

# **Movement, connectivity and population structure of *Acanthopagrus australis* (Yellowfin Bream) along the New South Wales coast**



**Holly Gunton**

Thesis submitted in fulfilment of the requirements for the degree

**Master of Science (Research)**

under the supervision of Prof. David Booth, Dr. Ashley Fowler (NSW DPI)

and Dr. John Stewart (NSW DPI)

University of Technology Sydney

Faculty of Science

June 2021

## **Certificate of original authorship**

I, Holly Gunton declare that this thesis, is submitted in fulfilment of the requirements for the award of Master of Science (Research), in the School of Life Sciences at the University of Technology Sydney. This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

Production Note:

Signature: Signature removed prior to publication.

Date: 15<sup>th</sup> June 2021

## **Acknowledgements**

I have been truly privileged to have worked with some extraordinary folks throughout the course of this thesis. First and foremost, I wish to thank my supervisors David Booth, Ashley Fowler and John Stewart. This thesis is considerably better off from your involvement, and I hope it has met your expectations. Dave, thank you for your support, guidance and confidence in my potential, particularly during my many moments of uncertainty. Ash, without your constant encouragement, contributions and belief in my abilities this project wouldn't exist, thank you for enduring my persistent questions and facilitating this achievement. John, thank you for your thoughtful comments and advice on all aspects of this thesis, and for providing me with countless opportunities to develop my professional career.

This project would not have been possible without the datasets and otoliths provided by the NSW Department of Primary Industries (DPI), Fisheries. Thank you to Ashley Fowler (DPI) for assisting in devising and refining this project. Thank you to my co-workers at DPI Fisheries, Mosman, for assisting with different aspects of this project, offering advice and making me feel comfortable and welcome. In particular I would like to thank Anne-Marie Hegarty for her encouragement, advice and friendship, as well as Chantelle Clain and Nick Meadows for their academic comradery and friendship. I would also like to thank David Bishop and Mika from UTS chemical technologies for their assistance and advice during LA-ICP-MS processing.

Last but certainly not least, I would like to thank my partner Riley Blair, and my parents Liz and Tony, for believing in and tolerating me over the last three years and providing me with ongoing advice, support and encouragement.

## Abstract

In this thesis, I investigate the population structure of Yellowfin Bream, *Acanthopagrus australis*, an important and popular fish species in eastern Australia. Archival collections of otoliths (ear stones) and long-term tag-recapture data were used to examine movement and potential stock segregation in New South Wales (NSW) at a range of spatial and temporal scales.

In Chapter 2, cooperative tag-recapture data was examined using generalized additive models, to assess potential environmental and intrinsic drivers of *A. australis* movement. Over 24 000 individuals were tagged along ~ 800 km of the NSW coastline, with anglers recapturing 2036 (8.2 %) individuals during a 19-year period. A broad range of movements were observed (up to 832 km), however a substantial proportion (37%) of individuals were recaptured at their release location, with only 8.6 % of individuals moving further than 100 km. Fish were more likely to move if they spent greater time at liberty, were of larger body length at release, or were released during Autumn. Fish that spent greater time at liberty and those released at more southerly latitudes were more likely to move a greater distance, with those that travelled in a northerly direction (61.5%) significantly more likely to move a greater distance.

In Chapter 3, connectivity of *A. australis* among estuaries was examined during recent life history using otolith elemental edge signatures, and throughout life history using otolith shape indices. Archived otoliths ( $n = 355$ ) from estuaries covering ~850 km of the NSW coastline were examined using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) and Elliptical Fourier Analysis. The results indicate complex stock structure of *A. australis*, with considerable differences in elemental edge signatures among a range of estuaries and sites at a variety of spatial and temporal scales. Differences in

elemental signatures from the juvenile region of adult otoliths were consistent with patterns of adult separation, suggesting they were established early in life. Differences in otolith edge signatures revealed at both the smallest (sites within estuaries) and largest scale of investigation (100s of km) highlight the importance of investigating multiple spatial scales.

The use of multiple techniques provided a more holistic understanding of population structure of *A. australis* in NSW. Overall, the results indicate that movement of *A. australis* is likely restricted over spatial scales considerably smaller than that of fisheries management in the region.

