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THE QUANTITATIVE ANATOMY
OF THE KANGAROO.

VOLUME I

A dissertation submitted for the Degree of Doctor of Philosophy

in the

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by

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Figure 1. Alizarin bone stain of an immature pouch young of the red kangaroo.

Figure 2. Adult female (left) and male red kangaroo.

VOLUME I

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PREFACE

This study was undertaken in the Department of Veterinary Anatomy, University of Sydney. The work was financed by the Australian Research Grants Committee and the University of Sydney.

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Professor R.M. Butterfield supervised the study. His guidance and encouragement is very gratefully acknowledged.

The material presented in this thesis is the result of the author's original research, unless otherwise indicated in the text.

Paul Hopwood

SUMMARY

"....... to measure all things that can be measured, and to make measurable what cannot yet be measured."

Galileo

"..... the data provided can only establish differences (or similarities) but it seldom has sufficient precision to establish causes. Indeed there is a very real danger in trying to read into the data more than it is designed to give."

Ledger (1968) on comparative
body composition studies

This work is presented in two volumes. Volume 1 contains the core of the investigation into the body composition of the kangaroo. Volume 2 contains material necessary to support or qualify the information presented in Volume 1.

Quantitative anatomical data were collected from dissections of forty-four grey kangaroos (Macropus giganteus Shaw), seventeen red kangaroos (Megaleia rufa). three wallaroos (Macropus robustus), two red-necked wallabies (Macropus rufogriseus; Wallabia rufogriseus) and three swamp wallabies (Wallabia bicolour).

The data is used to:-

1. define the body composition of the kangaroo;
2. define patterns of growth within the kangaroo body;
3. provide a base from which to develop hypotheses on the principles controlling growth and development in mammals, particularly those principles relating to animal production.

1. Body Composition

A. The body composition of the kangaroo is defined in respect to approximately two hundred organ and tissue relationships

B Sexual dimorphism is evident in the body composition of the kangaroo. The mature male body form is more thickset than that of the female. Males grow 2 - 3 times the size of females. When each sex is compared at the same empty body weight, females are heavier in the hindquarter and males heavier in the forequarter; females have a greater total carcass muscle and carcass fat weight than males; males have a greater total carcass bone weight than females; except for the genitalia and bladder, sexual dimorphism is not marked amongst the viscera.

C The carcass composition of the kangaroo in relation to the potential of the animal as a meat producer is examined. The carcass composition of sheep and kangaroos is compared. Kangar are found to yield more dressed carcass than sheep of the same empty body weight. At the same carcass weight, the kangaroo carcass will yield more muscle than that of the sheep. Within the carcass the muscle of the kangaroo is concentrated in the more "valuable" butt and loin. In comparison with cattle, shee and pigs, kangaroos have a high percentage of their carcass as muscle, an average percentage of their carcass as bone and a l percentage of their carcass as fat.

2. Patterns of Growth

A. Concepts of tissue maturity and phasic growth are defined. In particular the definitions given for monophasic and biphasic growth in this study are compared with those of Lohse (1971). The use of Huxley's (1932) allometric 'k' values and Griffith and Miller's (1973) two phase linear "b1, b2" values to defin early and late maturing biphasic growth are discussed.

B. The literature on centripetal and cranio-caudal growth patter evident within the tissues of the domestic animals is reviewe Evidence is presented to demonstrate that centripetal growth patterns occur within the tissues of the pectoral and pelvic limb of the kangaroo. In the body weight range of this stud a cranio-caudal growth pattern acting along the body axis is demonstrable. Evidence is presented to demonstrate a cranio thoracic growth pattern.

3. Hypotheses

A. Carcass muscle may be increased as a percentage of the carca in the domestic species.

The proportions of the three basic carcass tissues - mus potential of the animal as a meat producer is examined. The carcass composition of sheep and kangaroos is compared. Kangaroos are found to yield more dressed carcass than sheep of the same empty body weight. At the same carcass weight, the kangaroo carcass will yield more muscle than that of the sheep. Within the carcass the muscle of the kangaroo is concentrated in the more "valuable" butt and loin. In comparison with cattle, sheep and pigs, kangaroos have a high percentage of their carcass as muscle, an average percentage of their carcass as bone and a low percentage of their carcass as fat.

2. Patterns of Growth

A. Concepts of tissue maturity and phasic growth are defined. In particular the definitions given for monophasic and biphasic growth in this study are compared with those of Lohse (1971). The use of Huxley's (1932) allometric 'k' values and Griffiths and Miller's (1973) two phase linear "bl, b2" values to define early and late maturing biphasic growth are discussed.

B. The literature on centripetal and cranio-caudal growth patterns evident within the tissues of the domestic animals is reviewed. Evidence is presented to demonstrate that centripetal growth patterns occur within the tissues of the pectoral and pelvic limb of the kangaroo. In the body weight range of this study, a cranio-caudal growth pattern acting along the body axis is not demonstrable. Evidence is presented to demonstrate a cranio-thoracic growth pattern.

3. Hypotheses

A. Carcass muscle may be increased as a percentage of the carcass in the domestic species.

The proportions of the three basic carcass tissues - muscle, bone and fat are investigated in a number of species of mammals. Heavily muscled species of wild animals approach an upper limit of 80 - 85% of their carcass as muscle. It is suggested that artificial selection programmes aimed at "improving" the body composition of domestic animals raised for meat production may strive towards a similar carcass muscle percentage as found in wild animals.

B. Muscle-weight distribution may be altered in the domestic species. The muscle-weight distribution of the grey and red kangaroo is demonstrated to differ and the differences observed are explained in terms of environmentally suited adaptations of the gaits of the two species. The muscle-weight distribution in the two species is demonstrated to correlate to the functional muscular requirement of their gait. It is inferred that artificial selection aimed at altering the muscle-weight distribution of a species should be made on criteria which assess the functional muscular capability of an animal. The practicability of this suggestion both in implementation and in results obtained, in the domestic species is unknown.

C. Quantitative anatomical studies may have an application in the definition of "standard tissue bases".

Biochemical studies require standard tissue bases against which units of chemical activity may be scored. This study demonstrates that an intricate pattern of differential growth occurs in the animal (kangaroo) body. It may be anticipated that tissue physico-chemical processes will vary with the growth rate of the tissue. The description of tissue growth rates obtained from quantitative anatomical investigation allows the chemical activity determined for a tissue to be interpreted within the knowledge of the growth rate of that tissue at the time it was sampled.

CHAPTER 1.

GENERAL INTRODUCTION

Anatomy is the science of bodily structure. The word anatomy (ana (Gk) = apart; temnein (Gk) = to cut) literally means to cut apart. In this study, kangaroos were dissected into their component body organs and tissues. Specimens were taken from various stages in the life span of the kangaroo and the data obtained from the dissections analysed to elucidate how kangaroos grow and develop.

The kangaroo is a native animal of Australia and New Guinea. A mammal, it belongs to Order Marsupialia, Family Macropodidae. Walker (1968) listed 17 genera for Family Macropodidae, with some fifty-odd species. _Macropus giganteus_ Shaw, _Megaleia rufa_, _Macropus robustus_, _Macropus rufogriseus_, and _Wallabia bicolour_ were studied in this work. The eastern grey kangaroo (_Macropus giganteus_ Shaw) was studied as a type species for the kangaroo; the remaining kangaroos and wallabies were studied comparatively. A general description of each species studied is given in Appendix V.

The eastern grey kangaroo is distributed along the eastern coast of Australia from Queensland to Tasmania (Kirsch and Poole (1972)). Figure 3 illustrates the range of the species.

Russell (1974) discussed the biology of the eastern grey kangaroo, and its ecology in northern Queensland has been investigated by Bell (1973). Kaufmann (1974) studied habitat use and social organization. Other behavioural studies include those of Barrett (1932), Germann-Meyer and Schenkel (1971) and Grant (1974).

Griffiths and Barker (1966) listed plant species eaten by grey kangaroos grazing an area in south-western Queensland. They found

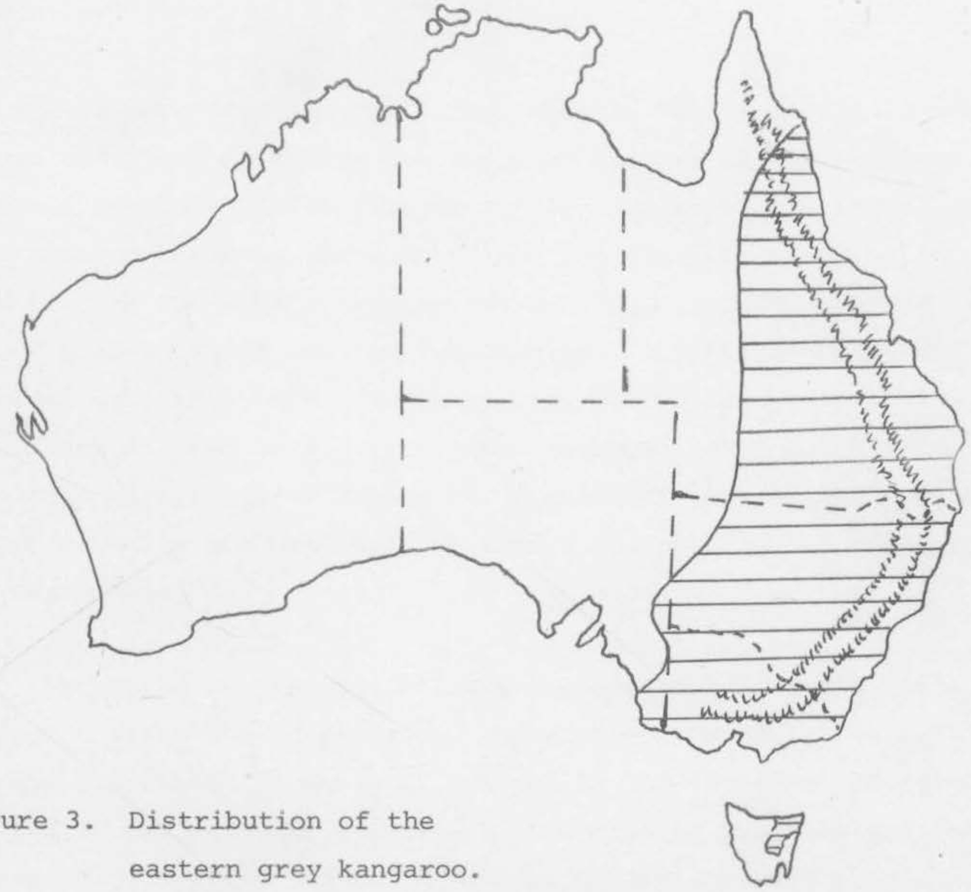

Figure 3. Distribution of the
eastern grey kangaroo.
Adapted from Kirsch, Poole (1972).

that the grey kangaroo preferred green herbage composed of 64 - 79% grass and 36 - 21% dicotyledonous plants. The food preferences of the grey kangaroo have also been studied by Kirkpatrick (1965). He found a marked preference for grasses, especially Aristida species. An interesting feature of some macropods is their ability to regurgitate food (Barker et al (1963)). Herrmann (1965) described food regurgitation in the grey kangaroo.

The digestive system of the kangaroo has been studied by Schafer and Williams (1876), Poulton (1883), MacKenzie (1918), Kirkpatrick (1964), Griffiths and Barton (1966), Calaby (1968), Forbes and Tribe (1969) and Henning and Hird (1970).

Sharman (1970) reviewed the reproductive cycle of marsupials. He summarized the reproductive cycle as follows. "The pro-oestrous phase of the marsupial oestrous cycle is characterized by enlargement of one or more Graafian follicles, mitotic proliferation of uterine lumen and gland epithelia and increase in size of the elements of the vaginal complex. These changes may be induced by the injection of the ovarian hormone, oestrogen, into the ovariectomized or intact female. In the intact female, the oestrogen induced changes reached their peak at about the time of oestrus. Ovulation occurs one to several days after oestrus and uterine epithelial proliferation continues at, and after, this time, accompanied by desquamation of the vaginal epithelia. There is no evidence that copulation, or other stimuli, are necessary to induce the shedding of ovarian eggs in marsupials."

"Ruptured ovarian follicles are replaced by corpora lutea, which induce the onset of a secretory phase in the marsupial uterus. Just as the proliferative phase is induced by the injection of oestrogen, so the luteal phase is induced by injection of progesterone. After a period of varying length in various marsupials, the luteal phase is replaced by anoestrus in monoestrous marsupials and by the post-luteal phase, which grades into the next pro-oestrus in polyoestrous marsupials."

"If insemination occurs at oestrus, the resulting pregnancy does not interrupt the oestrous cycle of any marsupial. Provided the newborn young are prevented from reaching the teat, or removed soon after birth, the next oestrous recurs when expected. In species which exhibit post-partum oestrus, the relationship between parturition and subsequent oestrus and mating is fortuitous - these occur at the same time as they would have occurred had the animal not been pregnant. Ovulation strictly alternates between left and right ovaries, so the closing stages of gestation in one uterus may be accompanied by the segmentation of a newly fertilized egg in the alternate uterus.

