
Access to this file is available from:


The author has certified to JCU that they have made a reasonable effort to gain permission and acknowledge the owner of any third party copyright material included in this document. If you believe that this is not the case, please contact ResearchOnline@jcu.edu.au and quote [http://eprints.jcu.edu.au/24115/](http://eprints.jcu.edu.au/24115/).
Age specific patterns of growth and reproduction in tropical herbivorous fishes

Thesis submitted by
Dong Chun Lou  BSc Hons (Shanghai)
in June 1992

for the degree of Doctor of Philosophy in
the Department of Marine Biology at
James Cook University of North Queensland
ABSTRACT

Research of growth and reproduction was undertaken for scarids and acanthurids in coral reefs around Lizard Island, the Northern Great Barrier Reef, Australia. The study species were mainly the scarids *Scarus rivulatus* and *Scarus schlegeli*, and the acanthurids *Ctenochaetus binotatus* and *Ctenochaetus striatus*. The study focussed on the establishment of validated aging information for both scarids and acanthurids, and the age-specific patterns of reproduction of scarids.

Age and growth parameters were determined by enumerating growth increments within otolith microstructure for each species. Various mounting and grinding/polishing techniques were employed to reveal both fine lapillus growth rings in juveniles and sagitta growth bands in adults. Daily periodicity in otolith increments was demonstrated in 55 juvenile individuals in four of the main study species: *S.rivulatus* (20), *S.schlegeli* (21), *C.binotatus* (12) and *C.striatus* (2), and 28 individuals of other species within the two families. Ring periodicity was determined by staining the otoliths *in situ* with tetracycline, and maintaining the individuals in captivity to compare the rings laid down with the number of elapsed days. Double staining techniques were also employed to determine the rings laid down between stainings.

Annual periodicity in otolith bands was demonstrated by tag-recapture experiments in the both the aquarium and the field, and by otolith marginal increment analyses for the four study species. All recaptured specimens, including four *S.schlegeli* and four *C.striatus*, showed annual otolith bands. The otolith marginal development on regular samples over the year for *S.rivulatus* and *S.schlegeli* also
indicated that a single otolith band was formed during December to May.

By enumerating otolith increments and bands, age of the field captured individuals of each study species was estimated. The age of scarids ranged up to 8 years with the majority being younger than 5 years. The growth rate was increasing with age in days during the juvenile phase, and gradually decreased after that. The acanthurids lived for relatively long period in excess of 16 years, and the growth rate decreased with age after settlement. In addition, the age of settlement was estimated to be from 28 to 47 days for scarids and from 47 to 74 days for acanthurids.

Reproductive biology of scarids was studied by seasonal examination of gonads. The gonads were examined histologically to determine the sexual identity and maturity state of individuals. By using validated aging information, the dynamics of sexual transition was observed.

Mature gonads of the two species were found throughout the year. However, a pronounced spawning peak occurred between May and September in *S. schlegeli* while a relatively less pronounced spawning peak took place from September to January in *S. rivulatus*. These patterns were indicated by seasonal development of gonadosomatic index, seasonal distribution of mature gonads, oocyte length, and the proportion of mature stage oocytes within the gonads. The proportion of mature stage oocytes within mature ovaries of two species also suggested that these species were serial spawners. Enumerating mature oocytes within the subsamples of 20 individuals in each species showed positive relationships between fecundity and body length or age.

Both females and primary males of the two species reached sexual maturity at 2 years. Females started to change sex at 3 years, and the sexual transition of the
population lasted for approximately another 3 years. Similarly, the primary males started changing color phase at 3 years. Growth rates appeared to be different between the initial phase and the terminal phase individuals, and the terminal phase individuals had a higher growth rate than that of the initial phase individuals of the same age.

The proportional liver weight in *S.rivulatus* and *S.schlegeli* changed over time, and this reflected the compositional states. Larger livers had high levels of lipids, which fact was indicated by the colour and lipid droplets. High proportional liver weight occurred immediately before spawning for both species, suggesting that the liver is an important energy storage organ providing lipids for the gonadal development. For the two species of scarids studied in similar microhabitats and similar physical environments both showed seasonal patterns of liver weight and gonadal development, but it varied in timing and magnitude.

