

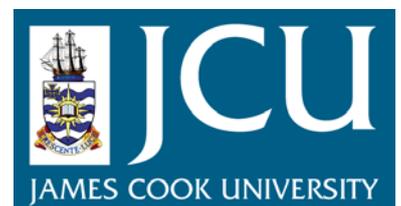
JCU ePrints

This file is part of the following reference:

Mutz, Stephanie J. (2006) *Comparative growth dynamics of Acanthurid fishes.*
Masters (Research) thesis, James Cook University.

Access to this file is available from:

<http://eprints.jcu.edu.au/2133>



**COMPARATIVE GROWTH DYNAMICS OF ACANTHURID
FISHES**

Thesis submitted by
Stephanie J. Mutz B.Sc. (Hons)
in March 2006

for the degree of Masters of Science in Marine Biology
within the School of Marine Biology and Aquaculture
James Cook University, Townsville, 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I understand that, as an unpublished work, a thesis has significant protection under the Copyright Act and;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 OF 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 Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.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

Abstract

Considerable variation exists in the demographic characteristics of coral reef fishes. Growth trajectories of size, growth and longevity of four species of the widespread coral reef family, Acanthuridae, were investigated. Growth data were obtained from growth increments in sagittal otoliths. Three species of these were studied in the tropical Atlantic, and one in the tropical South Pacific. The focus of the study is the variability of the demographic parameters at both large and small spatial scales. Large scales studies were conducted along both latitudinal and longitudinal gradients. Latitude has a direct influence on sea temperature, and this affects the growth and demography of teleosts. Longitudinal effects are not as well studied, and comparing the demographic characteristics of teleosts along a longitudinal gradient is the first of this type of study. Longitudinal comparisons of longevity and growth allow us to analyse the variability of life history characteristics of organisms at different localities across an ocean without having to consider the effects of sea temperature. In order to completely understand the mechanisms behind large scale variability in demography, a small regional scale study can aid in pinpointing possible factors that can discern these differences within a small region. A local scale study was conducted at Bermuda with study habitats 10's of kilometres apart.

Analysis of size at age data revealed that these acanthurids exhibit fast initial growth, until age 4, after which is substantially reduced generating a characteristic “square” growth curve. This indicates evidence that size and age of some reef fishes may be decoupled. All species at every study site follow similar growth patterns within the first four years of life. Acanthurids, including the species in this study, generally reach maximum size within the first 10% of their life span, irrespective of their maximum size and longevity. Nevertheless it must be noted that as most populations reach asymptotic size, there are exceptions for three species (*A. coeruleus*, *A. chirurgus* and *A. lineatus*) at two locations (Isla de Margarita and Marquesas). In these populations growth was reduced at older ages, but did not reach asymptote. Upwelling events and nutrient blooms may be responsible for these non-asymptotic growth trajectories, providing sufficient resources to allow growth to occur more prominently.

The species in this study exhibit a wide range of sizes, although maximum sizes and longevities were not correlated. This study found that populations of the longest lived acanthurids do not necessarily reach the largest body sizes contradicting previous age and body size correlation studies of acanthurids, and indeed ectotherms in general.

In the tropical Atlantic Ocean, the demography of *Acanthurus bahianus*, *A. coeruleus* and *A. chirurgus* was assessed at 12 locations on a large (56°) latitudinal scale. Mean sea temperature (MST) negatively correlated with longevity, absolute body size, and instantaneous growth (size-at-age at ages 1, 2.5 and 4) over a large latitudinal gradient. Decreasing growth with increasing temperature is a trend which is opposite to many previous demographic studies of ectotherms, and more specifically, teleosts. Populations of all Atlantic species in this study from cooler (i.e. lower MST) environments are longest lived, but not necessarily largest in size (i.e. Bermuda), while populations of all species in warmer waters consistently exhibited small size and short lifespan (i.e. Belize), indicating MST may not be the only factor driving these growth patterns. Mass island effects can also influence growth, as populations from the isolated oceanic islands have the longest lifespans and larger body sizes.