Pregnancy does not inhibit the cyclic recurrence of oestrus, but suckling-induced ovarian inactivity occurs post-partum."

Poole and Catling (1974) demonstrated the following points about the oestrous cycle of the eastern grey kangaroo. Oestrus was found to occur throughout the year, but was less common in winter when some females exhibited anoestrus. The length of an oestrous cycle was 45.6 days (±9.8) and females returned to oestrus 10.9 days (±4.8) subsequent to the loss of a pouch young. The females were uniparous and post-parturient lactation suppressed oestrus for 160 days post-partum. Successful matings with a current pouch young were followed by embryonic diapause.

Placentation and parturition are well documented for the eastern grey kangaroo. Owen (1834) described "the generation of the marsupial animals, with a description of the inpregnated uterus of the kangaroo". Matthews (1943) gave a brief review of the literature on parturition in the kangaroo. Pearson (1948) described "placentation of the marsupialia". The reproductive system has been described by Clark and Poole (1967). Kaye (1971) described "the evolution of placentation".

Sharman (1970) reviewed lactation in marsupials. Four mammary glands are present within the kangaroo pouch. Early in lactation, kangaroo milk is a clear fluid, low in fat. The composition of kangaroo milk changes during lactation; the sugar percentage decreases and the fat percentage increases up to 20 per cent in late lactation. If a kangaroo is suckling a young-at-foot as well as a pouch-young, the composition of the milk produced in each gland may be widely different.

Kirkpatrick (1964a) studied the growth of the pouch young of the eastern grey kangaroo with the view of developing methods of estimating age of pouch young. He was able to demonstrate sigmoidal growth relationships between length of tail, length of hind feet and the age of pouch young. He found the mean duration of pouch life to be 297 days. Poole (1973) examined 713 grey kangaroo pouch young. He found no significant difference in a male/female ratio of 105 : 100 for pouch young and 84 : 100 for young-at-foot. Poole (1973) further determined a mortality rate of 1.8% per 28 days for pouch young in the age range 113 - 280 days. Sharman et al (1964) made a detailed study of growth of the pouch young in the red kangaroo (Megaleia rufa).

Grant (pers comm), based on two animals, found that eastern grey kangaroos leave the pouch between 6 - 7 kg liveweight. Poole (pers comm), based on 14 animals, found that captive grey kangaroos leave the pouch at 7.16 (±0.34) kg liveweight.

Frith and Calaby (1969) gave relationships between age and liveweight for grey and red kangaroos. (Figure 4).

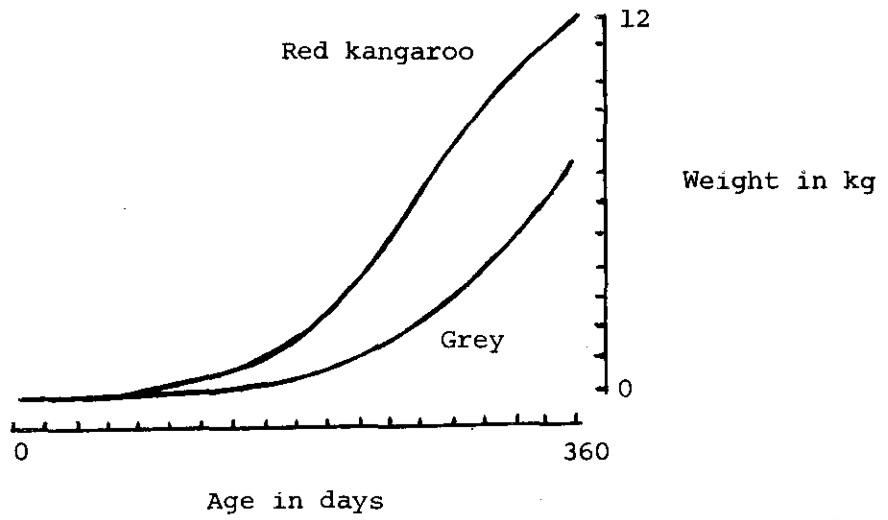

Figure 4. Relationship of weight to age for grey and red kangaroo joeys. Frith and Calaby (1969).
(Grey data extracted Kirkpatrick (1964) MSc Thesis, University of Queensland).

Sexual maturity occurs at different ages and liveweights for female and male eastern grey kangaroos. In females, Poole and Catling (1974) demonstrated that eversion of the teats at 18 months of age marked the onset of sexual maturity, initial mating began at 19 months and first parturition occurred at approximately 20 months of age. Poole (pers comm) kindly provided correlations between sexual maturity and liveweight for females. In a group of eight animals, all teats were everted at a mean weight of 17.4 kg (range 15.0 to 19.5 kg). First matings occurred at 16.6 kg (range 15.3 to 18.0 kg) - records for two animals only. Parturition occurred at 21.2 kg mean liveweight for a group of 8 animals (range 16.0 to 27.0 kg). Poole (pers comm) established the relationship:-

$$\text{female liveweight (kg)} = 3.68647 \left(\frac{\text{Age days}}{100}\right) - 0.0516086 \left(\frac{\text{Age days}}{100}\right)^2 - 0.00561396 \left(\frac{\text{Age days}}{100}\right)^3 + 0.000159851 \left(\frac{\text{Age days}}{100}\right)^4 - 4.565$$

for females between 24 and 3102 days of age.

In males, Poole and Catling (1974) demonstrated sexual maturity between 20 to 48 months of age, as evidenced by the presence of spermatozoa on testicular biopsy. Poole (1973) demonstrated sexual maturity between 20 to 72 months of age in males taken from a wild population. If the ages 20 and 72 months of age are substituted into the relationship given by Poole (pers comm) and based on males from 11 to 2390 days of age,

$$\text{male liveweight (kg)} = 1.73246 \left(\frac{\text{Age days}}{100}\right) + 0.550019 \left(\frac{\text{Age days}}{100}\right)^2 - 0.0423579 \left(\frac{\text{Age days}}{100}\right)^3 + 0.000848176 \left(\frac{\text{Age days}}{100}\right)^4 - 2.695$$

then eastern grey males are found to mature sexually between 19 to

49 kg liveweight. Figure 5 shows the relationship of testicular tubule diameter to liveweight for four animals on which a series of biopsys were taken. A marked change in growth rate of the testicular tubule diameter is evident between 30 - 35 kg liveweight and it is likely that this weight range is associated with puberty.

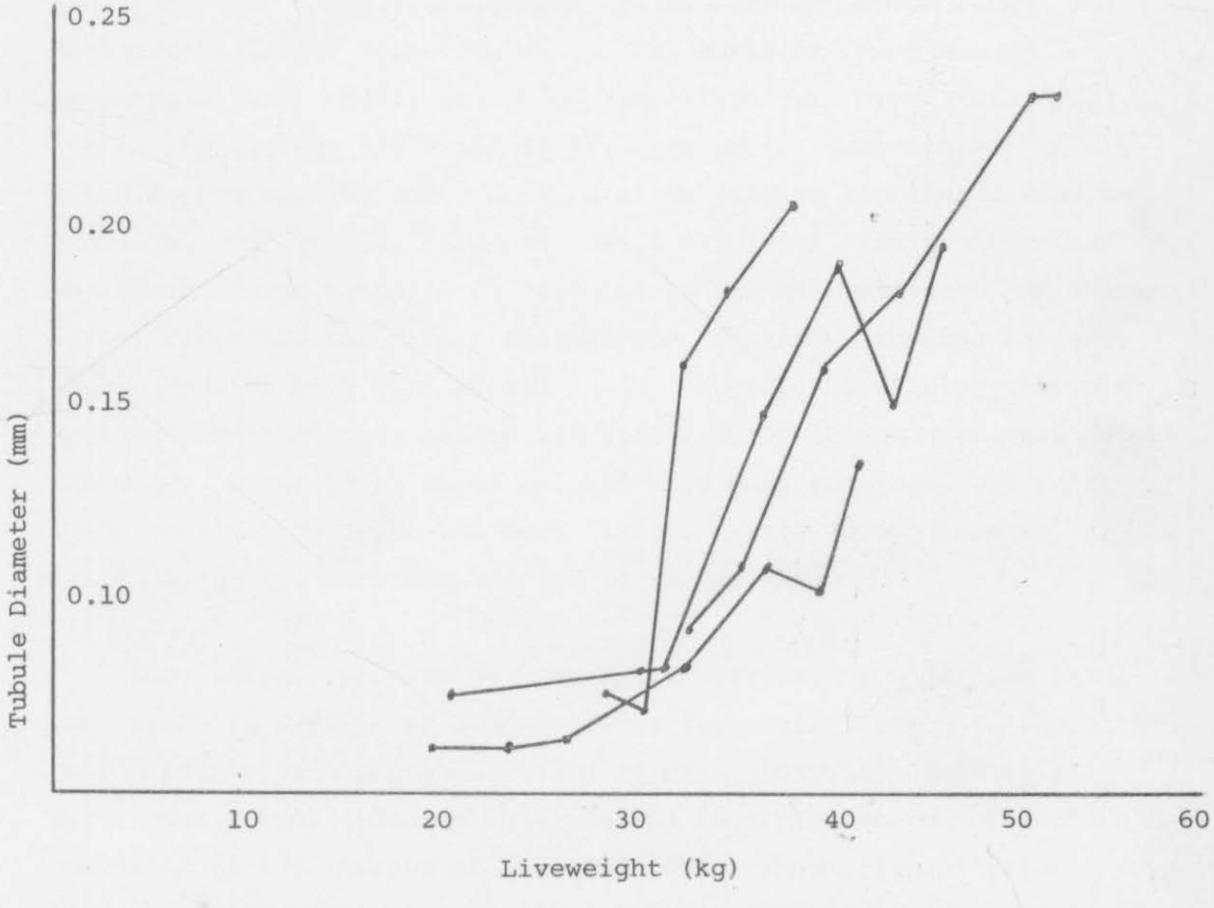

Figure 5. Relationship of testicular tubule diameter to liveweight for eastern grey kangaroos. Poole (pers comm).

Current Research.

The awareness of the general public to conservation and environmental issues has created increased interest and support for research activities into the biology of the native Australian fauna.

Taxonomic studies, species distribution and particularly population dynamics and reproductive biology have been fields of research emphasis.

Descriptions of the morphology of the kangaroo first appear in the ships' records of the early navigators. The identity of Captain Cook's kangaroo has generated considerable discussion by Raven (1939), Morrison-Scott and Sawyer (1950), Iredale and Troughton (1963) and Kirkpatrick (1963). Serious anatomical works on the kangaroo appeared with the publications of Home (1795) and Owen (1833, 1837, 1841a, 1841b, 1868, 1874 and 1877). Anatomical descriptions of the kangaroo are usually undertaken to allow studies in other fields to continue. For example, Kirkpatrick (1963, 1964b, 1965b) described the teeth of the kangaroo in relation to age determination and Sharman (1964) described the female reproductive system of the red kangaroo in conjunction with his studies on the reproductive biology of this species. Quantitative anatomical studies have seldom been made on the kangaroo. Occassional organ weights have been recorded, but apart from the study by Tribe and Peel (1963), little information is available on the body composition of the kangaroo.

Game animal cropping as a means of efficiently utilizing arid zone lands is a field of study drawing increasing interest. Kay (1970) gave a review on the possibilities of meat production from wild herbivores. Game cropping is a reality in Africa where a large number of native species are suitable for economic exploitation. Darling (1960), Talbot et al (1962), Ledger (1963), Ledger and Smith (1964), Maloiy (1965), Sachs (1967) and Ledger (1968) described the utilization of various species of African game animals.

Kangaroo populations are either not utilized or at best, harvested for skins and pet food. The commercial utilization of the kangaroo has been discussed by Newsome and Frith (1966), Ratcliffe

(1970) and the economics of kangaroo harvesting were reviewed at a symposium held by the Royal Zoological Society of N.S.W. by Frith, Macfarlane, Doohan, Livanes and Sharman (1971).

Basic to the potential of any species to produce meat is the composition of that species' body. An objective definition of the composition of the kangaroo body is given in this study. From the data presented, comparison between the body composition of the kangaroo and other species is possible.

Growth and Development - Concepts.

Growth is difficult to accurately define. It has been described as increase in size, increase in weight, a preponderance of anabolic over catabolic processes in the body, and as the physiological accretion of new tissue. Development has been described as integrated growth which leads to the mature form of an animal.

Maturity is a concept frequently used in this study. Maturity implies full development. Although maturation requires time, old age is not synonymous with maturity. In this study, a body region or tissue is regarded to be mature when it approaches its adult proportions. Consequently, a tissue or body region may be considered mature even though the animal as a whole is still very immature.