This study suggests that scarids, which have relatively fast growth rates and short lifespans, are more suitable candidates for intensive fisheries than the low-growth and long-lifespan acanthurids. However, as the population dynamics of scarids is complicated by the protogynous hermaphroditism, comprehensive management is required in scarid fisheries.
ACKNOWLEDGMENTS

I am very grateful to my supervisor, Prof. Howard Choat, for his constant guidance, enthusiasm and encouragement; also for his assistance in the sample collection. I would also like to make especial mention of two persons: Dr Kendall Clements, whose constant help in the field work, making a great contribution to this project; and Dr George Jackson, who made improvement on the earlier manuscript.

I would also like to thank:

The Chinese government for providing an initial financial support; James Cook University of North Queensland for supporting my research with a James Cook University Postgraduate Scholarship Research Award, and an ARC grant to Prof. J.H. Choat and Dr. G. Russ;

the staff of the Lizard Island Research Station;

the technical staff of the School of Bioscience, James Cook University, especially Leigh Winsor and Zolly Florian;

Dr David Bellwood, Brigid Kerrigan, Mark McCormick, Alison Green, Lida Axe, Beatrice Ferreira for additional help in the field.

Mark McCormick, Natalie Moltschaniwskyj, Mark Hearnden, Orpha Bellwood, Bodle Hendrarto, Frank Hoedt, Pat Vance, and Ann Sharp for help with production, computing, sampling design and analysis;

Phil McGuire, Jim Darley and L. R. Reilly for help with experiments and photograph;

Finally, I am grateful to my wife, for her love and support throughout this study.
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.

D.C. Lou
30 June 1992
STATEMENT OF ACCESS

I, the undersigned, the author of this thesis, understand that James Cook University of North Queensland will make it available for use within the University Library and, by microfilm or other photographic means, allow access to users in other approved libraries. All users consulting this thesis will have to sign the following statement:

"In consulting this thesis I agree not to copy or closely paraphrase it in whole or in part without the written consent of the author; and to make proper written acknowledgment for any assistance which I have obtained from it."

Beyond this, I do not wish to place any restriction on access to this thesis.

.................................  10/7/92
(signature)                      (date)
<table>
<thead>
<tr>
<th>TABLE OF CONTENTS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>i</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>iv</td>
</tr>
<tr>
<td>Declaration</td>
<td>v</td>
</tr>
<tr>
<td>Statement of Access</td>
<td>vi</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>vii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xiv</td>
</tr>
<tr>
<td>List of Tables</td>
<td>xix</td>
</tr>
<tr>
<td>List of Plates</td>
<td>xxiii</td>
</tr>
<tr>
<td>CHAPTER 1: GENERAL INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>CHAPTER 2: GENERAL METHODS</td>
<td>7</td>
</tr>
<tr>
<td>2.1 Study species</td>
<td>7</td>
</tr>
<tr>
<td>2.2 Study area</td>
<td>8</td>
</tr>
<tr>
<td>2.3 Sampling and preserving methods</td>
<td>9</td>
</tr>
<tr>
<td>2.4 Terminology</td>
<td>14</td>
</tr>
<tr>
<td>2.5 Colour phase and sexual identity of scarids</td>
<td>15</td>
</tr>
<tr>
<td>CHAPTER 3: VALIDATION OF AGING TECHNIQUE FOR JUVENILE ACANTHURIDS AND SCARIDS</td>
<td>16</td>
</tr>
<tr>
<td>3.1 INTRODUCTION</td>
<td>16</td>
</tr>
<tr>
<td>3.2 MATERIALS AND METHODS</td>
<td>18</td>
</tr>
<tr>
<td>3.2.1 Juvenile collection</td>
<td>18</td>
</tr>
<tr>
<td>3.2.2 Validation experiments</td>
<td>18</td>
</tr>
<tr>
<td>3.2.3 Otolith preparation</td>
<td>19</td>
</tr>
<tr>
<td>3.2.4 Otolith increment counting and its consistency test</td>
<td>22</td>
</tr>
<tr>
<td>3.3 RESULTS</td>
<td>23</td>
</tr>
</tbody>
</table>
3.3.1 General structures ........................................... 23
3.3.2 Validation of daily otolith increments .................... 24
3.3.3 Consistency test in increment counting .................... 31

3.4 DISCUSSION .................................................... 31
3.4.1 Daily otolith increments .................................... 34
3.4.2 Counting procedure ........................................ 36