To assess the potential influences of other environmental and fishing impacts, a study was conducted along a longitudinal scale at constant sea temperature. The demography of *A. lineatus* was estimated at five localities spanning 75° longitude across the South Pacific Ocean. The variation in body size and instantaneous growth among sites was equivocal. A negative relationship was found between longevity and longitude from the west to east end of the Pacific Ocean, however within Oceania, the difference

was not so great. This is in accordance with previous studies demonstrating exceptionally long life spans of coral reef fishes on the Great Barrier Reef.

Comparisons of the demographic patterns of *A. coeruleus* and *A. chirurgus* between the lagoonal and outer reefs of Bermuda allowed me to assess any variability in the life history characteristics on a small regional scale. Juveniles of *A. chirurgus* settled onto the lagoonal reefs and migrated to the outer reef as adults, while both juveniles and adults of *A. coeruleus* inhabited the outer reef. These differences in spatial distribution on a local scale may give us a better indication of the environmental effects on the general demographic patterns found at larger spatial scales.

Acknowledgments

Most importantly I would like to give a very special acknowledgment to my supervisor Professor J. Howard Choat who has extended to me his knowledge, insights and support more than I could ever imagine. I would also like to thank Dr. Craig Syms for his encouragement and assistance with statistical analysis. Furthermore, to Will Robbins, whose help in every aspect was imperative to completing this study; especially with the required fieldtrips. Much gratitude goes to Michael Berumen for his sound advice and assistance in the field. Thanks to Dr. Ross Robertson for organising the collections of samples, and giving pertinent insight into the extent of the environmental and temporal mechanisms occurring in the Atlantic region.

I would like to thank the incredible staff of the Richard. B. Gump South Pacific Research Station in Moorea, French Polynesia; in particular Dr. Neil Davies, Tony, Jacques and Irma You Sing, Val Brotherson and Frank Murphy who made the fieldwork all the more efficient and successful. I further thank the Gump Station for financial support.

Last but certainly far from least I am grateful for my friends and colleagues for their extensive discussions and undeniable encouragement and understanding along the way: Michael Berumen, Thea Brolund, Andy Brooks, Karin Büchler, Rob Burrison, Martial Depczynski, Maria Dornelas, Monica Gagliano, Lindsay Harrington, Matt Kay, Liz Laman Trip, Jen Lape, Jenny MacGregor, Katy Miller, Phil Munday, Kamal Ranatunga, Will Robbins, Ben Ruttenberg, Barbara Walker and Stefan Walker. Most importantly I would like to thank my parents; for what luck to be born out of love and to live in an atmosphere full of warmth and interest.

Table of Contents

Title Page	i
Statement of access	ii
Statement of sources	iii
Abstract	iv
Acknowledgments	viii
Table of Contents	ix
List of Figures	xiii
List of Tables	xvii
Chapter 1: General Introduction	1
Chapter 2: Comparisons of demographic characteristics among three species of surgeonfish in the tropical Atlantic Ocean and Caribbean Sea	7
2.1 Introduction.....	7
2.2. Materials and methods	9
2.2.2. Otolith preparation and age determination	12
2.2.3. Sagittal otolith growth.....	14
2.2.4. Age-based growth modelling.....	15
2.2.5. Randomization	20
2.3 Results.....	20

2.3.1 Sagittal growth.....	20
2.3.2 Geographic variation in demography.....	21
2.3.3. Growth trajectories at Isla de Margarita	22
2.3.4. Longevity and body size	23
2.3.5. Temperature versus size-at-age growth	23
2.4 Discussion.....	24
2.4.1 Growth trajectories.....	24
2.4.2 Sagittal growth.....	26
2.4.3 Geographic variation in longevity	27
2.4.4. Geographic variation in body size	28
2.4.5. Geographic variation in growth	31
Chapter 3: Demographic characteristics of <i>Acanthurus lineatus</i> on a longitudinal gradient across the tropical South Pacific Ocean	52
3.1 Introduction.....	52
3.2 Materials and methods	54
3.2.1 Study species.....	54
3.2.2 Study sites and field sampling	54
3.2.3 Sagittal preparation and growth and age determination	56
3.2.4 Age based growth modelling	57
3.3 Results.....	59