As will be demonstrated, the various body tissues reach their mature proportions at different periods in the development of the animal. Relating the time at which a tissue matures to the animal as a whole raises certain problems. Age may be used but the rate at which the animal grows is known to affect age correlations. Absolute size or weight may be used to define when tissues change their growth intensities. Liveweight may be refined by using empty body weight to avoid influence from the weight of digestive tract contents. An immediate problem to the use of empty body weight is that the body consists of many tissues. If one tissue was selected for study and related to empty body weight, and though it may grow at a constant rate, differential growth in other body tissues could radically affect its proportion of the whole body. Thus, in this study, differential growth within a tissue is related to the weight of that tissue as a whole.

Criticism of the preceding approach may be that it lacks biological meaning. However, it is possible to correlate tissue based growth patterns to empty body weight. Then from empty body weight to stages of life such as vacation of the pouch, weaning and sexual maturity.

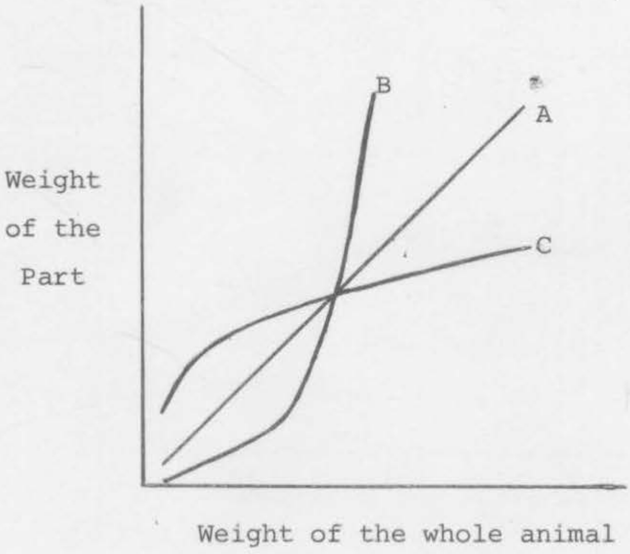

Figure 6. Illustration of three growth patterns.

Figure 6 illustrates three growth patterns. Growth pattern A exhibits constant proportion between the part and the whole. This type of growth is described in this study as monophasic. Growth patterns B and C are curvilinear, demonstrating that the proportion of the part to the whole is changing with growth. In this study, the growth patterns of B and C are considered to be biphasic. Growth patterns B and C may easily have been exerpted from the typical sigmoidal growth pattern demonstrated for many animals. If this were so, at a greater tissue weight than illustrated, the growth pattern of B would flatten out with a decrease in the growth rate of the part. And at a lesser tissue weight than illustrated in Figure 6, C would begin its sigmoidal inflection.

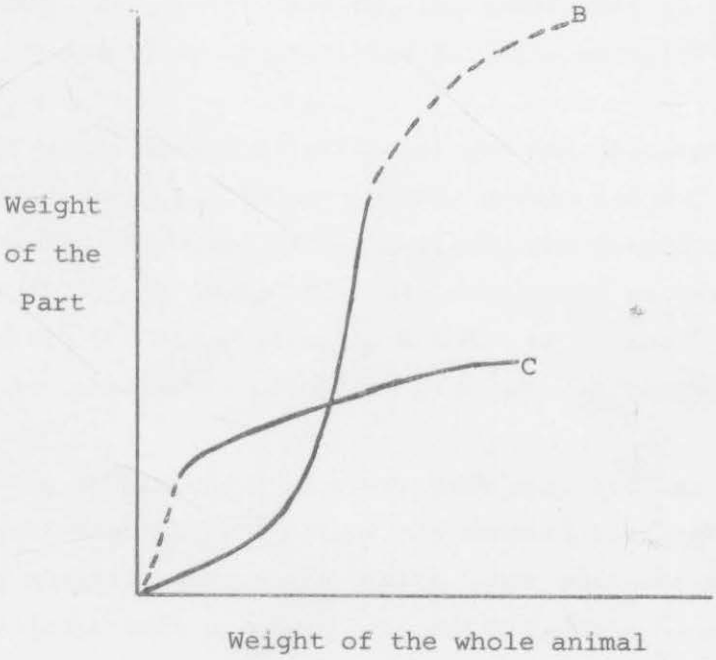

Figure 7. Projected sigmoidal growth patterns.

In the weight ranges usually investigated, that is, birth to maturity, growth patterns tend to be monophasic or biphasic. Biphasic patterns can be classed into late or early maturing growth patterns. In Figure 6, growth pattern B illustrates that of a late maturing tissue and growth pattern C an early maturing tissue. That is, C approaches its adult proportion earlier than B.

A mathematical expression for early and late maturity may be gained from Huxley's (1932) allometric model or Griffiths and Miller's (1973) two phase linear regression. Both these models are explained in Chapter 3. If the allometric function was fitted to growth patterns B and C respectively, growth coefficients of greater than 1 and less than 1 would be derived. Hence a "k" value of less than 1 implies early maturity and greater than 1, late maturity. If the two phase linear regression was fitted to growth patterns B and C, b1 would be less than b2 in the case of B and b1 greater than b2 in the case of C. Hence, where b1 is greater than b2, early maturity is indicated. Conversely, where b2 is greater than b1, late maturity is indicated.

An alternate concept of phasic growth was developed by Lohse (1971), and Lohse et al (1971). Phasic growth was not considered on the basis of the untreated data. Instead, the data was logged and curvilinearity in the logged data was considered as evidence of phasic growth. Hence, growth patterns A, B and C of Figure 6 would all be considered monophasic with average, high and low impetus respectively.

Depending on the point of view, each approach has its merits. For biological meaning, the author has adopted the previously defined meanings of maturity and phasic growth. The point of view expressed in this thesis is that an organ or part is undergoing multiphasic growth when it changes its proportion of the whole.

Berg and Butterfield (1976) reviewed the growth and development of cattle. Factors affecting body composition were listed as breed, sex, function and nutrition. Genetic difference is known to occur between and within species. Breeds and strains within breeds are known to exhibit different growth characters. Sex differences in body composition are common knowledge.

The basic design for this study is a species-sex partitioning of data derived from "normally" alimented animals.

It is evident that the more animals studied at a given body weight, the more accurate would be the assessment of body composition for that weight. A conflicting option is that the wider the weight range of animals studied, the more information that may be obtained on their growth and development. It was determined to study as wide a body weight range as practical, dissecting as many animals within that range as time and resources allowed.

The body composition of the kangaroo is defined in this study so that:-

1. principles underlying the growth and development of the kangaroo may be investigated. Principles elucidated may then be compared with those known to exist in other species. The implications drawn from similarities or differences found may consolidate existing theories on growth and development in mammals or else give rise to new hypotheses.

2. correlations between structure and function may be investigated. In particular, muscle-weight distribution and gait. Inferences, if any, may be drawn on the potential for selection to alter muscle-weight distribution in the domestic species.

3. the normal relationships of organs and tissues to the whole kangaroo body are known. A source of information on the body composition of the kangaroo would then be available in the literature. This information may then be used as a base on which a wide range of experimental work may be undertaken.

4. the kangaroo carcass may be assessed with a view to utilizing the animal as a meat producer.

5. the body composition of a wild animal may be compared with that of the domestic species. Inferences, if any, may be drawn on the progress made in selection on domestic species for "improved" body composition.

The preceding stated aims of this study do not imply that the author will attempt to raise all the issues implicit in each aim as it would be beyond the scope of one study or person to do so. Issues discussed are arbitrarily selected by the author on the basis of personal interest, practical importance and suitability of the data to analyses for the problem. However, the data collected for this study is fully tabulated in Appendix II to allow the reader to consider relationships not investigated by the author.

CHAPTER 2.

MATERIALS

> "First, catch your kangaroo"
>
> Anon.

Introduction.

The direct investigation of body composition, although laborious and time consuming, does not require elaborate or sophisticated laboratory equipment. The basic requirements can be divided into field equipment, dissection equipment, instruments of simple quantitative measurement, adequate cold storage, and computing facilities. The laboratory facilities used in this study were those used by Lohse (1971), Warren (1974) and Hilmi (1975). Similar laboratory equipment was used by Walker (1961), Butterfield (1963a), Bryden (1967) and Mukhoty (1969, 1971).

Materials.

A. Field Equipment

In the New England area, a short-wheel-base land-rover was used. The shooting was carried out at night and warm protective clothing was needed. A General Electric PB15 12 volt spot-light was used for locating animals. They were shot with a Remington 700 rifle, calibre .222 mounted with Scope Chief 4x telescopic sights, using Sako soft-point ammunition. A work box was carried in the vehicle which contained a clip-board, data sheets, stainless steel identification tags, pens, procaine penicillin, syringes, needles, a 2000lb maximum 7/1 ratio lightweight block and tackle and a torch. As required by law, licenses Nos. W/2999 and W/27/3833 issued by the National Parks and Wildlife Service of N.S.W. were carried in the field and used as authority to take protected fauna. A Wedderburn steelyard scale (P max. 302 lb) was used to weigh each specimen as collected.

B. Quantitative Measurement

Linear measurements were recorded using a straight metre rule equipped with a sliding vertical marker, a 1.5m plastic tape measure and a set of calipers measuring to 15cm.

Weight readings were recorded using a Mettler P 160N balance (P max. 160g, d ≙ 1mg), an Ohaus triple beam balance (P max. 2610g, d ≙ 0.1g) and a Wedderburn steelyard balance (P max. 302 lb. d ≙ 2 ozs).

Volumetric readings were recorded in glass measuring cylinders of capacity 50, 100 and 500 mls. Volumes were obtained from an overflow apparatus 90cm high by 8.5cm in diameter.

C. Dissection Instruments and Equipment

The following materials were used in the dissection:-

2 No. 4 scalpel handled and No. 21 disposable scalpel blades
2 No. 3 scalpel handles and No. 15 disposable scalpel blades
2 solid blade scalpels
2 pair 7" straight pointed scissors
2 pair 6" plain tissue forceps
2 pair 6" rat-tooth tissue forceps
1 5" boning knife
1 5" skinning knife
1 20" beef meat saw
1 steel
1 silicon carbide 108 sharpening stone
1 pair 6" blunt end pliers
1 butchers pouch
1 wooden dissection platform and dome as illustrated by Lohse (1971)
A dissection bench
Glass beakers 25ml, 100ml and 250ml
Heavy cotton drapes

Plastic sheeting

2 2-gallon plastic buckets

2 plastic dissection tubs 60cm x 36cm x 26cm deep

Nolex Clean Cut Meat Band Saw.

D. Refrigeration

The dissection laboratory was maintained between 20°C and 22°C throughout the total muscle dissection program and was equipped with a household refrigerator. Parts of a specimen awaiting dissection were wrapped in moist cloth and held in this refrigerator.

The preparation laboratory was equipped with a cabinet freezer and a freezing room, both operating between -18°C and -15°C. A chiller unit was also available and operated between 0°C and 5°C.

Field refrigeration facilities included commercial kangaroo chillers, commercial ice works and the freezing and chiller facilities of the Meat Research Laboratory, CSIRO Pastoral Research Station, Armidale.

E. Computing

The dissection results were analysed using a Sharp Model EL 816 electronic calculator, a Sharp Compet Model 365P electronic calculator and the facilities of the CSIRO Division of Computing Research, Canberra. Mr. Ian Gardiner, Departmental Statistician, Department of Veterinary Anatomy, and Dr. David Griffiths and Ms. Jean Williams, Division of Mathematics and Statistics, CSIRO, prepared the necessary computer programmes and supervised the selection and use of the various statistical procedures used in this study.