CHAPTER 4: VALIDATION OF AGING TECHNIQUE FOR ADULT
ACANTHURIDS AND SCARIDS ........................................ 37

4.1 INTRODUCTION .................................................. 37

4.2 MATERIALS AND METHODS .................................... 38
4.2.1 Specimen collection ......................................... 38
4.2.2 Analysis of otoliths ......................................... 39
4.2.2.1 Whole otoliths ......................................... 39
4.2.2.2 Transverse section ..................................... 39
4.2.3 Validation of periodicity of otolith growth bands ........ 41
4.2.3.1 Tagging experiment ..................................... 41
4.2.3.2 Analysis of otolith marginal increments ............... 42
4.2.4 Scale analysis ................................................ 42

4.3 RESULTS ......................................................... 46
4.3.1 Analysis of otoliths .......................................... 46
4.3.1.1 Whole sagittae .......................................... 46
4.3.1.2 Transverse sections .................................... 47
4.3.2 Validation of the periodicity of band formation .......... 64
4.3.2.1 Tagging recapture ....................................... 64
4.3.2.2 Analysis of otolith marginal increments ............... 65
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3.3 Analysis of scales</td>
<td>75</td>
</tr>
<tr>
<td>4.3.4 Comparison of otolith and scale methods</td>
<td>76</td>
</tr>
<tr>
<td>4.4 DISCUSSION</td>
<td>76</td>
</tr>
<tr>
<td>4.4.1 Otolith aging method</td>
<td>76</td>
</tr>
<tr>
<td>4.4.2 Scale aging method</td>
<td>89</td>
</tr>
<tr>
<td>CHAPTER 5: AGE AND GROWTH IN SCARIDS AND ACANTHURIDS</td>
<td>92</td>
</tr>
<tr>
<td>5.1 INTRODUCTION</td>
<td>92</td>
</tr>
<tr>
<td>5.2 MATERIALS AND METHODS</td>
<td>93</td>
</tr>
<tr>
<td>5.2.1 Estimation of age and growth for juveniles</td>
<td>93</td>
</tr>
<tr>
<td>5.2.2 Settlement checks</td>
<td>94</td>
</tr>
<tr>
<td>5.2.3 Estimation of age and growth for adults</td>
<td>94</td>
</tr>
<tr>
<td>5.2.3.1 Growth functions and curves</td>
<td>95</td>
</tr>
<tr>
<td>5.2.4 Growth comparison</td>
<td>96</td>
</tr>
<tr>
<td>5.2.4.1 Between species</td>
<td>96</td>
</tr>
<tr>
<td>5.2.4.2 Between locations</td>
<td>97</td>
</tr>
<tr>
<td>5.3 RESULTS</td>
<td>98</td>
</tr>
<tr>
<td>5.3.1 Age and growth in scarids</td>
<td>98</td>
</tr>
<tr>
<td>5.3.1.1 SL-WT relationship</td>
<td>98</td>
</tr>
<tr>
<td>5.3.1.2 Juvenile growth</td>
<td>98</td>
</tr>
<tr>
<td>5.3.1.3 Age structure and growth in adults</td>
<td>99</td>
</tr>
<tr>
<td>5.3.2 Age and growth in acanthurids</td>
<td>110</td>
</tr>
<tr>
<td>5.3.2.1 SL-WT relationship</td>
<td>110</td>
</tr>
<tr>
<td>5.3.2.2 Juvenile growth</td>
<td>110</td>
</tr>
</tbody>
</table>
5.3.2.3 Age structure and growth in adults .................. 111
5.3.3 Settlement age ........................................... 121
5.3.4 Comparison on growth between acanthurids and scarids ... 121
  5.3.4.1 Juveniles ............................................. 121
  5.3.4.2 Adults ............................................... 122
5.3.5 Growth differences between locations in Scarus rivulatus .. 122
  5.3.5.1 Magnetic Island ....................................... 122
  5.3.5.2 Arlington & Thetford Reefs ............................ 128
  5.3.5.3 Growth comparison ................................... 128
5.4 Discussion .................................................. 131
  5.4.1 Juvenile growth ........................................ 131
  5.4.2 Adult growth .......................................... 132
  5.4.3 Growth comparison ..................................... 135

