two sets of spines revealing the new spine growth and banding in the lower group of 3 spines. (bar = 10mm)

Figure 2.3a-c. Spine ossicle samples from 3 marked and recaptured individuals which demonstrate the growth and banding pattern developed over 12 to 14 months; arrowheads indicate light bands (L) developed between dark bands (D) on the shaft after spine apex (scale approx. bar = 0.7mm):

(a) Released 10/89, for 14 months (growth = D + L)

(b) Released 10/89, for 18 months (growth D + L + D)

(c) Released 3/90, for 14 months (growth L + D)

(d) Recapture after identification in the field using two adjacent regenerated arms (arrows) which are smaller than neighbouring arms and the spines are commensurately short (body diameter = 37cm).

CHAPTER 3. The Davies Reef population study

CHAPTER 5