F. The Animals

Tables 1A, 1B and 1C of Appendix II summarize the relevant information on source, method of collection, time of collection, sex,

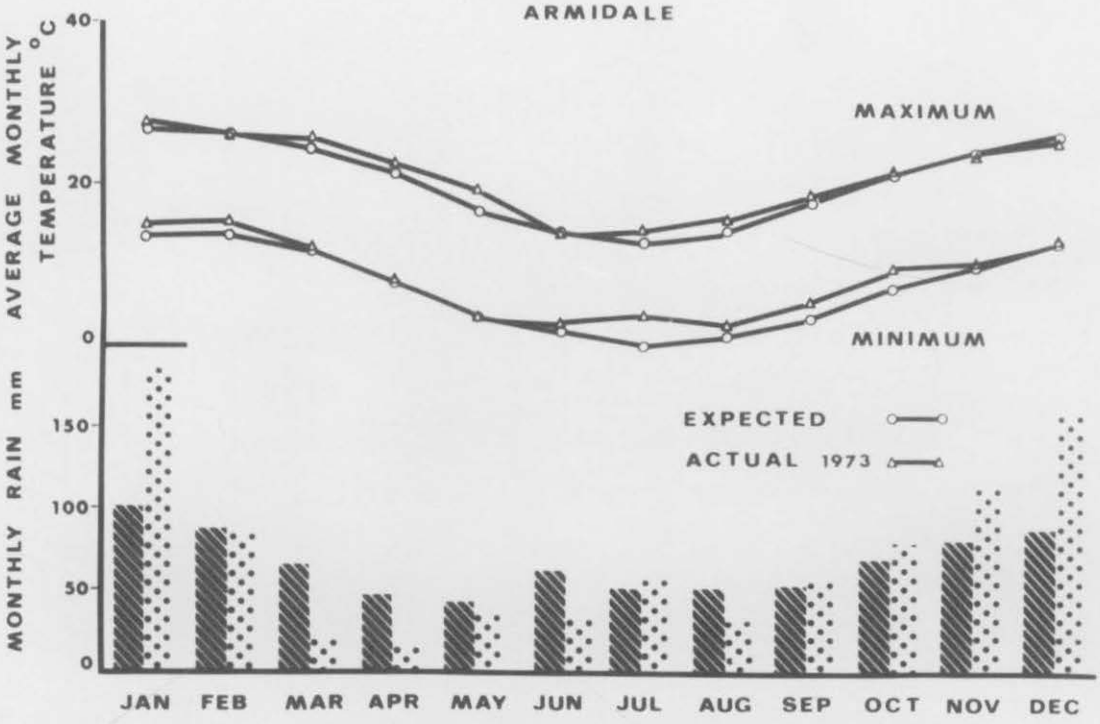

Figure 8. Expected and actual average monthly rainfall and temperature for Armidale, N.S.W. 1973.

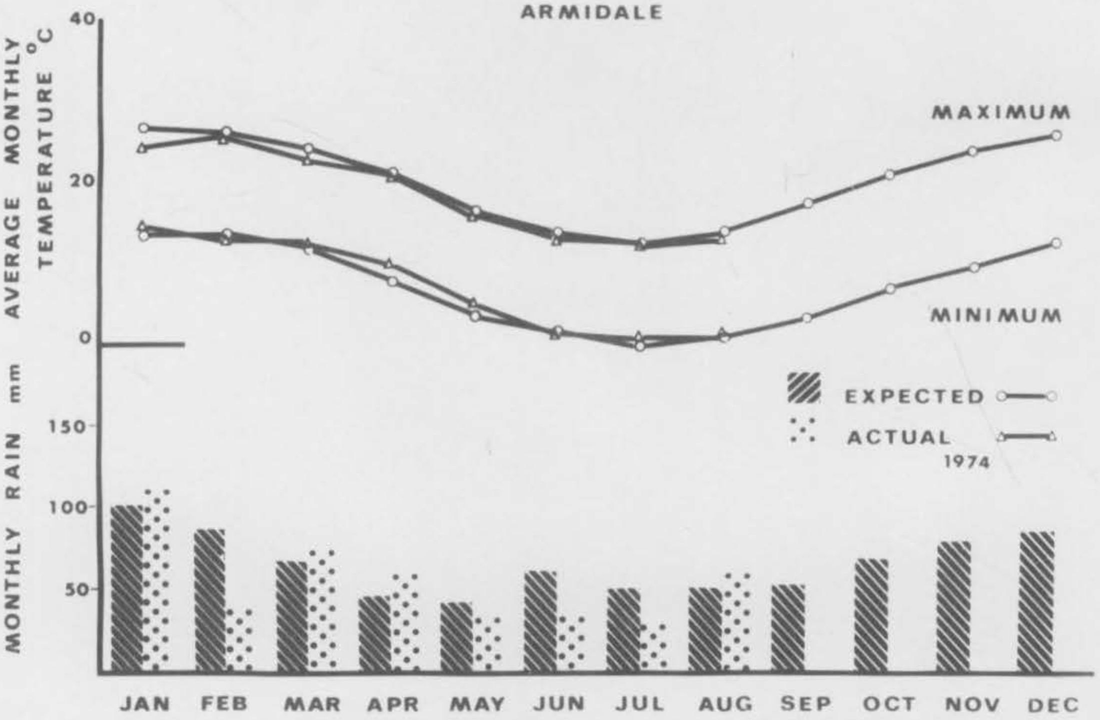

Figure 9. Expected and actual average monthly rainfall and temperature for Armidale, N.S.W. 1974.

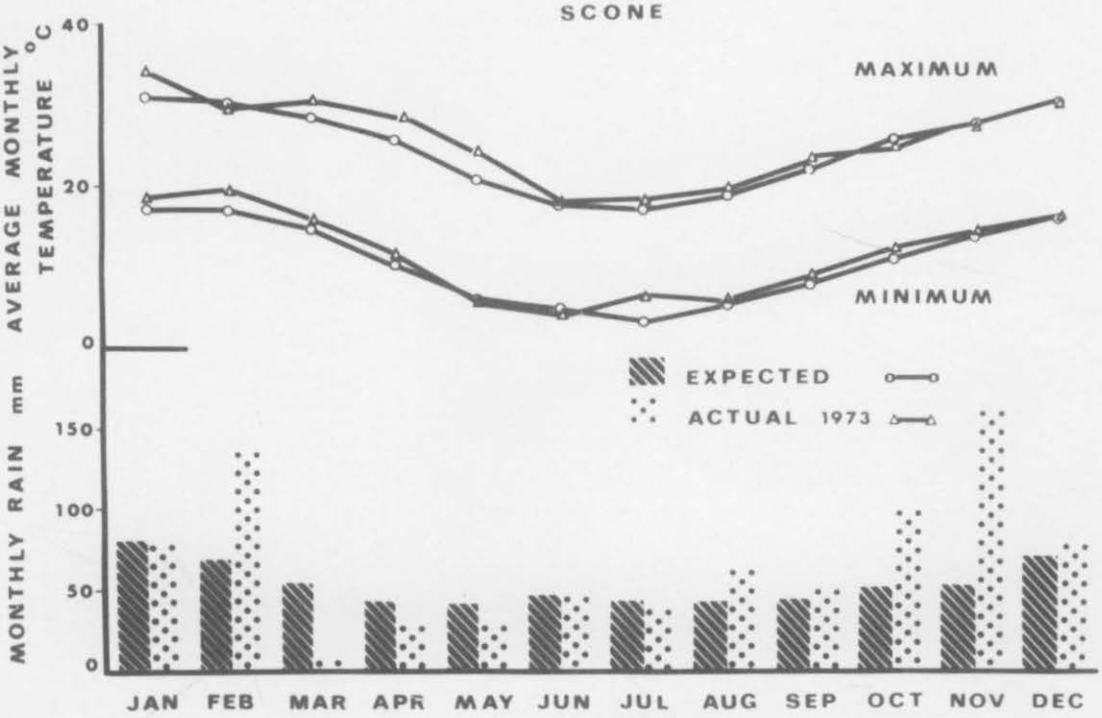

Figure 10. Expected and actual average monthly rainfall and temperature for Scone, N.S.W. 1973.

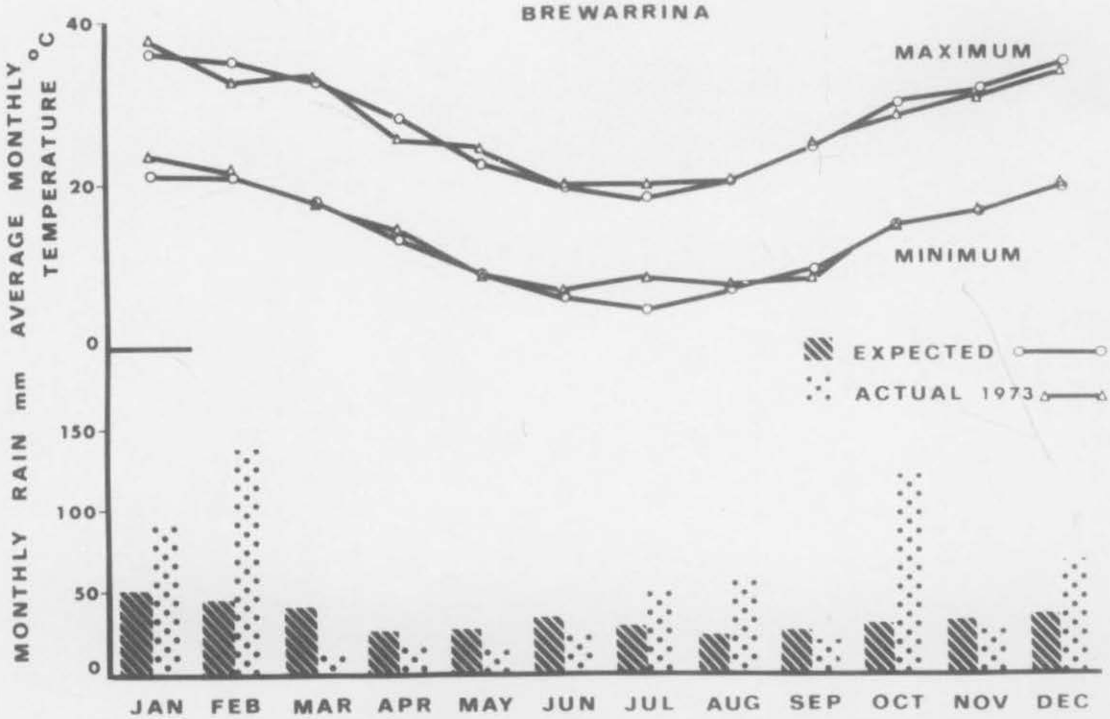

Figure 11. Expected and actual average monthly rainfall and temperature for Brewarrina, N.S.W. 1973.

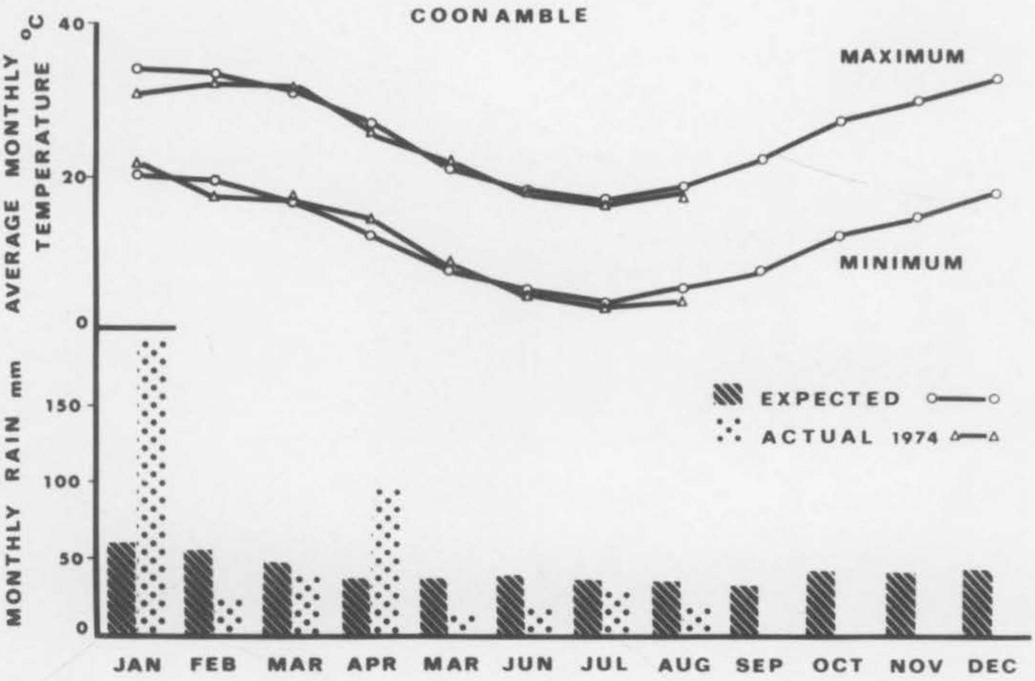

Figure 12. Expected and actual average monthly rainfall and temperature for Coonamble, N.S.W. 1974.