CHAPTER 6: REPRODUCTIVE BIOLOGY OF SCARIDS ............... 137
6.1 INTRODUCTION .............................................. 137
6.2 MATERIALS AND METHODS ................................... 138
  6.2.1 Specimen collection and processing ..................... 138
  6.2.2 Histological examination of gonads .................... 138
    6.2.2.1 Classification of gonads .......................... 139
      6.2.2.1.1 Female and secondary male .................... 139
      6.2.2.1.2 Primary male .................................. 146
    6.2.2.1.3 Distinction between 1°♂♂ and 2°♂♂ .............. 146
  6.2.2.2 Pilot study on oocyte sampling ...................... 146
  6.2.2.3 Ovary examination .................................. 147
6.2.3 Gonadosomatic index ........................................ 149
6.2.4 Fecundity .................................................... 149
6.2.5 The relationship between sex and growth rate ............ 150
6.3 RESULTS ....................................................... 150
6.3.1 Anatomical features of the gonads ......................... 150
6.3.2 General sexual structure ........................................ 151
6.3.3 Distribution of sexual and colour patterns ..................... 151
   6.3.3.1 Scarus rivulatus ............................................. 154
   6.3.3.2 Scarus schlegeli ............................................ 155
6.3.4 Seasonal pattern of gonad activities ......................... 162
   6.3.4.1 Temporal distribution of gonad development classes ... 162
      6.3.4.1.1 Scarus rivulatus ....................................... 162
      6.3.4.1.2 Scarus schlegeli ....................................... 163
   6.3.4.2 Seasonal variation in oocyte size and relative abundance of mature stages in the gonad ............. 164
      6.3.4.2.1 Pilot sampling program ................................ 164
      6.3.4.2.2 Distribution of mature oocytes and their sizes ... 170
         6.3.4.2.2.1 Scarus rivulatus .................................. 170
         6.3.4.2.2.2 Scarus schlegeli .................................. 171
6.3.4.3 Multiple spawning and fecundity ............................ 178
6.3.5 Size at age among sexes and color phases ...................... 181
6.4 DISCUSSION .................................................. 182
   6.4.1 Anatomical features of the gonads and sexual transformation schedule ......................................... 182
   6.4.2 The breeding season, multiple spawning, and fecundity .... 191
6.4.3 Growth among sexes and color phases ....................... 192

CHAPTER 7: LIVER AND HEPATIC LIPIDS OF TROPICAL SCARIDS 195

7.1 INTRODUCTION ................................................. 195
7.2 MATERIALS AND METHODS ......................................... 195
  7.2.1 Liver collection ........................................... 196
  7.2.2 Histological examination .................................. 196
    7.2.2.1 Process .............................................. 196
    7.2.2.2 Hepatic lipid measurement ............................ 196
7.3 RESULTS ...................................................... 197
  7.3.1 General structure .......................................... 197
  7.3.2 Hepatisomatic index ...................................... 201
    7.3.2.1 Distribution by SL and age .......................... 201
    7.3.2.2 Seasonal distribution ................................ 208
      7.3.2.2.1 Scarus schlegeli ................................ 208
      7.3.2.2.2 Scarus rivulatus ................................ 208
  7.3.3 Hepatic lipids ............................................. 209
    7.3.3.1 Lipid droplets ....................................... 209
    7.3.3.2 The relationship between liver colour and HLI .... 212
    7.3.3.3 Distribution of HLI .................................. 212
      7.3.3.3.1 Scarus rivulatus ................................ 216
      7.3.3.3.2 Scarus schlegeli ................................ 216
7.4 DISCUSSION .................................................. 219

CHAPTER 8: GENERAL DISCUSSION AND CONCLUSIONS ................. 223

8.1 GENERAL DISCUSSION .......................................... 223
## LIST OF FIGURES

### Chapter Two

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>The map of Lizard Island showing all sampling sites</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>The maps of Arlington &amp; Thetford Reefs and Magnetic Island</td>
<td>11</td>
</tr>
</tbody>
</table>

### Chapter Three

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Regressions of otolith increments counted against number of days for individuals maintained after tetracycline staining</td>
<td>29</td>
</tr>
</tbody>
</table>

