

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Characterisation of limb development and locomotion in the
brown kiwi (*Apteryx mantelli*)**

A thesis presented in partial fulfillment of the requirements for the degree of

Master of Science

in

Zoology

at Massey University, Palmerston North, New Zealand

Erica Anne Jones

2010

Abstract

This thesis covers broad topics concerning limb growth and development and their effects on locomotion in the brown kiwi (*Apteryx mantelli*).

I begin by describing the morphological features of a collection of unknown-age wild kiwi embryos from early development to point of hatch. Using these features, I assign developmental stages to each embryo and compare the progress of development to the same-staged ostrich and chicken embryos. Measurements of the hindlimb, bill and crown-rump length are used to develop an aging scheme based on comparisons with the ostrich and the chicken. The ostrich model and chicken model create age predictions for the unknown aged kiwi embryos. One kiwi embryo was of known age and both models gave identical predictions for this marker embryo, but gave differing predictions for all other kiwi embryos.

Using captive-reared kiwi chicks, I characterise hindlimb, bill and bodyweight growth from the time of hatch to 3 months of age. Growth patterns are very linear within this time period for all measurements but bodyweight. Female kiwi hatch with longer bills than males, but the growth of both sexes converges by the end of the 3-month period. Growth of bodyweight in the males slows earlier than in females. Bodyweight and bill length were then compared to a wild population of kiwi. Captive-reared chicks were found to hatch with shorter bills than the wild birds and to increase in bodyweight at a faster rate than wild birds. Rapid weight gain has been implicated in developmental limb deformities in other precocial and long-legged birds and has the potential to produce similar results in captive kiwi.

I further studied the movement of the hindlimb during locomotion in two adults and one juvenile kiwi by filming them while they were walking on a treadmill. Kinematic parameters were measured from the video recordings and compared to overground parameters from another study. Similarity between the treadmill and overground locomotor parameters validates the use of a treadmill in studying kiwi locomotion. None of the birds achieved the theoretical transition from a walk to a run at a duty factor of 0.5. After normalising for size, the juvenile showed a longer stride length and lower

stride frequency with increasing speed than the adults. Lateral head oscillations were observed during the stride cycle, which I propose having a sensory function as well as a biomechanical one.

Acknowledgements

My unexpected adventure into a Masters degree did not take a smooth path. Nevertheless, my family's, friend's, supervisors' and co-authors' faith in my abilities pulled me over the finish line. Thank you to my family and friends overseas who have taken great interest in my work – especially Mom and Dad, whose inherent fascination with the scientific world rubbed off on me and to Adele, who has been floating in the same boat with me all along. Thank you to Aunt Dogs, whose care packages with American junk food made life in front of my computer more bearable.

I've been especially fortunate to meet a great deal of people while working on this project, such as the whole Kiwi Encounter crew who welcomed me like one of their own. Emma remained as my lifeline to the kiwis I worked with and was generous in helping fill in the gaps in my kiwi care knowledge. Without the cooperation of the Department of Conservation, Wellington Zoo, Mt. Bruce and Dawne Morton, I would have had no kiwi for my treadmill trials. I thank them for their forward thinking and willingness to allow their birds to participate in my trials. And while I did not meet my partner, Reuben, through anything kiwi-related, his unflinching support throughout the writing process made my life a little less painful, even though he probably bore the brunt of my frustrations. His parents also proved to be essential in the manufacturing process of my experimental equipment. I am also grateful for the essential equipment and time off provided by my friend and employer, Wayne.

Additionally, I would like to acknowledge the financial assistance provided by the Frank M. Chapman Memorial Foundation and the IVABS Postgraduate Fund.

Preface

This thesis has been written and organised as self-contained chapters that will act as submissions to peer-reviewed scientific journals. Therefore, each chapter is written as a fully-referenced paper, causing overlap of some material, but each presents a unique aspect of kiwi hindlimb growth, development or movement.