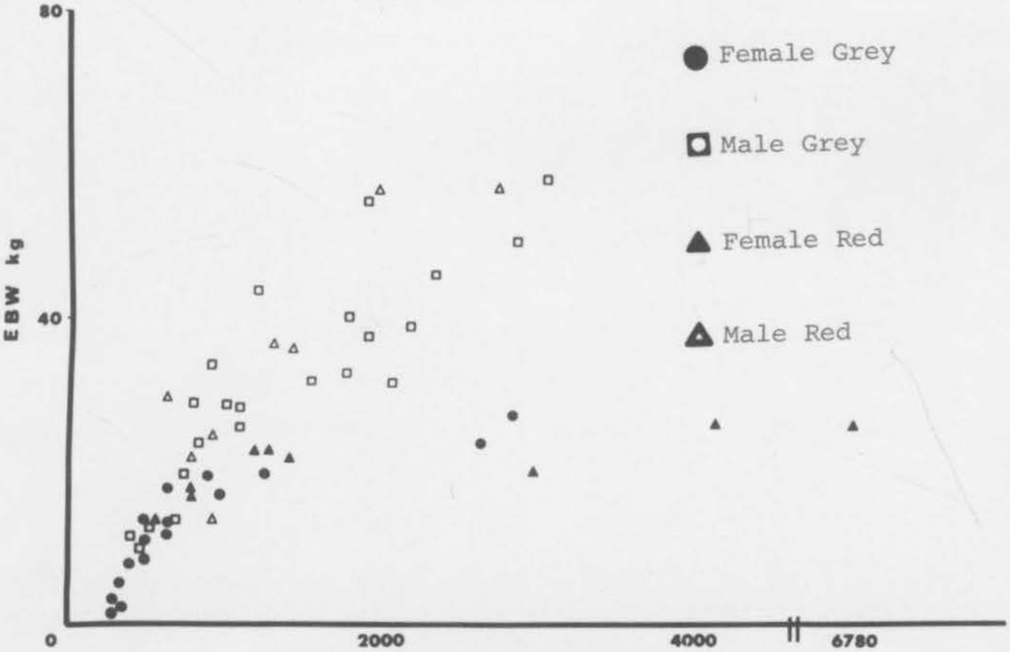

Figure 13. Relationship of empty body weight to age for grey and red kangaroos.

estimated age and weight of the specimens used in this study. Figures 8 - 12 summarize the relevant seasonal conditions prevailing in the areas of collection at the times animals were collected.

Figure 13 illustrates the variations in growth rate found amongst the kangaroos.

Discussion of Materials.

With the exception of the animals, the standard nature of the materials used calls for no comment.

No history was available for the animals. Consequently, they were grouped according to species and sex. Genetic variation within a species is accepted as species variation and no attempts are made to differentiate breed or strain differences. The area of origin and season were recorded for each animal, but regional and seasonal effects on body composition are not investigated. The nutritional history of individual animals is known to vary. Some animals were collected from unimproved properties with native grass pasture and some from highly improved properties, where the animals had access to fodder crops. Assuming other factors affecting growth rate to be equal, the known differences in nutrition alone would be expected to result in differences in growth rate. Figure 13 illustrates the estimated differences in average lifetime growth rates. It must be remembered that the differences observed are estimated differences based on the estimated ages of the animals.

The mobility of kangaroo populations prevented identification of animals according to the type of feed they had previously grazed, as there was no method of determining the length of time that any particular animal had spent grazing in the one area. Thus the inability to define an individual animal's previous nutritional history precluded the investigation of the effect of plane of nutrition on body composition. Furthermore, it raised the point of the validity of the results obtained in this study as applied to nutritionally-defined animals.

Severe malnutrition will markedly effect body composition. Reviews on the subject have been made by McCance (1962, 1971). Animals with a negative energy balance will utilize body tissue in different proportions, as their nett catabolic process depletes body tissue, to animals in a positive energy balance, whose nett anabolic processes are increasing body tissue (Butterfield (1966), Seebeck (1967), Seebeck and Tulloh (1968)). Thus the initial and final body composition of an animal which is grown to a given weight, is grown past that weight and then starved back to the initial weight, may be different. Furthermore, animals placed on low quality diets, deficient in vitamins or trace elements or with a poorly balanced protein/carbohydrate ratio, may not be able to grow according to their genetic potential. The question now is what is the likelihood that the animals used in this experiment were suffering from malnutrition and therefore atypical? Unfortunately, the question cannot be answered critically with a probability set on the accuracy of the results obtained. However, three checks are available. Firstly, the conditions most favourable to malnutrition are those of drought. Figures 8 - 12 give the expected and actual climatic conditions prevailing in the months preceding specimen collection. Inspection of these figures gives rise to no evidence of seasonal conditions consistent with drought. Secondly, many disease and body processes resulting from malnutrition are clinically evident, and only those animals clinically "normal" on examination at dressing, were selected. Finally, in retrospect, the high correlation coefficients and low residual sums of squares for the regressions of carcass bone and muscle on empty body weight, demonstrated a uniformity in the animals studied, which is inconsistent with a hypothesis of malnutrition;

unless it were to be postulated that animals from different areas were suffering from malnutrition, and that the level of malnutrition was to the same degree. A final point on gross malnutrition is that, as some of the older animals in this study range to an estimated age of up to twenty years, it is highly likely that they have lived through drought periods many years preceding the study. The effect of this on the results obtained is unknown. It is anticipated that compensatory growth would return these animals to a normal body composition, provided recovery time was adequate.

Preston and Willis (1970) reviewed compensatory growth following malnutrition in cattle. Berg and Butterfield (1975) summarized the effect of malnutrition and realimentation on the musculature by the following statement. "Loss of weight from the musculature is differential in such a way that those muscles most vital for survival, are least affected by muscle weight loss. These are muscles which are well developed at birth and are of low post-natal growth impetus. The net result of this phenomenon is that the musculature following weight loss achieves distribution of weight which approaches that of the newborn calf. On regaining weight, the musculature quickly returns to its normal proportions, as would be expected of such a vital system."

Although the kangaroos studied were unlikely to be suffering from severe malnutrition, it is obvious that their individual levels of nutrition varied. The second issue to be investigated is the effect of differing levels of nutrition, within the levels consistent with the expression of the normal genetic growth potential of an animal, on body composition. It is evident from the different estimated growth rates of the kangaroos that this factor, if significant, will affect the values obtained for the body composition of the kangaroos used in this study. Hammond (1932) showed that the plane of nutrition had a profound effect on the amount of fat in the body and critical assessment of the experiments of McMeekan (1940) and Palsson and Verges

(1952) by comparing animals at the same tissue weight supports this conclusion. However, the low amount of body fat in the kangaroo, irrespective of level of nutrition, precluded even large percentage fluctuations in fat tissue from having anything but a minor effect on the percentage tissue distribution of carcass bone and muscle. The low fat levels found in this study were consistent with those found by Tribe and Peel (1963).

Warren (1974) defined the differential partitioning of body fat and the effect of level of nutrition on body fat for merino sheep. Differential partitioning of body fat depots has been demonstrated to affect dressing percentage in domestic animals. Hilmi (1975) demonstrated a significant difference in dressing percentage between sheep fed on two different planes of nutrition. The magnitude of the difference in this experiment was small despite the relatively large percentage of body fat in sheep. It would be expected that if the results obtained here could be extrapolated to the kangaroo, the effects of level of nutrition on carcass dressing percentage, if significant in the kangaroo, would be of a low magnitude.

The effect of growth rate on carcass muscle and bone is a controversial subject. Two main schools of thought are advanced. Workers such as Hammond, McMeekan, Palsson and Verges propounded that "any part, organ, or tissue of the animal's body is proportionately most retarded by restricted nutrition at the age when it has its highest natural growth intensity" (Palsson (1955)). The opposite view is that, except for fat, restricted nutrition produces a uniform retardation of development. Wallace (1948) was an early critic of McMeekan's (1940) conclusions pointing out that they were based on comparisons of animals at different tissue weights. Wilson (1952, 1954) in the domestic fowl, advocated that the effects of treatments on body composition should be compared against fat-free tissue weights. Wilson (1958) in analysing the body composition of East African dwarf goats on the preceding basis, found no evidence of growth rate affecting muscle or bone. Elsley et al (1964) reassessed the data presented by McMeekan (1940) and Palsson and Verges (1952) using fat-free tissue as a basis of comparison. They found no evidence of any effect of growth rate and level of nutrition on carcass bone or muscle relative to the total weight of bone plus muscle together.

In conclusion, it is highly likely that the body composition information obtained from the kangaroos studied will reflect their species characteristics. The results, however, must be interpreted in the context of the preceding discussion, with the validity of assumptions based on domestic species left in question.

CHAPTER 3

GENERAL METHODS

"In the geometrical sense the animal body is of such a complicated shape that any one or any few measurements could approximate a description of it in only the crudest way."

J.L. Lush (1928)

"The direct analysis of the gross body composition is a laborious procedure ...."

Keys and Brozck (1953)

INTRODUCTION.

The body composition of an animal may be studied by both direct and indirect techniques. Its composition may be expressed quantitatively in terms of weight, volume, density and length or qualitatively in terms of form, texture and colour. Body composition studies can be broadly divided into anatomical studies and chemical studies, ramifications of which lead into the fields of histology, embryology and biochemistry. Indirect techniques for investigating body composition such as isotope dilution studies, carcass specific gravity determination and prediction formulae depend on correlation factors determined in previous direct anatomical and chemical studies.

Anatomical investigation of gross body composition is the most ancient of the various methods used. McCance (1962) cited Xenophon (BC 400) as being able ".... to predict the ultimate size of a horse by measurement of its shin bone at birth." Critical methods of investigating body composition appeared with the work of Lawes and Gilbert (1859, 1861). John Hammond (1920, 1921, 1922) precipitated an avalanche of publications in the field of body composition this century.

Basic changes have occurred in the methods used in studying body composition. Body composition was correlated to age, then to body weight and finally comparisons were made between animals of the same tissue weight. These changes developed in order to demonstrate real differences between species and breeds. Definition of the constituent parts of the animal has become more refined. Early studies concentrated on the separation of the body tissues into bone, muscle, fat and viscera. Later studies looked at jointed carcasses, dividing each joint into its component bone, muscle and fat. Current methods involve the separation of carcass muscle into its component muscles, the separation of the individual carcass bones, and separation of carcass fat into forequarter and hindquarter fat, with the division of each into subcutaneous and intermuscular fat.

The basic methods used in this study were similar to those used by Walker (1961) on dairy cattle, Butterfield (1963a) on beef cattle, Bryden (1967) on the Southern Elephant Seal (*Mirounga Leonina* (Linn)), Mukhoty (1969, 1971) on beef cattle and Lohse (1971), Warren (1974) and by Hilmi (1975) on sheep.

METHODS.

A. Collection of Specimens

1. ARMIDALE.

Twenty eight grey kangaroos were collected at Armidale under commercial shooting conditions. Specimens were shot in the head, high neck or heart, and weighed immediately after shooting. Each specimen was assigned an identification tag and then hung from the back of a vehicle by the hock. Procaine penicillin was injected into the stomach to limit gas formation and bacterial contamination of the carcass. Specimens exhibiting visible pathological change were excluded from the sample. Five specimens were collected each night and held for dressing on the following day in a chiller at the meat research laboratory, CSIRO, Pastoral Research Station, Armidale.

A further eight animals were collected at Armidale. They were collected under the same conditions as the grey kangaroos and included two female red neck wallabies (*Macropus rufogriseus*), three female wallaroos (*Macropus robustus*) and one female and two male swamp wallabies (*Wallabia bicolour*).

2. MUSWELLBROOK - SCONE

Eleven grey kangaroos were collected by a similar technique from the Scone area. The bodies were placed in the back of a covered utility, packed in ice and transported to the University of Sydney for dressing.

3. BREWARRINA

Three grey kangaroos were collected from the Brewarrina area. They were captured using the drug etorphine (M99, Immobilon) at a dose rate of 0.05mg/Kg. delivered by a hypodermic dart fired from a "Cap-chur" gun. On capture, each animal was placed in a wool pack and the packs were then hung from the roof of a panel van. The animals were transported to the University of Sydney where they were anaesthetized with sodium pentobarbitone, the carotid artery severed and the animals allowed to bleed to death. Blood weights were recorded from these three animals, and the bodies were then dressed and frozen.

4. MOREE

Two grey kangaroos were collected from the Moree area. Both were pouch-young and were frozen whole and transported to the University of Sydney packed in ice.

5. COONAMBLE

Seventeen red kangaroos were collected from the Coonamble area. The method of collection was similar to that used at Armidale. The animals were dressed in a shed set up as a temporary field station and the dressed carcasses were held in a commercial kangaroo shooter's chiller unit. The chilled dressed carcasses were then transported from Coonamble to the University of Sydney wrapped in plastic and packed in ice.

B. Dressing Procedure

The author dressed all the animals used in this study. An assistant was required to record the various readings and to generally assist with the dressing. It was found that five kangaroos could be processed in a working day.

All linear body measurements were recorded from the left side of the body. In cases of tissue damage, the reading involved was taken from the right side. The linear body measurements taken are illustrated in Figure 14 and defined anatomically in Table 1.

After the surface linear measurements had been recorded, the animal was suspended by the hocks and weighed. The weight at dressing and time of dressing, were recorded. A plastic tub was placed under the animal to collect any fluid lost during the dressing process. Each organ was weighed on removal from the carcass.