### Chapter Four

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Sagitta diagrams</td>
<td>45</td>
</tr>
<tr>
<td>4.2</td>
<td><em>Ctenochaetus binotatus</em>. Relationships between otolith dimensions and fish length (SL)</td>
<td>52</td>
</tr>
<tr>
<td>4.3</td>
<td><em>Ctenochaetus striatus</em>. Relationships between otolith dimensions and fish length (SL)</td>
<td>53</td>
</tr>
<tr>
<td>4.4</td>
<td><em>Scarus rivulatus</em>. Relationships between otolith dimensions and fish length (SL)</td>
<td>54</td>
</tr>
<tr>
<td>4.5</td>
<td><em>Scarus schlegeli</em>. Relationships between otolith dimensions and fish length (SL)</td>
<td>55</td>
</tr>
<tr>
<td>4.6</td>
<td>Relationships between fish length (SL) and relative growth rates (RG) of otolith dimensions</td>
<td>56</td>
</tr>
<tr>
<td>4.7</td>
<td><em>Scarus rivulatus</em>. Percent of otoliths with opaque margins by each sampling occasion</td>
<td>72</td>
</tr>
<tr>
<td>4.8</td>
<td><em>Scarus schlegeli</em>. Percent of otoliths with opaque margins by each sampling occasion</td>
<td>72</td>
</tr>
<tr>
<td>4.9</td>
<td><em>Ctenochaetus binotatus</em>. Percent of otoliths with opaque margins by each sampling occasion</td>
<td>73</td>
</tr>
<tr>
<td>4.10</td>
<td><em>Ctenochaetus striatus</em>. Percent of otoliths with opaque margins by each sampling occasion</td>
<td>73</td>
</tr>
<tr>
<td>4.11</td>
<td>Relationships between scale radius (SR) and fish length (SL)</td>
<td>82</td>
</tr>
<tr>
<td>4.12</td>
<td>Schematic diagram of parrotfish scale</td>
<td>83</td>
</tr>
</tbody>
</table>

### Chapter Five

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
</table>

xiv
Fig. 5.1 *Scarus rivulatus*. The relationship between standard length and body weight .............................................. 106

Fig. 5.2 *Scarus schlegeli*. The relationship between standard length and body weight .............................................. 106

Fig. 5.3 *Scarus rivulatus*. The growth curve of juveniles ............. 107

Fig. 5.4 *Scarus schlegeli*. The growth curve of juveniles ............. 107

Fig. 5.5 *Scarus rivulatus*. Means of observed SL versus age and means of back-calculated SL ...................................... 108

Fig. 5.6 *Scarus schlegeli*. Means of observed SL versus age and means of back-calculated SL ...................................... 108

Fig. 5.7 *Scarus rivulatus*. The overall theoretical growth curves ...... 109

Fig. 5.8 *Scarus schlegeli*. The overall theoretical growth curves ...... 109

Fig. 5.9 *Ctenochaetus striatus*. The relationship between standard length and body weight .............................................. 117

Fig. 5.10 *Ctenochaetus binotatus*. The relationship between standard length and body weight .............................................. 117

Fig. 5.11 *Ctenochaetus striatus*. The growth curve of juveniles ............. 118

Fig. 5.12 *Ctenochaetus binotatus*. The growth curve of juveniles ............. 118

Fig. 5.13 *Ctenochaetus striatus*. Means of the observed SL versus age and means for back-calculated SL ................................. 119

Fig. 5.14 *Ctenochaetus binotatus*. Means of the observed SL versus age and means of back-calculated SL ................................. 119

Fig. 5.15 *Ctenochaetus striatus*. The overall theoretical growth curves .. 120

Fig. 5.16 *Ctenochaetus binotatus*. The overall theoretical growth curves .. 120

Fig. 5.17 The juvenile growth curves of *Ctenochaetus binotatus*, *C.striatus*, *Scarus rivulatus* and *S.schlegeli* ................................. 126

Fig. 5.18 Otolith increment width series from ten juveniles ............. 127

Fig. 5.19 von Bertalanffy growth curves for *Ctenochaetus binotatus*, *C.striatus*, *Scarus rivulatus* and *S.schlegeli* ................................. 130

xv
Fig. 5.20 von Bertalanffy growth curves for *Scarus rivulatus* collected from Lizard Island, Magnetic Island and Arlington & Thetford Reef ............ 130

**Chapter Six**

Fig. 6.1 Summary of the pilot study on oocyte measurements .......... 148

Fig. 6.2 The schematic diagrams showing morphological change of testes in 1°♂ and 2°♂ with age ........................................ 153

