Fisheries biology and population dynamics of the pale octopus (Octopus pallidus)

Thesis submitted by:


November 2008

Submitted in fulfillment of the requirements for the degree of

Doctor of Philosophy

University of Tasmania
Frontispiece: *Octopus pallidus*
Declaration of originality

This thesis contains no material which has been accepted for a degree or diploma by the University of Tasmania or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgment is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

Stephen C. Leporati ______________________ Date __________________

Statement of access

This thesis may be made available for loan. Copying any part of this thesis is prohibited for two years from the date this statement was signed; after that limited copying is permitted in accordance with the Copyright Act 1968.

Stephen C. Leporati ______________________ Date __________________
Abstract

Although global octopus catches are increasing, the lack of a direct ageing technique has resulted in the use of inappropriate or non-validated growth and longevity determination methods for octopus fisheries assessments. This has limited our understanding of the inter-relationships between age, growth, reproductive investment and recruitment, potentially jeopardising the ecologically sustainable development of octopus fisheries. The present study is the first to determine the age composition of a wild octopus population by quantifying validated growth rings within stylets (vestigial shells), and examine the effect of both temperature and hatchling size on captive juvenile growth using simulated seasonal temperature regimes. This information was combined with reproductive biology and fishery data, to determine the life history characteristics and dynamics of a wild octopus population.

The focus of this study was the holobenthic species *Octopus pallidus* and its expanding fishery in south-east Australian waters. The results demonstrated that the typical life span of *O. pallidus* is 12 months, with a maximum age of approximately 18 months. Strong individual growth heterogeneity, ranging from 1.32 – 6.9% body weight per day, resulted in age having no distinguishable relationship with either size or reproductive development. Maturation was proven to be primarily a size driven process that varied between genders, with females reaching 50% maturity at 473 g and all males
sampled mature at 250 g, which was the minimum capture size for both genders. At the population level there appeared to be some reproductive synchronicity, with a peak spawning period during late summer – early autumn. This may be an ‘optimal’ spawning period as captive juvenile growth trials determined that octopus hatched during summer will grow faster and ultimately larger than those hatched during spring. Juvenile growth was also shown to have a positive relationship with initial size and food consumption in the spring/summer (14 – 18° C) treatment. However, in the summer/autumn (18 – 14° C) treatment, high temperatures at hatching caused a spike in growth, particularly for initially smaller octopus. The catch per unit of effort (CPUE) in the commercial fishery was heavily influenced by seasons, with strong annual fluctuations in female CPUE that peaked every two years during summer/autumn. Consistent fishing pressure on a fixed position research area led to a progressive reduction in female fecundity, which would eventually impact upon recruitment. This was not identified in catch rates, suggesting that repeated fishing pressure on localised stocks of a holobenthic octopus species could lead to size selective fishing mortality and localised depletion, which would not be detected by the analysis of fishery data.

By combining age-specific life history and population dynamics information with detailed analysis of fishery data, this study provides an in-depth and integrated assessment of the biology, ecology and fisheries dynamics of a wild population.
Statement of co-authorship

Chapters 2-5: Were prepared as scientific manuscripts as identified on the first page of each chapter. In all instances the candidate had the primary responsibility, however, the supervisors contributed to the experimental design and implementation of the research program, data analysis, interpretation of results and manuscript preparation. The contribution of each co-author was as follows:

Chapters 2, 3 and 4: Dr Jayson Semmens and Dr Gretta Pecl of the Tasmanian Aquaculture and Fisheries Institute (TAFI) were supervisors for this Ph.D. project. They contributed to the experimental design and data analysis, manuscript preparation and animal husbandry.

Chapter 5: Dr Philippe Ziegler (TAFI) provided advice on statistical analysis, demonstrated how to run the appropriate statistical computer packages and contributed to manuscript preparation. Dr Jayson Semmens (TAFI) edited the manuscript and provided directional advice.
Acknowledgements

I would like to thank my supervisors Dr Jayson Semmens and Dr Gretta Pecl for giving me the opportunity to undertake a PhD and for their continuing support, encouragement and enthusiasm. I also thank Dr Philippe Zeigler for his supervision on the fisheries chapter and being patient enough to show me how to use R. Thanks also to Dr George Jackson who was there to lend a hand when needed.