Circumferential skin incisions were made level with the tibiotarsal, radio-carpal and atlanto-occipital articulations. A mid-ventral incision was made from the head to the tip of the tail, circumventing the cloaca. Medial incisions were made along all four limbs. At this stage, the testes were removed from males and the mammae from females. The skin was then removed, taking care to

TABLE 1

LINEAR BODY MEASUREMENTS

Measurement	Anatomical Landmarks	Aspect	Instrument
AB Ear length	A skin margin at tip B hairline at base	lateral surface	calipers
CD Head length	C philtrum D nuchal crest	mid-dorsal line	tape measure
CE Body length	C philtrum E skin margin at the tip of the tail	mid-dorsal line	tape measure
NN Chest circumference	N cranial extremity of the xiphisternum	transverse plane	tape measure
MM Antebrachium circumference	M immediately distal to the elbow joint	maximum circumference	tape measure
LK Antebrachium length	L olecranon K radio-carpal joint	lateral aspect carpus flexed	tape measure
JJ Crus circumference	J immediately distal to the stifle joint	maximum circumference	tape measure
JI Crus length	J proximal tibial crest I lateral malleolus of the fibula	lateral aspect	tape measure
GH Foot length	G distal extremity of digital pad IV H tuber calcis	plantar surface	straight rule
EF Tail length	E skin margin at tip F root of the tail	mid-ventral line	straight rule
FF Tail circumference	F root of the tail	maximum circumference	tape measure

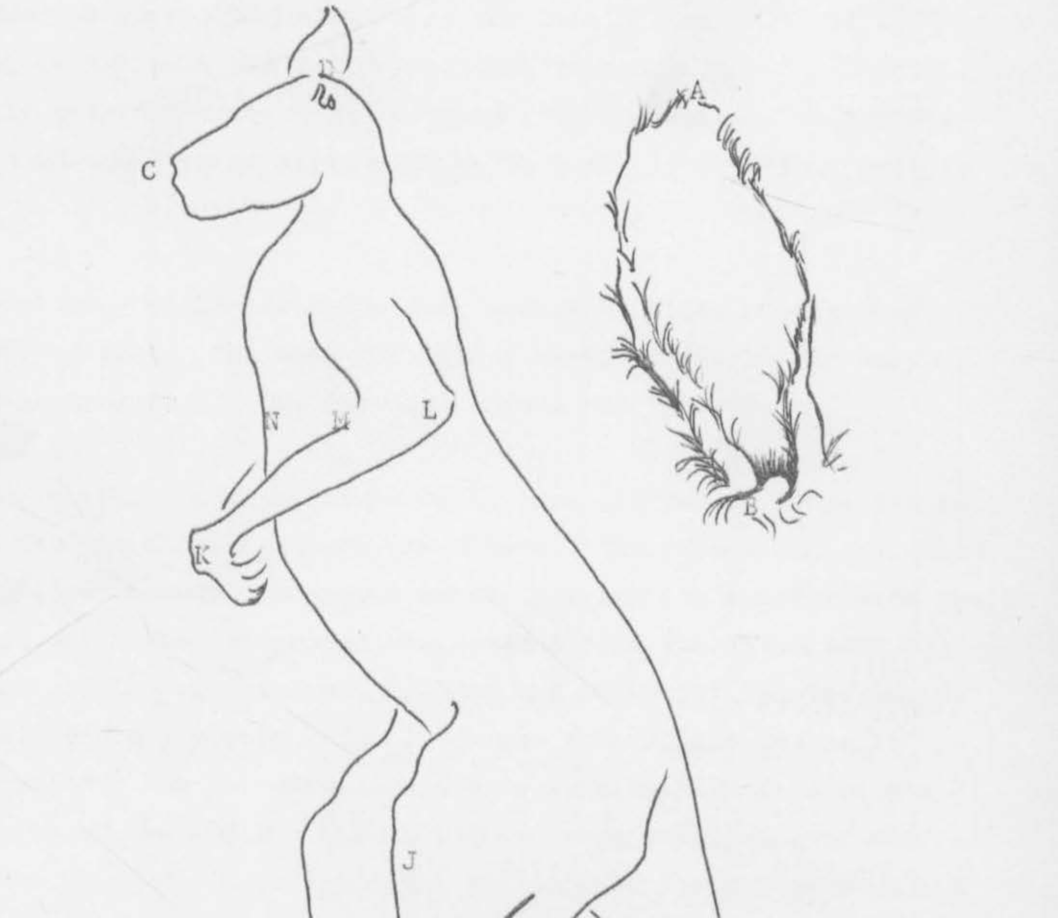

Figure 14. Illustration of the position of the surface linear body measurements.

prevent tearing of the musculature at the base of the tail, on the lateral abdominal wall and in the pectoral region. Tail fat adhering to the tail skin was removed and weighed with the dressed tail. Skin weight included weight of scrotum in males and weight of the pouch in females.

The salivary glands from the left and right sides of the head were dissected free. The head was then disarticulated at the atlo-occipital articulation. The cervical thymus was removed.

A mid-ventral incision involving sternum and pelvic symphysis was made from the first sternebra to the cloaca. The cloaca was dissected free and pulled through the pelvic canal to allow its removal with the rest of the gut. The oesophagus was severed from its attachment to the stomach and the gut, spleen, bladder and mesentery removed as one mass and placed in a bucket. The liver was removed and the gall bladder emptied. The two adrenal glands were dissected free of the cranial poles of the kidneys. Both kidneys were stripped from their capsules and weighed. Left and right perinephric fat was removed and weighed collectively. The diaphragm was divided and the oesophagus, heart and lungs removed.

The tail was removed level with the tuber ischii and weighed. The dressed carcass was then weighed and with the head and tail, dusted with antibiotic powder to ensure minimal deterioration during cold storage, wrapped in plastic, and frozen. (Note - at this stage, the pes and manus were still attached to the carcass).

The heart was dissected free of the great vessels and pericardium. Each chamber was incised and emptied. The oesophagus was separated from the trachea. The lungs and trachea were dissected free of any connective tissue and weighed together.

The remaining abdominal viscera were then processed. The spleen was removed and trimmed of mesentery. The bladder was dissected free from the cloaca and emptied of urine. In the female, the ovaries and uterus were removed, trimmed of mesometrium and weighed. Next the mesentery and omenta were stripped from the stomach and intestines. As it was not practical to try to separate omenta and mesentery from the fat deposits within them, they were weighed together, and with the pancreas, termed "abdominal fat". The cloaca was then removed from the large intestine.

The gastrointestinal tract was weighed, the weight being recorded as "gut full". The stomach was separated from the small intestine at the pyloris, the small intestine was separated from the caecum at the ileo-caecal orifice and the caecum was separated from the large intestine at the level of the ileo-caecal orifice. Each section was weighed to record the "stomach-full", "small intestine-full", "caecum-full" and "large intestine-full" weights. The stomach was opened along its greater curvature and the contents removed. Care was necessary to ensure that the contents of each sacculation were removed and that washing water was effectively wrung from the empty stomach. The contents of the small intestine, caecum and large intestine were removed by running the bowel between the fingers. The weights of empty stomach, small intestine, caecum and large intestine were recorded.

Finally, the connective tissue waste and the fluid drip were weighed. Fluid drip included bile, urine, clotted blood and tissue fluid.

Carcasses dressed at field stations were transferred from the various field freezers to the freezer of the Department of Veterinary Anatomy, University of Sydney at the end of each field trip. The plastic wrapped, frozen carcasses were packed in ice when transported.

C. Total Dissection

The total dissection of each half-carcass into its component tissues with the jointing of the corresponding half-carcass, required between twenty and twenty-five working hours. All carcass dissection was carried out by the author, except for the time consuming process of scraping the carcass bones clean of tissue fragments. Each carcass was removed from the freezer twenty-four hours before dissection and allowed to thaw at room temperature in its plastic wrapping.

The date and weight of the carcass were recorded. Prior to splitting the carcass into a left and right half-carcass, the carcass length and pelvic width were measured, as illustrated in Figure 15. A meat band-saw was used to divide the carcass. Three men were required for this procedure, one on the forelimbs and one on the hindlimbs to keep the spine straight and in the vertical plane, and one man to guide the carcass as it was sawn. Each half-carcass was weighed and the least-damaged half used for total dissection. The remaining side was jointed. No attempt was made to select for total dissection, the same half-carcass side from each animal. The tail was weighed and with the half-carcass for total dissection, wrapped in moist cloth and removed to the dissection laboratory.

The half-carcass to be jointed was divided into a forequarter and hindquarter by an incision made from the sternum, along the costal arch to the thirteenth rib, along the cranial border of the thirteenth rib, and through the spine. Each quarter was weighed and divided into component areas. The forequarter was divided into manus, antebrachium, omo-brachium, neck and thorax. The manus was disarticulated at the radio-carpal joint. The antebrachium was disarticulated at the elbow joint. The omobrachium was removed by an incision along the profile of the scapula so as to leave the bulk of the extrinsic musculature attached to the neck and thorax. The neck and thorax were separated by disarticulating the last cervical from the first thoracic vertebra.

Figure 15. Dorsal view of a dressed carcass, illustrating the positions used for measuring carcass length and pelvic width.

Abbreviations to Figure 15.

AB	Pelvic width
CD	Carcass length

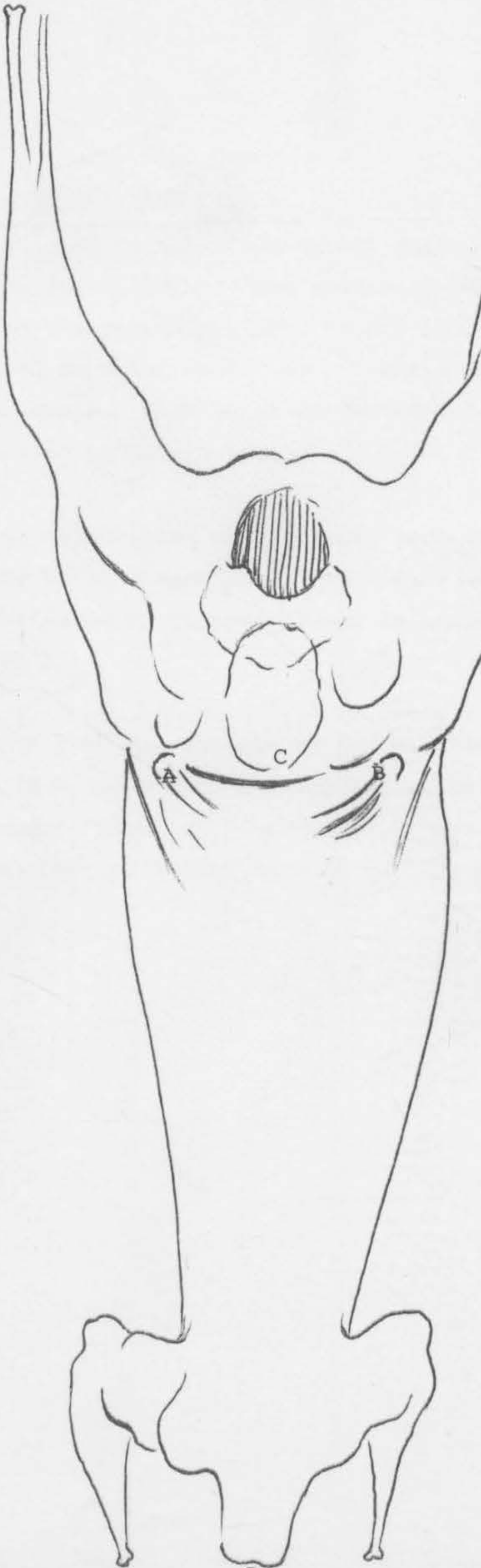

Figure 15.

Each joint was weighed and after the thorax weight was recorded, the remnant of the diaphragm was dissected free and weighed. The hindquarter was divided into abdominal wall, loin, "butt", crus and pes. The pes was disarticulated at the tibio-tarsal joint. The crus was disarticulated at the stifle joint. The abdominal wall musculature was dissected free of the thirteenth rib, lumbar fascia and pelvis. The loin was separated from the "butt" by a transverse cut immediately cranial to the tuber coxae. Each joint was weighed. The jointing procedure is illustrated by Figure 16.

The remaining linear carcass measurements were recorded from the half-carcass used for total dissection. The linear carcass measurements taken are illustrated by Figures 17 and 18 and defined anatomically in Table 2.

The manus and pes were disarticulated and weighed. The half-carcass was wrapped in moist cloth, leaving the gluteal area exposed, and the individual muscle dissection commenced. To maintain uniformity of method, the individual carcass muscles were removed in a given sequence.

Figure 16. Lateral view of a kangaroo carcass illustrating the regional carcass areas.

Abbreviations to Figure 16.