3.3.1 Sagittal preparation and growth and age determination	59
3.3.2 Geographic variation in demography.....	60
3.4 Discussion.....	62
3.4.1 Growth trajectories.....	62
3.4.2 Sagittal growth.....	64
3.4.3 Longevity, size-at-age and terminal growth	64
Chapter 4: Age-based demographic comparisons on a local spatial scale in Bermuda	76
4.1 Introduction.....	76
4.2 Methods and Materials.....	78
4.2.1 Study species.....	78
4.2.2 Study sites and field sampling	79
4.2.3 Otolith preparation and age determination	80
4.2.4 Age based growth modelling	81
4.3 Results.....	81
4.3.1 Sagittal growth.....	81
4.3.2 Growth trajectories.....	82
4.3.3 Age-based demographics on a local scale	83
4.4 Discussion.....	84
4.4.1 Sagittal growth.....	84

4.4.2 Age-based demographics on a local scale	85
4.4.3 Demographic patterns of reef fishes at local spatial scales.....	87
Chapter 5: General Discussion	92
5.1 Discussion.....	92
5.2 Future directions	97
References	101
Appendix	127

List of Figures

- Figure 2.1:** Map of the study sites at which *Acanthurus bahianus*, *A. chirurgus* and *A. coeruleus* were collected throughout the tropical Atlantic Ocean. All three species are found in the shaded areas except *A. chirurgus* and *A. coeruleus* are not found at St. Helena. 40
- Figure 2.2:** Otolith growth trajectories of *Acanthurus bahianus*: power functions of sagittal weight and age at Jamaica and Isla de Margarita. Correlations for the other populations are found in Robertson et al. (2005). There was a positive correlation between age and sagittal weight at all study sites indicating the continuous growth of otoliths throughout an individual's lifetime..... 41
- Figure 2.3:** Otolith growth trajectories of *Acanthurus coeruleus*: power functions of sagittal weight and age at seven sites. There was a positive correlation between age and sagittal weight at all study sites. 42
- Figure 2.4:** *Acanthurus chirurgus*: Using least squares linear regression, the relationship between sagittal weight and age was calculated for *A. chirurgus* at all five localities. There was a positive correlation between age and sagittal weight at all study sites. 43
- Figure 2.5:** *Acanthurus bahianus*: Von Bertalanffy growth curves at 12 study sites. All of the graphs were constructed from the data from Robertson et al. (2005) except Jamaica and Isla de Margarita. 44
- Figure 2.6:** *Acanthurus coeruleus*: Growth trajectories at 7 study sites. All populations fit the VBGF except Isla de Margarita which fits the Power² model best..... 45
- Figure 2.7:** *Acanthurus chirurgus*: Growth trajectories at 5 study sites. All populations fit the VBGF except Isla de Margarita which fits the Power² model best..... 46

Figure 2.8: Differences in body length in the early life history stages of all of the populations of three species of *Acanthurus*. The black bars represent growth from settlement to age 1 year, the light grey bars represent growth from ages 1 to 2.5 years, and the dark grey bars represent growth from ages 2.5 to 4 years..... 47

Figure 2.9: Power² growth models of *Acanthurus coeruleus* (SS=27437, $r^2=0.88$) and *A. chirurgus* (SS=44225, $r^2=0.86$) at Isla de Margarita. These two species do not demonstrate an asymptotic growth curve that is generally characteristic of Acanthurids around the world. 48

Figure 2.10: A linear regression of 20% maximum longevity vs. mean sea surface temperatures. The dashed line and exes represent (---, x) *A. coeruleus* ($y = -5.0041x + 151.26$, $r^2=0.66$; $p=0.0283$); 7 sites, the dash-dot line and open circles (—·—, °) represent *A. bahianus* ($y = -3.1016x + 92.983$, $r^2=0.82$; $p=0.0004$); 11 sites, and the solid line and solid circles (—, •) represent *A. chirurgus* ($y = -1.3117x + 44.701$, $r^2=0.66$; $p=0.0408$); 5 sites..... 49

Figure 2.11: Linear regressions of 20% maximum body size vs. mean sea surface temperatures. The solid line and solid circles (—, •) represent *A. chirurgus* ($y = -5.531x + 392.1$, $r^2=0.22$; $p=0.4206$); 5 sites, the dashed line and exes (---, °) represent *A. coeruleus* ($y = -2.8026x + 300.96$, $r^2=0.03$; $p=0.7079$); 7 sites, the dash-dot line and open circles (—·—, x) represent *A. bahianus* ($y = -10.764x + 477.68$, $r^2=0.58$; $p=0.0061$); 12 sites. There is an indication of a negative trend in *A. chirurgus* and *A. coeruleus* even though the trend is not statistically significant. 50