Special thanks go to Jessica André and Zoë Doubleday, who I was lucky enough to have gone through the whole PhD experience with. These two entertaining, intelligent and fantastic individuals, helped me in all facets of my project from collecting samples to listening to my rants and raves, I cannot thank them enough.

Thanks to the Hardy family Michael, Jan, Brad and Craig who collected samples, provided me with all the facilities I needed whilst in the field and gave me an insight into commercial octopus fishing. This project could not have been performed without them. Thanks also to Colin Stokes who also helped collect samples and all of the workers at Tasmanian Octopus Products (T.O.P. Fish) Pty Ltd for their assistance.

The Department of Primary Industries and Water provided additional funding for this project. From the department I especially thank Rod Pearn...
and James Parkinson for their help instigating the initial meetings with the fishers and providing historical catch information.

Thanks to all the staff and students at the Tasmanian Aquaculture and Fisheries Institute (TAFI). In particular: Assoc Prof Malcolm Haddon who provided advice on statistical analyses; Alan Beech, Ed Smith, Craig Thomas, Bill Wilkinson and Graeme Ewing for helping with the culturing of the juvenile octopus; and Bob Hodgson for general help around the place and keeping things in order. I would also like to thank my volunteers Ty Hibberd, Dave Young, Fabian Trinnie and Justin Hulls.

Thanks to all the people who have helped make the PhD years fun, by sharing houses, offices and beers with me, in particularly Arani Chandrapavan, Ana Lara Lopez, Adam Barnett, Camille White, John Keane, Laura Parsley, Luisa Lyall, Sarah Metcalf, Tim Alexander and Tobias Probst. Thanks to all the my friends back in Melbourne who’s visits to Tassie during the first two years, parties back home and general support helped keep me motivated and minimized the extent of the nerdification process.

Finally I would like to thank the Leporati˚s, Henry, Mary and Clare. I am very fortunate to have a supportive and loving family and I thank them with all my heart.
Contents

Declaration of originality .................................................................................................................. II
Statement of access .......................................................................................................................... II

Abstract ............................................................................................................................................ III
Statement of co-authorship .............................................................................................................. V
Acknowledgements ......................................................................................................................... VI
List of figures ...................................................................................................................................... XI
List of tables ....................................................................................................................................... XVI
List of plates ....................................................................................................................................... XVI

Chapter 1: General Introduction ..................................................................................................... 17
  Aims and thesis structure ................................................................................................................. 29
  Study species ................................................................................................................................... 32
  Animal ethics ................................................................................................................................. 33

Chapter 2: Cephalopod hatchling growth: the effects of initial size and seasonal temperatures .............................................. 39
  Abstract ........................................................................................................................................... 39
  Introduction ..................................................................................................................................... 40
  Methods .......................................................................................................................................... 43
    Specimen collection ................................................................................................................... 43
    Experimental design ................................................................................................................... 44
    Feeding ......................................................................................................................................... 47
    Data collection and analysis ....................................................................................................... 48
  Results ............................................................................................................................................ 49
Discussion ............................................................................................................. 58

Chapter 3: Determining the age and growth of wild octopus using stylet increment analysis. ........................................................ 65

Abstract ................................................................................................................. 65

Introduction .......................................................................................................... 66

Methods ................................................................................................................. 69

Specimen collection ............................................................................................. 69

Stylet preparation. .............................................................................................. 70

Data analysis ....................................................................................................... 72

Results ................................................................................................................... 77

Chapter 4: Reproductive status of *Octopus pallidus*, and its relationship to age and size ............................................................... 94

Abstract ................................................................................................................. 94

Introduction .......................................................................................................... 95

Methods ................................................................................................................. 97

Specimen collection and dissection ..................................................................... 97

Maturity stages ................................................................................................... 99

Fecundity and egg size ...................................................................................... 100

Ageing ............................................................................................................... 101

Data analysis ..................................................................................................... 101

Results ................................................................................................................. 103

Discussion ........................................................................................................... 113
Chapter 5: Assessing the stock status of holobenthic octopus fisheries: is CPUE data enough? .................................................... 122

Abstract .................................................................................................................. 122

Introduction ............................................................................................................ 123

Materials and methods .......................................................................................... 126

Commercial data ................................................................................................... 126