AB	Forequarter
BC	Hindquarter
D	Neck
E	Omobrachium
F	Antebrachium
G	Manus
H	Thorax
I	Lumbar
J	Abdominal wall
K	Butt
L	Crus
M	Pes

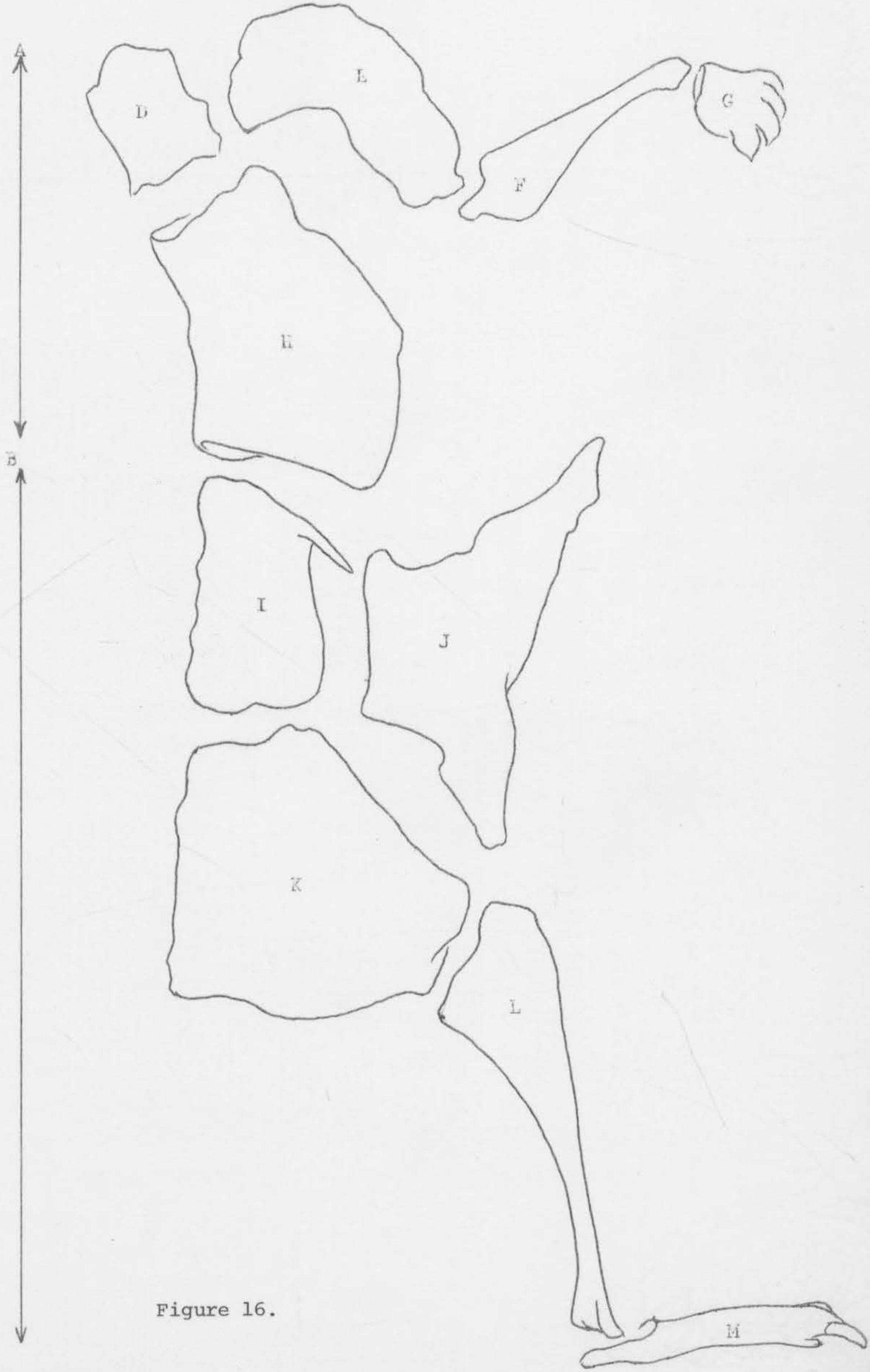

Figure 16.

TABLE 2

LINEAR CARCASS MEASUREMENTS

Measurement	Anatomical Landmarks	Aspect	Instrument
AB Carcass length	A exposed caudal vertebra B atlas	mid-dorsal line	tape measure
DC Antebrachium length	D olecranon C distal extremity of the radius	lateral surface	tape measure
EE Antebrachium circumference	E immediately distal to the elbow joint	maximum circumference	tape measure
GF Crus length	G proximal tibial crest F lateral malleolus of the fibula	lateral surface	tape measure
GG Crus circumference	G immediately distal to the stifle joint	maximum circumference	tape measure
HI Tail length	HI length of the severed dressed tail	ventral mid-line	straight rule
HH Tail circumference	H point of severence from the body	maximum circumference	tape measure

Figure 17. Lateral view of dressed carcass and tail illustrating the position of the linear carcass measurements.

Figure 17.

TABLE 2 (CONT.)

LINEAR CARCASS MEASUREMENTS

Measurement	Anatomical Landmarks	Aspect	Instrument
HG Cervical vertebral length	H body of the atlas G the intervertebral disc between C7 and T1	ventral surface	tape measure
GF Thoracic vertebral length	G as above F the intervertebral disc between T13 and L1	ventral surface	tape measure
FE Lumbar vertebral length	F as above E lumbosacral intervertebral disc	ventral surface	tape measure
ED Sacrum length	E as above D the intervertebral disc between S2 and Ca1	ventral surface	tape measure
DC Proximal caudal vertebral length	D as above C point of severence of the tail	ventral surface	tape measure
AB Chest depth	A xiphisternum B body of T8	median plane	straightrule

Figure 18. Medial view of dressed half-carcass illustrating the position of linear carcass measurements.

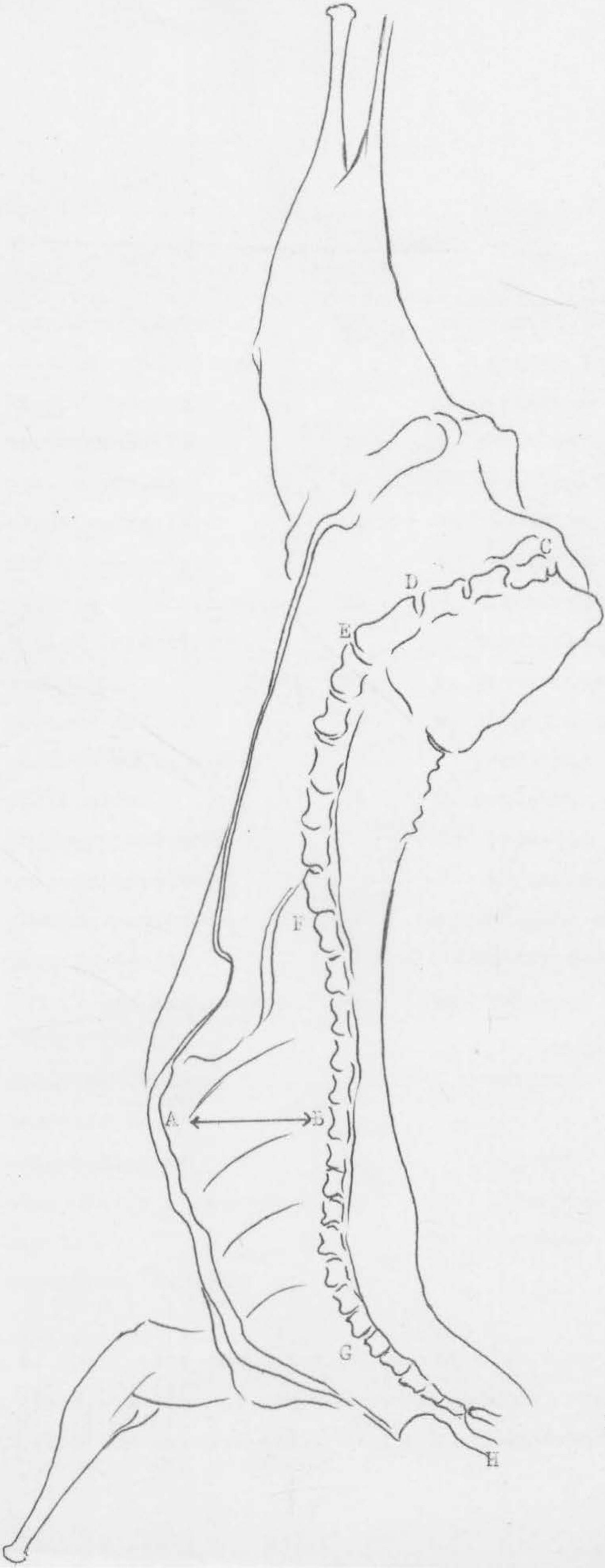

Figure 18.

The muscles of the hindlimb were removed in the following order:-

Identification Number	
1	M. cutaneous trunci (gluteal insertion)
2	M. biceps femoris
3	M. caudofemoralis pars caudalis
4	M. caudofemoralis pars cranialis
5	M. gluteus superficialis
6	M. vastus lateralis
7	M. sartorius
8	M. gluteus medius
9	M. gluteus accessorius
10	M. piriformis
11	M. gluteus profundus pars cranialis
12	M. gluteus profundus pars caudalis
13	M. tensor fasciae latae
14	M. rectus femoris
15	M. abductor cruris caudalis
16	M. semitendinosus
17	M. marsupialis (females)
18	M. gracilis
19	M. quadratus femoris
20	Mm. vastus medialis vastus intermedius
21	M. pectineus
22	M. semimembranosus
23	M. adductor longus
24	Mm. adductor magnus adductor brevis
25	M. flexor digitorum superficialis
26	M. gastrocnemius
27	M. flexor digitorum profundus
28	M. popliteus
29	Mm. tibialis cranialis peroneus tertius
30	M. extensor digiti II et III longus
31	Mm. extensor digitorum longus extensor digitorum lateralis peroneus brevis peroneus digiti IV peroneus digiti V

In view of their close association, particular care had to be exercised in the dissection of the following muscles. The m. gluteus superficialis from the cranial belly of the m. caudofemoralis, the mm. vastus lateralis and vastus intermedius, the mm. gluteus medius and gluteus accessorius, the mm. abductor cruris caudalis and semitendinosus, the mm. semimembranosus and adductores and the m. flexor digitorum profundus from the peroneal group of muscles. The mm. extensor digitorum longus, extensor digitorum lateralis, peroneus brevis, peroneus digiti IV, peroneus digiti V were removed as a single group. The thigh fat pad was removed after the removal of the m. vastus lateralis.

The hindlimb bones were removed from the carcass by severing the insertions of the mm. obturatorius externus and iliopsoas and by disarticulation of the hip joint. The stifle fat pad was weighed. The patelloid was incised to confirm the absence of a bony patella. The femur, tibia, fibula and lateral fabella were wrapped in moist cloth and placed in a refrigerator.

The muscles of the trunk were removed in the following order:-

Identification Number	
32	M. obturatorius externus
33	Mm. gemelli
34	M. coccygeus lateralis (proximal segment)
35	M. coccygeus medialis (proximal segment)
36	M. obturatorius internus
37	Mm. sacrocaudalis ventralis (proximal segment)
38	M. psoas minor
39	M. quadratus lumborum
40	M. psoas major
41	M. iliacus
42	Mm. multifidi lumborum
43	M. sacrocaudalis dorsalis lateralis (proximal segment)
44	M. sacrocaudalis dorsalis medialis (proximal segment)
45	Mm. intertransversarii caudae (proximal segment)

Identification Number	
46	M. intermammillares lumborum dorsalis
47	M. intermammillares lumborum ventralis
48	M. erector spinae pars lumborum
49	M. diaphragma
50	M. cremaster
51	Mm. obliquus internus abdominis transversus abdominis
52	M. latissimus dorsi
53	Mm. pectorales
54	M. pyramidalis
55	M. rectus abdominis
56	M. obliquus externus abdominis
57	M. trapezius pars thoracica
58	Mm. trapezius pars cervicalis omotransversarius omohyoideus
59	M. rhomboideus
60	M. serratus ventralis
61	M. subclavius
62	M. scalenus
63	M. splenius
64	M. serratus dorsalis
65	M. sterno-cleido-mastoideus
66	M. sternohyoideus
67	M. iliocostalis thoracis
68	M. longissimus thoracis et cervicis
69	M. longissimus capitis
70	M. semispinalis capitis
71	M. spinalis et semispinalis thoracis et cervicis
72	Mm. multifidi cervicis
73	Mm. rectus capitis
74	Mm. multifidi thoracis
75	M. obliquus capitis caudalis
76	Mm. longus capitis longus colli
77	Mm. intertransversarii cervicis
78	M. transversus thoracis
79	Mm. intercostales

Care had to be exercised in the removal of the mm. intermammillares lumborum dorsalis and intermammillares lumborum ventrales, the mm. pyramidalis and rectus abdominis, the mm. scalenus and serratus ventralis and the mm. tensor fasciae antebrachii and latissimus dorsi, due to their close association. In the cases of the mm. obliquus internus abdominis and transversus abdominis, the mm. longus capitis and longus colli, the mm. pectorales and the mm. erector spinae pars lumborum, it was not practical to dissect out the individual muscles. The longissimus and iliocostalis systems were separated from the m. erector spinae pars lumborum by a transverse incision, level with the twelfth thoracic vertebra.