Figure 2.12: Instantaneous growth rates measured as size-at-age for populations of all three species of surgeonfish at three different ages vs. mean sea surface temperature. The solid line and open circles (—, °) represent size at age 1 year, the dashed line and exes (---, x) represent size at age 2.5 and the dash-dot line and solid circles (—·—, •) represent size at age 4. (A) *Acanthurus bahianus*: age 1 $y = -6.8112x + 327.37$, $r^2=0.25$, $p<0.0001$; age 2.5 $y = -8.7492x + 408.58$, $r^2=0.45$, $p<0.0001$; age 4 $y = -9.6897x + 439.65$, $r^2=0.54$, $p<0.0001$. (B) *Acanthurus coeruleus*: age 1 $y = -4.5308x + 258.6$,

$r^2=0.11$, $p=0.8520$; age 2.5 $y = -3.5636x + 277.79$, $r^2=0.12$, $p<0.0001$; age 4 $y = -2.1324x + 256.21$, $r^2=0.06$, $p<0.0001$. (C) *Acanthurus chirurgus*: age 1 $y = 0.3848x + 161.23$, $r^2=0.003$, $p=0.0888$; age 2.5 $y = 587.73x - 0.3109$, $r^2=0.13$, $p<0.0001$; age 4 $y = 978.74x - 0.4518$, $r^2=0.22$, $p<0.0001$ 51

Figure 3.1: Study sites spanning 75° longitude or 8500 km across the South Pacific Ocean. 70

Figure 3.2: Cross sections of sagittal otoliths of *Acanthurus lineatus* from A) Marquesas, 19 years B) Moorea, 18 years and C) Moorea, 43 years, the oldest *A. lineatus* in this study. Line measures 1 mm. 70

Figure 3.3: *Acanthurus lineatus* otolith growth trajectories. Power functions of sagittal weight and age at locations in the tropical South Pacific Ocean. There was a positive correlation between age and sagittal weight at all study sites indicating the continuous growth of otoliths throughout an individual’s lifetime. 71

Figure 3.4: *Acanthurus lineatus*: Growth models from all populations in the tropical South Pacific Ocean. Von Bertalanffy growth function (VBGF) models fit four of the five populations best, but the size at age data from Marquesas fit the Power² model best indicated by sum of squares results. 72

Figure 3.5: A linear regression of mean of 20% maximum longevity of *Acanthurus lineatus* from west to east across the South Pacific Ocean on a proportional, spatial scale. There is no apparent spatial gradient in longevity across the Pacific Ocean. 73

Figure 3.6: A linear regression of mean of 20% of maximum body size of *Acanthurus lineatus* from west to east across the South Pacific Ocean on proportional, spatial scale. There is no apparent spatial gradient in body size across the Pacific Ocean. 73

Figure 3.7: Instantaneous growth rates of *Acanthurus lineatus* at different ages vs. location from west to central tropical South Pacific. The solid line and open circles (—, O) represent size at age 1 year, the dashed line and exes (---, x) represent size at age 2.5

and the dash-dot line and solid circles (—·—, •) represent size at age 4. Age 1: $y = 0.0021x + 128.84$, $r^2=0.0215$, $p=0.8138$; age 2.5: $y = y = 0.0044x + 176.54$, $r^2=0.1095$, $p=0.5865$; age 4 $y = 0.0042x + 192.39$, $r^2= 0.1509$, $p=0.5181$. There is no apparent trend in initial growth across the Pacific Ocean..... 74

Figure 3.8: Differences in body length of *Acanthurus lineatus* between settlement and age 1 (black bar), ages 1 and 2.5 (white bar) and ages 2.5 and 4 (grey bar). As this species gets older, growth decreases..... 75

Figure 4.1: Cross sectioned sagittae of (A) *A. coeruleus* (16 years) and (B) *A. chirurgus* (10 years) from Bermuda. These images illustrate the clear and consistent increments that are formed from each species. Line measures 1.5 mm..... 89