Research line ......................................................................................................... 129

Results ..................................................................................................................... 130

Commercial data ................................................................................................... 130

Research line ......................................................................................................... 140

Discussion .............................................................................................................. 146

Chapter 6: General Discussion ............................................................................. 153

Future studies ......................................................................................................... 163

References ............................................................................................................. 169

Appendices ............................................................................................................ 191
List of figures

Fig 1.1 Distribution of Octopus pallidus..............................................................35

Fig 1.2 An Octopus pallidus stylet.................................................................36

Fig 1.3 Plastic pots used in the Octopus pallidus Fishery.............................36

Fig 1.4 Octopus pallidus and commercial fishery pot..................................37

Fig 2.1 Temperatures recorded every 15 mins for the spring/summer (black line) and the summer/autumn (grey line) temperature treatments; mean monthly ocean temperatures from the NTF in north western Tasmania spring/summer (black dots, black line) and summer/autumn (white squares, grey dashed line)..........................................................46

Fig 2.2a Initial size vs. final size for O. pallidus in the spring/summer and summer/autumn temperature treatments..................................................51

Fig 2.2b Initial size vs instantaneous growth rate for O. pallidus in the spring/summer and summer/autumn temperature treatments............52

Fig 2.3a Mean instantaneous growth rate of O. pallidus at 14-day intervals over 114 days for the spring/summer and summer/autumn temperature treatments..........................................................53

Fig 2.3b Mean grams eaten over 14-day intervals for O. pallidus in the spring/summer and summer/autumn temperature treatments............53

Fig 2.4 Raw data distribution of weight at 14-day intervals over 114 days for O. pallidus with fitted exponential growth curves for the for the spring/summer and summer/autumn temperature treatments........56
Fig 2.5 Total growth vs. total feed eaten for *O. pallidus* in the spring/summer and summer/autumn temperature treatments. .........................................57

Fig 2.6 Total feed eaten vs initial size for *O. pallidus* in the spring/summer and summer/autumn temperature treatments. .........................................57

Fig 3.1 Location of the stylet in an adult male octopus after removal of the mantle wall and gill from the left side (adapted from Bizikov 2004). .....74

Fig 3.2 Composite image of a stylet at 400x magnification (reduced to 46%), taken from a male *O. pallidus*, total weight 472 g, estimated age of 206 days.................................................................75

Fig 3.3 Mean age for all haul seasons for *O. pallidus*. .........................79

Fig 3.5 Total weight vs. age for male (●) and female (○) *O. pallidus*. ............81

Fig 3.6 Mean instantaneous growth rate by hatch season for *O. pallidus*, with significant differences in mean growth denoted by letters (a, b) derived from a Tukey B post hoc test...............................................................82

Fig 3.7 Percentage frequency of octopus for each hatch month and categorised by haul-season for female *O. pallidus*. ........................................84

Fig 3.8a Mean instantaneous growth and temperature for each hatch season for *O. pallidus*. .........................................................................................85

Fig 3.8b Mean total weight, grouped in to hatch seasons for *O. pallidus*. .....85

Fig 4.1 Proportion of female to male *O. pallidus* caught per haul season with *n* values........................................................................................................105

Fig 4.2 Size (whole weight) at 50% maturity (MW50%) for 20 g weight classes, for female *O. pallidus* n = 657. .................................................................105
Fig 4.3 Proportion of immature (stages I, II), mature (III, IV) and spent (V) *O. pallidus* females in each 20-day age class....................................................107

Fig 4.4a+b Mean standardized residuals for the relationship between whole weight (WW) and the whole reproductive complex weight for stage III and IV *O. pallidus*, with significant differences in mean standardized residuals between haul-seasons denoted by letters (A, B, C) derived from LSD post hoc tests. (a) males and (b) females........................................108

Fig 4.5 Mean standardized residuals for the relationship between whole weight (WW) and the whole female reproductive complex weight (FRW) for stage III and IV *O. pallidus* from each hatch-season, with significant differences in mean standardized residuals denoted by letters (A, B) derived from a LSD post hoc test. The dashed line represents expected levels of reproductive investment...............................................................109

Fig 4.6 Percentage frequency for the number of ovary eggs for stage III female *O. pallidus*, n = 180. ...........................................................................111