## Contents

<b>Certificate of original authorship .....</b>	<b>i</b>
<b>Acknowledgements .....</b>	<b>ii</b>
<b>Abstract.....</b>	<b>iii</b>
<b>Contents .....</b>	<b>v</b>
<b>List of Figures.....</b>	<b>vii</b>
<b>List of Tables .....</b>	<b>ix</b>
<b>Chapter 1    General Introduction .....</b>	<b>1</b>
1.1    Importance of understanding connectivity and movement patterns .....	1
1.2    Methodological approaches to estimating movement and population structure in fishes .....	4
1.3    Study species: <i>Acanthopagrus australis</i> .....	6
1.3.1    Biology & Ecology.....	6
1.3.2    Significance to fisheries.....	8
1.3.3    Movement, connectivity and population structure.....	9
1.4    Objectives and thesis structure.....	10
<b>Chapter 2    Patterns and drivers of movement in the estuarine associated sparid               <i>Acanthopagrus australis</i> from a large-scale cooperative tagging               program.....</b>	<b>12</b>
2.0    Abstract.....	12
2.1    Introduction.....	13
2.2    Methods.....	17
2.2.1    Data processing.....	18
2.2.2    Data analysis.....	18
2.3    Results.....	20

2.4	Discussion.....	27
<b>Chapter 3</b>	<b>Otolith elemental signatures and shape descriptors demonstrate potential population structuring of the estuarine obligate sparid <i>Acanthopagrus australis</i>, in southeastern Australia.....</b>	<b>34</b>
3.0	Abstract.....	34
3.1	Introduction.....	35
3.2	Methods.....	38
3.2.1	Study location and sample collection.....	38
3.2.2	Otolith preparation.....	42
3.2.3	Otolith microchemistry .....	43
3.2.4	Otolith shape.....	46
3.2.5	Statistical analyses.....	47
3.3	Results.....	51
3.3.1	Elemental signatures at the otolith edge.....	51
3.3.2	Otolith shape analysis .....	61
3.3.3	Combined elemental edge signatures and shape data .....	61
3.3.4	Juvenile elemental signatures from adult otoliths.....	62
3.4	Discussion.....	63
<b>Chapter 4</b>	<b>General discussion.....</b>	<b>71</b>
4.1	Multiple methods for detecting stock structure.....	72
4.2	Implications for management.....	75
4.3	Future research directions.....	77
<b>References</b>	<b>.....</b>	<b>80</b>

## List of Figures

- Figure 1. Map of the NSW coast indicating the proportion of releases (light bars) and recaptures (dark bars) of *Acanthopagrus australis* at each degree of latitude. Release proportion includes all individuals tagged and released (~25 000), while recapture proportion includes all individuals recaptured and reported (~2 000).....22
- Figure 2. Distribution of movement distance for *Acanthopagrus australis* that were deemed as having moved a detectable distance from their tagging location ( $n = 1191$ ). Note the break in the y-axis.....23
- Figure 3. Partial effects of smooth terms and the parametric term Season for the generalised additive model of the odds of movement for *Acanthopagrus australis*. The contribution of the smoother to the model's fitted values are shown on the y-axis. Solid lines represent the model estimates; shaded regions and dashed lines indicate 95% confidence intervals. Length is fork length in mm and latitude is degrees south. The values for Season are on the modelled (log) scale.....25
- Figure 4. Partial effects of smooth terms and the parametric terms Season and Direction for the generalised additive model of movement distance for *Acanthopagrus australis*. The contribution of the smoother to the model's fitted values are shown on the y-axis. Solid lines represent the model estimates; shaded regions and dashed lines indicate 95% confidence intervals. Length is fork length in mm and latitude is degrees south. The values for Season and Direction are on the modelled (log) scale.....26
- Figure 5. Locations of estuaries sampled on the NSW coast, South-eastern Australia, (a) insets showing locations of (b) and (c) within Australia, (b) the location of regional study estuaries and (c) the location of the larger scale, coastwide study estuaries.....40
- Figure 6. *Acanthopagrus australis* otolith section showing the location of laser ablation spots for ICPMS at (a) the otolith edge or margin, representing the period ~ 3 to 9 months prior to capture, (b) the previous increment, representing a similar amount of time, during the period 12 to 24 months prior to capture, and (c) the juvenile section of the adult otolith.....45



Figure 7.	<p>Canonical analysis of Principal Coordinates (CAP) for the coastwide component of the current study, for (a) 2008 otolith elemental edge signatures and (b) 2009 otolith elemental edge signatures, (c) Fourier descriptors of otolith shape, (d) 2008 Fourier descriptors and edge signatures combined, (e) 2009 Fourier descriptors and edge signatures combined and (f) elemental signatures from the juvenile zone of adult otoliths. Vector overlays in (a), (b) and (f) show correlations of individual elements with primary axis. Note different axis scales on each plot.....</p>	56
Figure 8.	<p>Linear regression of distance among centroids and geographical distance among estuaries for coastwide study estuaries. (a) otolith edge signatures (2008), (b) otolith edge signatures (2009), (c) otolith shape descriptors and (d) signatures from the juvenile zone of adult otoliths. <math>R^2</math> value denotes the strength of the relationship and <math>p</math> value denotes the significance of the relationship (<math>p &lt; 0.05</math> is significant).....</p>	57
Figure 9.	<p>Canonical analysis of Principal Coordinates (CAP) for the within-region component of the current study, for (a) otolith elemental edge signatures, (b) elliptical Fourier descriptors of otolith shape, (c) combined Fourier descriptors and edge signatures and (d) elemental signatures from the juvenile zone of adult otoliths. Vector overlays in (a) and (d) show correlations of individual elements with the primary axis. Note differences in axis scales on each plot.....</p>	60