Fig. 6.3 Proportions of each sexual type in successive 20 mm SL groupings of *Scarus rivulatus* from Lizard Island ......................... 160

Fig. 6.4 Proportions of each sexual types in each age group of *Scarus rivulatus* from Lizard Island ........................................... 160

Fig. 6.5 Proportions of each sexual type in successive 20 mm SL groupings of *Scarus schlegeli* from Lizard Island ............................. 161

Fig. 6.6 Proportions of each sexual type in each age group of *Scarus schlegeli* from Lizard Island ........................................... 161

Fig. 6.7 Number of individuals of *Scarus rivulatus* in each ovary development class .............................................................. 165

Fig. 6.8 Distribution of average mature ovary indices (GSI) from *Scarus rivulatus* ................................................................. 165

Fig. 6.9 Number of individuals of *Scarus rivulatus* in each testes development class ............................................................... 166

Fig. 6.10 Average mature testes indices (GSI) from IP male *Scarus rivulatus* ................................................................. 166

Fig. 6.11 Number of individuals of *Scarus schlegeli* in each ovary development class .......................................................... 167

Fig. 6.12 Average mature ovary indices (GSI) from *Scarus schlegeli* ...... 167

Fig. 6.13 Number of individuals of *Scarus schlegeli* in each testes development class ......................................................... 168

Fig. 6.14 Average mature testes indices (GSI) from IP male *Scarus schlegeli* ................................................................. 168

Fig. 6.15 Distribution of the different stage oocytes from testing specimens of *Scarus schlegeli* .................................................. 174
Fig. 6.16 Distribution of the different stage oocytes from the testing specimens of *Scarus rivulatus* ............................... 175

Fig. 6.17 Average proportion of stage 4 and 3 oocytes for mature females of *Scarus rivulatus* ........................................... 176

Fig. 6.18 Average oocyte length for mature females of *Scarus rivulatus* ................................................................. 176

Fig. 6.19 Average proportion of stage 4 and 3 oocytes for mature females of *Scarus schlegeli* .............................................. 177

Fig. 6.20 Average oocyte length for mature females of *Scarus schlegeli* ................................................................. 177

Fig. 6.21 Distribution of the total number of vitellogenic oocytes by SL of *Scarus rivulatus* ................................................... 179

Fig. 6.22 Distribution of the total number of vitellogenic oocytes by age of *Scarus rivulatus* .................................................. 179

Fig. 6.23 Distribution of the total number of vitellogenic oocytes by SL of *Scarus schlegeli* ................................................... 180

Fig. 6.24 Distribution of the total number of vitellogenic oocytes by age of *Scarus schlegeli* .................................................. 180

Fig. 6.25 Mean lengths for successive age groups of females, IP 1♂♂, TP 1♂♂ and 2♂♂ of *Scarus rivulatus* ............................. 187

Fig. 6.26 Mean lengths for successive age groups of females, IP 1♂♂, TP 1♂♂ and 2♂♂ of *Scarus schlegeli* ............................. 188

Chapter Seven

Fig. 7.1 A schematic diagram of histological liver sections .................. 198

Fig. 7.2 *Scarus rivulatus*. The distribution of hepatosomatic index (HSI) by SL in different sexual types and color phases .......... 206

Fig. 7.3 *Scarus rivulatus*. HSI distribution by age classes in different sexual types and color phases ................................. 206

Fig. 7.4 *Scarus schlegeli*. HSI distribution by SL in different sexual types and color phases ................................................ 207

Fig. 7.5 *Scarus schlegeli*. HSI distribution by age class in different sexual types and color phases ........................................ 207
Fig. 7.6 Average HSI from *Scarus schlegeli* .................. 210

Fig. 7.7 Average HSI from *Scarus rivulatus* .................. 210

Fig. 7.8 Distribution of hepatic lipid droplets in four measuring areas (DO, VE, PR and CE) in 276 *Scarus rivulatus* .................. 215

Fig. 7.9 Distribution of hepatic lipid droplets in four measuring areas (DO, VE, PR and CE) in 289 *Scarus schlegeli* .................. 215

Fig. 7.10 An overall distribution of hepatic lipid index (HLI) by HSI for *Scarus rivulatus* .................. 217

Fig. 7.11 An overall distribution of hepatic lipid index (HLI) by HSI for *Scarus schlegeli* .................. 217