Fig 4.7 Mean potential fecundity per haul-season for female *O. pallidus*, with significant differences in mean fecundity denoted by letters (A, B) derived from a LSD post hoc test...............................................................112

Fig 5.1a+b (a) Total annual catch and (b) total number of pot lifts per year (effort), in the *O. pallidus* Fishery (OPF) during 1995 – 2007 in all areas (solid black line) and from the 4E fishing blocks (dotted grey line)......133

Fig 5.2 Fishing area and total catch per fishing block for *O. pallidus* for each year during 1995 – 2007. Block number is given for fishing blocks with
catch returns. Legend provided in the 1995 map is applicable to all others maps. ........................................................................................................................................134

**Fig 5.3** Percentage of male and female *O. pallidus* caught in the 50-pot sampling program (observed) and used in the catch rate standardisation (model). Numbers represent male and female 50-pot sample sizes for each season. The model data is derived from the weighted mean of the observed data for each season. ........................................................................................................................................136

**Fig 5.4a** Seasonal standardized CPUE, for female *O. pallidus* caught in the 4E1, 4E2, 4E3 and 4E4 fishing blocks between summer 1995 and winter 2007 (straight line) and mean seasonal sea surface temperature for 1998–2006 (line with points). Vertical dashed lines denote the spring 1998 to summer 2006 period that was used in the autocorrelation analysis. 137

**Fig 5.4b** Seasonal standardized CPUE, for male *O. pallidus* caught in the 4E1, 4E2, 4E3 and 4E4 fishing blocks between summer 1995 and winter 2007. Vertical dashed lines denote the spring 1998 to summer 2006 period that was used in the autocorrelation analysis. ........................................................................................................................................138

**Fig 5.5a+b** Standardized CPUE separated by season for (a) female and (b) male *O. pallidus* caught in the 4E1, 4E2, 4E3 and 4E4 fishing blocks during 1998–2006. ........................................................................................................................................141

**Fig 5.6a** Autocorrelation and partial correlation plots of the standardized CPUE for seasonal catches of female *O. pallidus*, with 5% significance levels denoted by dotted lines. ACF is the autocorrelation function and lag is equal to one year with quarterly (seasonal) increments. ........................................................................................................................................142
Fig 5.6b  Autocorrelation and partial correlation plots of the standardized CPUE for seasonal catches of male *O. pallidus*, with 5% significance levels denoted by dotted lines. ACF is the autocorrelation function and lag is equal to one year with quarterly (seasonal) increments..............143

Fig 5.7a+b  Cross-correlation analysis of the standardized CPUE for seasonal catches of (a) male and (b) female *O. pallidus* and mean seasonal sea surface temperature, with 5% significance levels denoted by dotted lines. ........................................................................................................................................144

Fig 5.8a+b+c  For *O. pallidus* (a) percentage occupancy rate and CPUE for males and females (b) proportion of spawning females, and (c) mean total weight for female and males for *Octopus pallidus* caught on the research line in each haul-season.................................................................145
### List of tables

**Table 2.1** Temperature profiles for the spring/summer and summer/autumn temperature treatments for the duration of the experiment .................46

**Table 2.2** Size class, carapace width and the mean weight an weight range of crabs (*Petrolisthes elongatus*)........................................................................................................47

**Table 2.3** Initial and final size comparisons for *Octopus pallidus* in the spring/summer and summer/autumn temperature treatments ..........50

**Table 3.1** Summary of the catch and composition of *O. pallidus* from the research line........................................................................................................................................78

**Table 5.1** Statistical models compared in the standardisation of *Octopus pallidus* catch per unit of effort (CPUE). Model 1 is the equivalent to the geometric mean of the CPUE and acts as a base for the remaining models. Model 6 was the model with the lowest Akaike’s Information Criterion (AIC) and was hence chosen as the best model. The adjusted $r^2$ (adj $r^2$) and degrees of freedom (df) are provided............................139

### List of plates

**Plate 1.1** *Octopus pallidus* ........................................................................................................................................34

**Plate 3.1** Juvenile *Octopus pallidus*..................................................................................................................64

**Plate 4.1** *Octopus pallidus* eggs in a commercial pot ......................................................................................93

**Plate 5.1** A catch of *Octopus pallidus* ...............................................................................................................121