## List of Tables

Table 1.	Summary of <i>Acanthopagrus australis</i> tag-recapture studies, including details of the number of fish tagged and recaptured, whether they were recaptured within or outside the estuary or embayment of tagging, and the maximum time at liberty in days for each study.....	16
Table 2.	Summary of tagging programs that provided data for this study, including the project investigators, tagging periods, estuaries where fish were tagged, sampling methods and tag types used.....	17
Table 3.	Model results for the generalised additive model of <i>Acanthopagrus australis</i> likelihood of movement. Values in parentheses specify 95% confidence limits around parametric estimates, which are back transformed from the modelled (log) scale. $s()$ signifies smooth terms; $\beta$ signifies effective degrees of freedom (degree of nonlinearity) for smooth terms or the coefficient estimate for the parametric Season terms. * denotes significant results.....	24
Table 4.	Model results for the generalised additive model of movement distance for <i>Acanthopagrus australis</i> . Values in parentheses specify 95% confidence limits around parametric estimates, which are back transformed from the modelled (log) scale. $s()$ signifies smooth terms; $\beta$ signifies effective degrees of freedom (degree of nonlinearity) for smooth terms or the coefficient estimate for the parametric Season terms. * denotes significant results. .....	24
Table 5.	Sampling summary of <i>Acanthopagrus australis</i> used for microchemical and shape analysis at two spatial scales, among region, spanning ~ 1000 km of the NSW coast, and within region, spanning ~ 100km of the NSW coast. Table includes estuary coordinates, date of capture (Year, Month), number of individuals ( $N$ ), Mean size and range, and age range. Estuary abbreviations included here are used in subsequent tables and figures.....	41
Table 6.	Outline of Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) operational parameters used for elemental analysis of <i>Acanthopagrus australis</i> otoliths.....	44

Table 7.	Summary of among-region PERMANOVA results for the multivariate analysis of (a)(b)(c) elemental signatures from the otolith edge, (d) otolith shape descriptors and (e) elemental signatures from the juvenile zone of adult otoliths for <i>Acanthopagrus australis</i> , sourced from multiple estuaries along the NSW coast. There were > 9500 unique permutations for each term in the models. Bold and * denote significant results.....52
Table 8.	Summary of coastwide pairwise PERMANOVA results for <i>Acanthopagrus australis</i> collected from seven estuaries on the NSW coast, including (a)(b) elemental signatures from the otolith edge (split by collection year), (c) otolith shape coefficients, and (d) elemental signatures from the juvenile zone of adult otoliths. Letters denote estuaries and their position on the NSW coast relative to studied estuaries, locations are ordered by distances between estuaries, descending. Bold and * denote significant results, corrected for each PERMANOVA using the procedure outlined in Benjamini & Hochberg (1995), FDR $q < 0.05$ . There were > 9900 unique permutations for each comparison in the model.....53
Table 9.	Summary of allocation success of <i>Acanthopagrus australis</i> individuals back to the estuary in which they were captured based upon canonical analysis of principal coordinates (CAP). Results presented for (a) 2008 elemental signatures from the otolith edge, (b) 2009 elemental signatures from the otolith edge, (c) fourier coefficients from the otolith outline (d) combined edge signatures and shape coefficients from 2008, (e) combined edge signatures and shape coefficients from 2009, and (f) juvenile elemental signatures from adult otoliths. The % allocation to each estuary in a random assignment would be ~ 20 % for (a) & (d) and ~14 % for (b), (c), (e) & (f). Locations are ordered corresponding to their position on the NSW coast, beginning with the northern most estuary.....55
Table 10.	Summary of regional PERMANOVA results for the multivariate analysis of (a) elemental signatures from the otolith edge, (b) otolith shape descriptors, and (c) elemental signatures from the juvenile zone of adult otoliths, of <i>Acanthopagrus australis</i> sourced from three estuaries along ~ 100 km NSW coast. There were > 9500 unique permutations for each term in the model, apart from the term estuary, which repeatedly had less than < 999 unique permutations, where Monte Carlo p-values were employed as there were not

enough unique permutations to determine permutational p-values. Bold and \* denote significant results. ~ denotes Monte Carlo p-values.....58

Table 11. Summary of allocation success of *Acanthopagrus australis* individuals back to the estuary in which they were captured based upon canonical analysis of principal coordinates (CAP). Results presented for (a) elemental signatures from the otolith edge, (b) otolith shape descriptors, (c) combined otolith shape and elemental edge signatures, and (d) elemental signatures from the juvenile zone of adult otoliths. The % allocation to each estuary in a random assignment would be ~ 33 % .....59