Figure 4.2: Von Bertalanffy growth trajectories of (A) *Acanthurus chirurgus* (n=86 on the inner reef and n=30 on the outer reef) and (B) *A. coeruleus* (n=11 on the inner reef and n=94 on the outer reef) in two habitats at Bermuda. Open circles and broken line (◦, ---) indicate samples taken from outside the reef and solid circles and line (•, —) indicate samples taken from inside the lagoon. 90

Figure 4.3: Sagittal growth trajectories of (A) *Acanthurus chirurgus* and (B) *A. coeruleus* in Bermuda. Open circles and broken line (◦, ---) indicate samples taken from outside the reef, and solid circles and line (•, —) indicate samples taken from inside the lagoon. *A. chirurgus*: outer reef: $y=10160x^{2.1382}$, $r^2=0.81$, $p<0.0001$; inner reef: $y=178.74x^{1.0983}$, $r^2=0.80$, $p<0.0001$. *A. coeruleus*: outer reef: $y=4714.8x^{1.7795}$, $r^2=0.88$, $p<0.0001$; inner reef: $y=80.715x^{0.9357}$, $r^2=0.83$, $p<0.0001$ 91

List of Tables

Table 2.2. The locations in the tropical Atlantic Ocean where every species of <i>Acanthurid</i> was sampled.	35
Table 2.3: Demographic data on the populations of <i>Acanthurus chirurgus</i> , <i>A. coeruleus</i> and <i>A. bahianus</i> at the respected study sites. Size at age zero (L_0) in the growth trajectories were constrained to 27 mm for each species. Size at age is derived from the reparameterized von Bertalanffy growth function (rVBGF). MMA refers to mean maximum age and is represented in years. Values for t_0 , k and L_∞ do not pertain to Margarita for <i>A. coeruleus</i> and <i>A. chirurgus</i> since the growth trajectories do not fit the VBGF model.	36
Table 2.4: Sum of squares results for nine growth models fitted to <i>A. coeruleus</i> and <i>A. chirurgus</i> at Isla de Margarita. Power ² growth model fits the growth trajectories best for both species for the entire lifespan. Power ² and VBGF form the growth trajectories best for both species in their early life history stages. VBGF was used in this study in order to properly be fit with rVBGF, and tested similarly to the other populations.	38
Table 2.5: A randomization test was used in place of parametric ANOVA to test for statistical significance associated with the parameters of rVBGF, $L(1)$, $L(2.5)$ and $L(4)$ of <i>A. bahianus</i> , <i>A. coeruleus</i> and <i>A. chirurgus</i> . The observed p-value was compared with the distribution of randomized p-values, and if it occupied the lower 5% of the distribution, then it was deemed statistically significant. The bold values indicate significant results.	39
Table 3.1: Five study sites in the tropical South Pacific Ocean. MCR LTER = Moorea Coral Reef Long Term Ecological Research.	68
Table 3.2: Demographic data on the populations of <i>Acanthurus lineatus</i> at the respected study sites. Size at age zero (L_0) in the growth trajectories were constrained to 25 mm for each species. Size at age is derived from the reparameterized von Bertalanffy growth function (rVBGF). MMA refers to mean maximum age and is represented in years.	

MMS refers to the mean maximum size and is represented in FL millimetres. MMA and MMS values are taken from the average ages and sizes of the top 20% of a population. Values for t_0 , k and L_∞ do not pertain to Marquesas since the growth trajectories do not fit the VBGF model..... 68

Table 3.3: Results of analysis of variance (ANOVA) using the Randomization test indicated that the body lengths of *A. lineatus* associated with the parameters of rVBGF, $L(1)$, $L(2.5)$ and $L(4)$, displayed no significant spatial gradient pattern across the tropical Pacific Ocean. The observed p-value was compared with the distribution of randomized p-values, and if it occupied the lower 5% of the distribution, then it was deemed statistically significant. 69

Table 4.1: *Acanthurus chirurgus* and *A. coeruleus*. Demographic data on the populations in the inner and outer reefs of Bermuda. In the VBGF growth trajectories size at age zero (L_0) was constrained to 27 mm. MMA refers to mean maximum age and MMS refers to mean maximum size. These estimates were derived from 20% of the oldest and largest individuals in a population respectively. 89