Contents

Abstract	iii
Acknowledgements	v
Preface	vi
Contents	vii
List of Figures	ix
List of Tables	x

Chapter One: General Introduction

1.1 Current status and ecology of kiwi	3
1.1.1 Taxonomy and phylogeny of kiwi	3
1.2 Avian growth and development	5
1.2.1 Reproductive biology of kiwi	5
1.2.2 Embryonic development of kiwi	6
1.2.3 Postnatal growth of kiwi	7
1.2.4 Developmental deformities in precocial avian species	8
1.3 Bipedal Locomotion	9
1.3.1 Evolution of avian posture and locomotion	11
1.3.2 Applications of gait analysis	12
1.3.3 The function of head movement in locomotion and vision	13
1.4 Thesis aims and organisation	14
References	16

Chapter Two: Development of a preliminary method for estimating the age of brown kiwi (*Apteryx mantelli*) embryos

Abstract	29
2.1 Introduction	30
2.2 Materials and Methods	31
2.3 Results	32
2.4 Discussion	38
References	41

**Chapter Three: Postnatal growth in brown kiwi (*Apteryx mantelli*)
raised in captivity and in the wild.**

Abstract	47
3.1 Introduction	48
3.2 Materials and Methods	49
3.2.1 Captive-reared birds	49
3.2.2 Husbandry	50
3.2.3 Morphological measurements	51
3.2.4 Wild birds	52
3.2.5 Statistical analysis	52
3.3 Results	53
3.3.1 Captive-reared birds	53
3.3.2 Captive-reared versus wild growth	56
3.4 Discussion	58
References	61

**Chapter Four: Locomotion parameters and oscillating lateral head
motion in brown kiwi (*Apteryx mantelli*)**

Abstract	67
4.1 Introduction	68
4.2 Materials and Methods	69
4.2.1 Stride characteristics	71
4.2.2 Treadmill versus overground	72
4.2.3 Head movement	72
4.3 Results	72
4.3.1 Stride characteristics	73
4.3.2 Treadmill versus overground	75
4.3.3 Head movement	76
4.4 Discussion	77
References	81

Chapter Five: General Discussion 87

References	93
------------	----

Appendix

Appendix 1

99

List of Figures

Figure 2.1	Kiwi embryos are arranged in increasing chronological order	33
Figure 2.2	Linear regressions of crown-rump and femur length measurements and polynomial regression of bill length with predicted age based on ostrich and chicken models	36
Figure 2.3	Linear regression of tibiotarsus, tarsometatarsus and toe length measurements and predicted age based on ostrich and chicken models	37
Figure 3.1	Measuring tarsometatarsal length in kiwi chick	52
Figure 3.2	Weight gain in captive-reared kiwi (n=28) from hatching through to three months of age	53
Figure 3.3	Bill length in captive-reared kiwi from hatching through to three months of age	54
Figure 3.4	Bill width and depth in captive-reared kiwi from hatching through to three months of age	54
Figure 3.5	Tibiotarsal length, width and depth and tarsometatarsal length in captive-reared kiwi from hatching through to three months of age	55
Figure 3.6	Femoral length, tarsometatarsal width and depth, and toe length, width and depth in captive-reared kiwi from hatching through to three months of age	56
Figure 3.7	Weight gain in female and male captive-reared and wild kiwi from hatch to three months of age	57
Figure 3.8	Bill length growth in female and male captive-reared and wild kiwi from hatch to three months of age	58
Figure 4.1	Treadmill apparatus for recording of kiwi locomotion	70
Figure 4.2	Stride characteristics plotted against speed and relative speed in juvenile (1) kiwi and adult (2) kiwi	72
Figure 4.3	Maximum foot height in the swing phase plotted against speed in juvenile (1) kiwi and adult (2) kiwi	75
Figure 4.4	Track of head movement superimposed over footfall patterns during locomotion in kiwi	76

List of Tables

- Table 2.1** Estimation of Hamburger and Hamilton (HH) stage for kiwi embryos, embryo age estimates based on ostrich and chicken models, and feature descriptions are presented for each kiwi embryo. 35
- Table 4.1** Regression lines for all relative parameters plotted against relative speed for treadmill locomotion (this study) and overground locomotion (Abourachid and Renous, 2000). 75