Fig. 7.12 Seasonal distributions of hepatic lipid index (HLI) for female, male and immature *Scarus rivulatus* .................. 218

Fig. 7.13 Seasonal distributions of hepatic lipid index (HLI) for female, male and immature *Scarus schlegeli* .................. 218
LIST OF TABLES

Chapter Two

Table 2.1 Summary of samples from various sites around Lizard Island .......................... 12
Table 2.2 *Scarus rivulatus* collected from the other sites ........................................... 13

Chapter Three

Table 3.1 The details of validation experiments at Lizard Island ................................. 20
Table 3.2 Results of Chi-square tests of the validation experiments at Lizard Island ............. 28
Table 3.3 Results of ring counts between left and right otoliths .................................... 32
Table 3.4 Results of otolith ring counts between readers .............................................. 33

Chapter Four

Table 4.1 Details of sampling for the otolith marginal analysis in surgeonfishes ................. 43
Table 4.2 Details of sampling for the otolith marginal analysis in parrotfishes .................. 44
Table 4.3 *Ctenochaetus striatus*. Comparison between otolith dimensions and fish length (SL) ........................................... 48
Table 4.4 *Ctenochaetus binotatus*. Comparison between otolith dimensions and fish length (SL) ........................................... 49
Table 4.5 *Scarus rivulatus*. Comparison between otolith dimensions and fish length (SL) .......... 50
Table 4.6 *Scarus schlegeli*. Comparison between otolith dimensions and fish length (SL) ........ 51
Table 4.7 Comparison of two counts on otolith bands from surgeonfishes ......................... 66
Table 4.8 Comparison of two counts of the otolith bands from parrotfishes ......................... 67
Table 4.9 Results of otolith band counting between two readers in *Scarus rivulatus* .................. 68
Table 4.10 Results of otolith band counting between

xix
two readers in *Scarus schlegeli* .................................................. 69

Table 4.11 Results of tag-recapture experiments .................................. 70

Table 4.12 The results of counts on the fine increments in otoliths of tag-recaptured *Scarus schlegeli* ........................................... 71

Table 4.13 *Scarus rivulatus*. The age composition of samples used in the otolith marginal analysis ........................................... 77

Table 4.14 *Scarus schlegeli*. The age composition of samples used in the otolith marginal analysis ........................................... 78

Table 4.15 Comparison between scale radius (SR) and fish length (SL) ........ 79

Table 4.16 *Scarus rivulatus*. Comparison of age estimates from otoliths and scales ................................................................. 80

Table 4.17 *Scarus schlegeli*. Comparison of age estimates from otoliths and scales ................................................................. 81

Table 4.18 Otolith annual bands of the other tetracycline mark-recapture parrotfishes from the Great Barrier Reef (GBR) ............... 91

Chapter Five

Table 5.1 Length-weight relationships for *Scarus rivulatus* and *S. schlegeli* between males (M) and females (F) ......................... 101

Table 5.2. *Scarus rivulatus*. Comparison between the mean of observed SL and the predicted SL .................................................. 102

Table 5.3 *Scarus schlegeli*. Comparison between the mean of observed SL and the predicted SL .................................................. 103

Table 5.4 *Scarus rivulatus*. Back-calculated lengths for each age group .... 104

Table 5.5 *Scarus schlegeli*. Back-calculated length (mm) for each age group ................................................................. 105

Table 5.6 *Ctenochaetus striatus*. Comparison between the mean of observed SL and the predicted SL .................................................. 113

Table 5.7 *Ctenochaetus binotatus*. Comparison between the mean of observed SL and the predicted SL .................................................. 114

Table 5.8 *Ctenochaetus striatus*. Back-calculated length
for each age group ................................................................. 115

Table 5.9 Ctenochaetus binotatus. Back-calculated lengths
for each age group ................................................................. 116

Table 5.10 Summary of settlement patterns for the species studied ...... 123

Table 5.11 Growth performance indexes (Ø) of the species studied ...... 124

Table 5.12 Mean SL of Scarus rivulatus
from different parts of the GBR .............................................. 129

Chapter Six

Table 6.1 Stages of scarids' oogenesis ........................................ 141

Table 6.2 Stages of scarids' spermatogenesis ................................ 141

Table 6.3 Frequency of sexual types, color phase in
each 20-mm size class for Scarus rivulatus .............................. 156

Table 6.4 Frequency of sexual types and color phase in
each age group of Scarus rivulatus ........................................ 157

Table 6.5 Frequency of sexual types and color phase in
each 20-mm size class for Scarus schlegeli .............................. 158

Table 6.6 Frequency of sexual types and color phase in
each age group of Scarus schlegeli ........................................ 159

Table 6.7 Results of ANOVA on the data of oocyte length
for Scarus schlegeli in the pilot study ................................. 172

Table 6.8 Results of ANOVA on the data of oocyte length
for Scarus rivulatus in the pilot study ............................... 173

Table 6.9 Mean SL ± s.d. (sample size) of Scarus rivulatus .......... 183

Table 6.10 Mean SL ± s.d. (sample size) of Scarus schlegeli ........ 184

Table 6.11 Means of gonad weight (g) ± s.d.
(sample size) of Scarus rivulatus ........................................ 185

Table 6.12 Means of gonad weights (g) ± s.d.
(Sample size) of Scarus schlegeli ........................................ 186

Chapter Seven

xxi
Table 7.1 Means±s.d. of HSI between sexual types, color phases in each 20-mm size class for *Scarus rivulatus* ........................................ 202

Table 7.2 Means±s.d. of HSI between sexual types, color phases in each age class for *Scarus rivulatus* ........................................ 203

Table 7.3 Means±s.d. of HSI between sexual types, color phases in each 20-mm size class for *Scarus schlegeli* ........................................ 204

Table 7.4 Means±s.d. of HSI between sexual types, color phases in each age class for *Scarus schlegeli* ........................................ 205

Table 7.5 Relationship between liver colour and hepatic lipids in *Scarus schlegeli* ........................................ 213

Table 7.6 Relationship between liver colour and hepatic lipids in *Scarus rivulatus* ........................................ 214
LIST OF PLATES

Chapter Three

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Microstructure of lapilli of the juvenile surgeonfish and parrotfish</td>
<td>25</td>
</tr>
<tr>
<td>3.2</td>
<td>Validated daily increments on the lapilli of surgeonfishes</td>
<td>26</td>
</tr>
<tr>
<td>3.3</td>
<td>Validated daily increments on the lapilli of parrotfishes</td>
<td>30</td>
</tr>
</tbody>
</table>

Chapter Four

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td><em>Ctenochaetus binotatus</em>. Otolith transverse sections with the various number of bands</td>
<td>57</td>
</tr>
<tr>
<td>4.2</td>
<td><em>Ctenochaetus striatus</em>. Otolith transverse sections with the various number of bands</td>
<td>58</td>
</tr>
<tr>
<td>4.3</td>
<td><em>Scarus rivulatus</em>. Otolith transverse sections with the various number of bands</td>
<td>59</td>
</tr>
<tr>
<td>4.3 Cont.</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>4.4</td>
<td><em>Scarus schlegeli</em>. Otolith transverse sections with the various number of bands</td>
<td>61</td>
</tr>
<tr>
<td>4.4 Cont.</td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>4.5</td>
<td>Otolith transverse sections of tag-recapture specimens from both field and the aquarium</td>
<td>74</td>
</tr>
<tr>
<td>4.6</td>
<td>Parrotfish scales</td>
<td>84</td>
</tr>
</tbody>
</table>

Chapter Five

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Settlement checks (SC) on the lapillus</td>
<td>125</td>
</tr>
</tbody>
</table>

Chapter Six

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td><em>Scarus rivulatus</em>. Photomicrographs of ovary development classes 1 through 4</td>
<td>142</td>
</tr>
<tr>
<td>6.2</td>
<td><em>Scarus schlegeli</em>. Photomicrographs of ovary development classes 1 through 4</td>
<td>143</td>
</tr>
<tr>
<td>6.3</td>
<td>Photomicrographs of gonad development for male <em>Scarus rivulatus</em> and <em>S.schlegeli</em></td>
<td>144</td>
</tr>
</tbody>
</table>
Plate 6.4 The gonads of transitional and $1^\circ\sigma\varphi$ individuals .............. 145
Plate 6.5 The testes of $2^\circ\sigma\varphi$ individuals ............................ 152

Chapter Seven

Plate 7.1 General structure of a transverse section of scarid liver from 230 mm *Scarus schlegeli* ................................. 200
Plate 7.2 Comparison between the normal histological liver sections and the liver-extracted sections in the scarids ............. 211