After the removal of the m. erector spinae pars lumborum, the exposed lumbar, sacral and coccygeal vertebrae were disarticulated from the thorax, wrapped in moist cloth and placed in the refrigerator. Following the removal of the m. subclavius, the clavicle was disarticulated from the sternum and the pectoral limb wrapped in moist cloth and placed in the refrigerator. The remaining muscles of the thorax and neck were dissected free and weighed. The thoracic vertebra, cervical vertebra, ribs and remnant of the sternum, were placed in the refrigerator and the dissection of the pectoral limb commenced.

The muscles of the pectoral limb were removed in the following order:-

Identification Number		Identification Number	
80	M. teres major	90	M. brachialis
81	M. coracobrachialis	91	M. anconeus (medial belly)
82	M. subscapularis	92	M. brachioradialis
83	M. deltoideus	93	M. extensor carpi radialis
84	M. teres minor	94	Mm. extensor digitorum communis extensor digitorum lateralis ulnaris lateralis extensor digiti I, II et III
85	M. infraspinatus		
86	M. supraspinatus		
87	M. tensor fasciae antebrachii		
88	M. biceps brachii		
89	M. triceps brachii		

Identification Number		Identification Number	
95	M. abductor digiti I longus	100	M. flexor carpi ulnaris
96	M. supinator	101	Mm. flexor digitorum profundus flexor digitorum superficialis
97	M. pronator teres		
98	M. flexor carpi radialis		
99	M. palmaris longus	102	M. pronator quadratus

In large specimens, apart from the lateral extensor group of the antebrachium, all the individual muscles of the limb could be isolated and weighed. In smaller specimens, the mm. brachioradialis and extensor carpi radialis; and the mm. palmaris longus, flexor carpi ulnaris, flexor digitorum profundus and flexor digitorum superficialis were weighed together. The mm. extensor digitorum communis, extensor digitorum lateralis, ulnaris lateralis and extensor digiti I, II et III were removed as a single group in all specimens.

The tail muscles were dissected into four groups, right and left, dorsal and ventral tail muscles. The ventral tail muscles consisted of all the muscles ventral to the transverse processes of the caudal vertebra, including the mm. intertransversarii.

Identification Number		
105	Mm. sacrocaudalis dorsalis lateralis sacrocaudalis dorsalis medialis	Left side tail
106	Mm. intertransversarii ventralis caudae sacrocaudalis ventralis lateralis sacrocaudalis ventralis medialis interhaemalis	Left side tail

Identification Number		
107	Mm. sacrocaudalis dorsalis lateralis sacrocaudalis dorsalis medialis	Right side tail
108	Mm. intertransversarii ventralis caudae sacrocaudalis ventralis lateralis sacrocaudalis ventralis medialis interhaemalis	Right side tail

The caudal vertebrae were counted and weighed.

The musculature of the carcass has been described in Appendix I.

The bones were cleaned and weighed following the completion of the muscle dissection. The cervical, thoracic, lumbar and proximal caudal vertebrae were weighed as groups of vertebrae. The sacrum and os coxae were weighed as one unit. The long bones of the limbs were cleaned and weighed. The functional length of the femur and humerus and the maximum length of the tibia, fibula, radius, ulna, scapula, clavicle and marsupial bone were recorded. Figures 19 and 20 illustrate the lengths measured and the anatomical landmarks are defined in Tables 3 and 4.

Throughout the dissection program, tissue fragments were placed in a series of glass beakers labelled subcutaneous fat, intermuscular fat, scrap muscle and waste. Depot fat was weighed on removal from the carcass and consisted of a thigh fat pad and the stifle joint fat pad. Fascia, tendons, ligaments, nerves, blood vessels and the patelloid were classed as "waste".

TABLE 3

FORELIMB LINEAR BONE MEASUREMENTS

Measurement	Anatomical Landmarks	Instrument
AB Scapula length	A scapular tuberosity B proximal extremity	straight rule
CD Clavicle length	C acromial extremity D sternal extremity	straight rule
EF Humerus length	E articular surface of condyle F articular surface of head	straight rule
GH Radius length	G styloid process H head of radius	straight rule
IJ Ulna length	I olecranon J styloid process	straight rule

Figure 19. Forelimb bone profile drawings illustrating the position of the linear bone measurements.

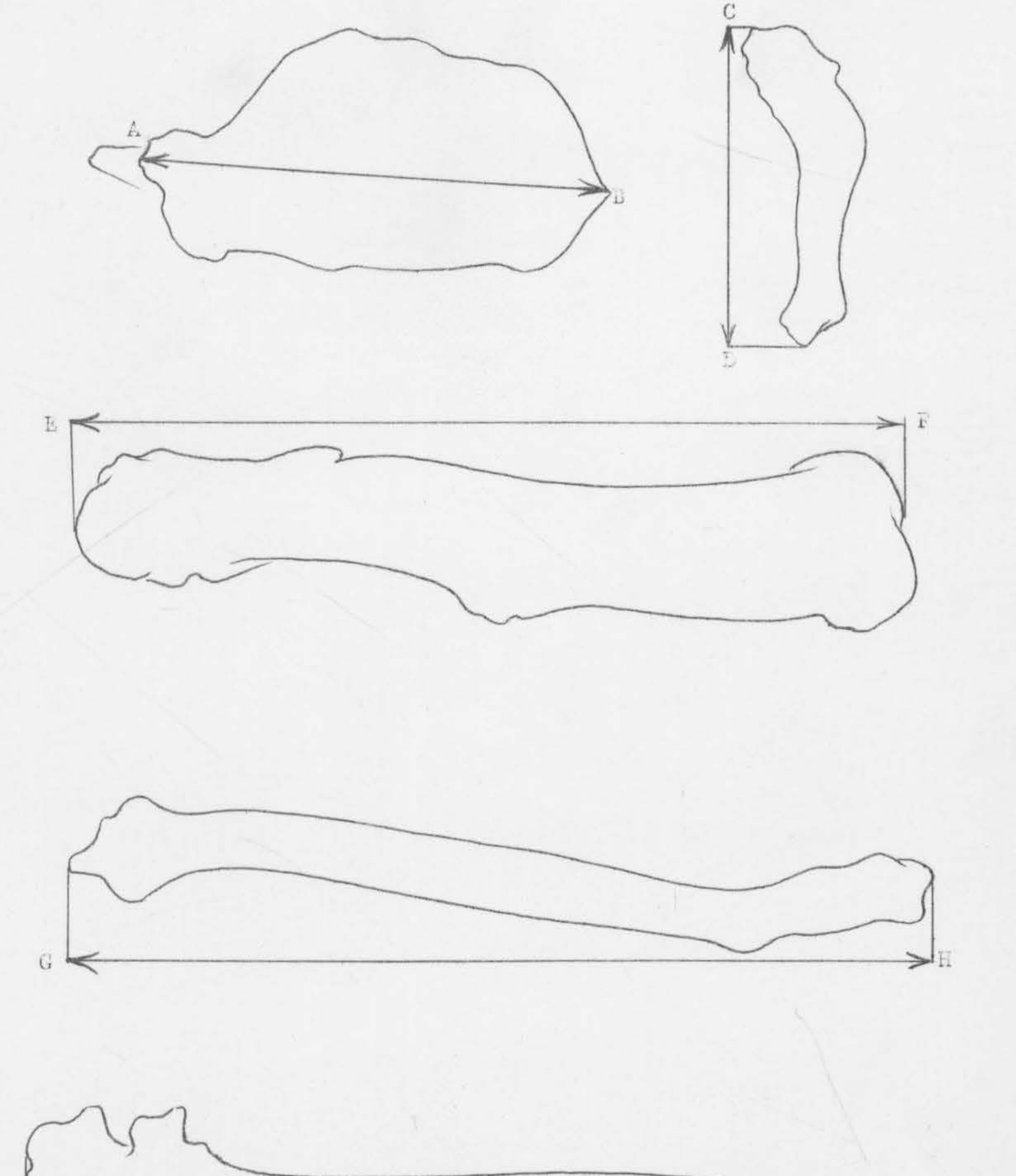

Figure 19.

TABLE 4

HINDLIMB LINEAR BONE MEASUREMENTS

Measurement	Anatomical Landmarks	Instrument
AB Marsupial length	A proximal extremity B distal extremity	straight rule
CD Femur length	C articular surface of head C articular surface of lateral condyle	straight rule
EF Tibia length	E intercondyloid eminence F medial malleolus	straight rule
GH Fibula length	G head H lateral malleolus	straight rule

Figure 20. Hindlimb bone profile drawings illustrating the position of the linear bone measurements.

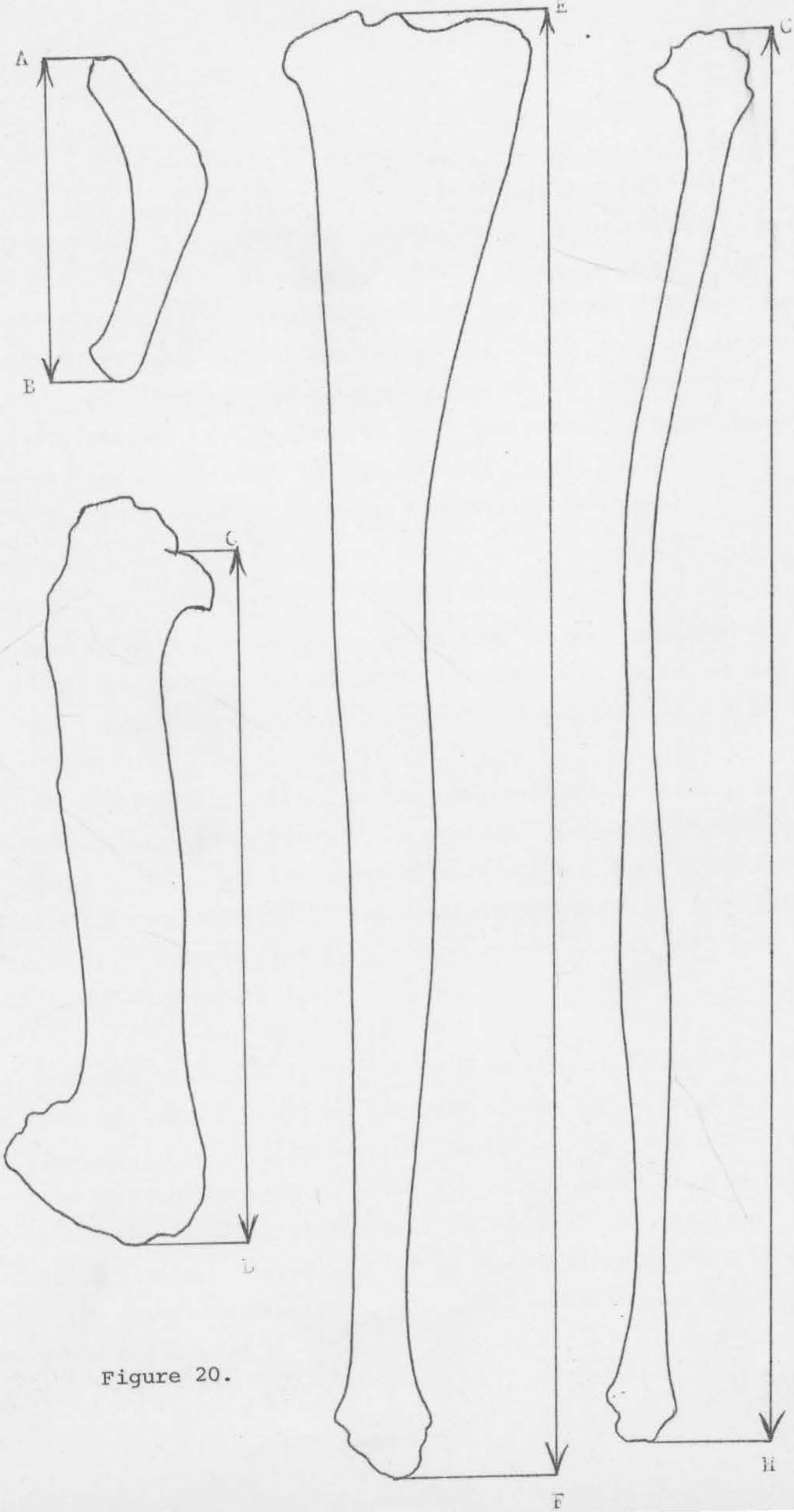

Figure 20.

D. Ageing Method

Introduction.

Methods of estimating the age of wild kangaroos have been investigated by Sadleir (1963), Kirkpatrick (1963, 1964b), Sharman *et al* (1964), Kirkpatrick (1965b) and Kirkpatrick and Johnson (1969). The methods cited are based on parameters such as linear body measurement, liveweight, tooth eruption and molar progression. Estimated ages for the kangaroos studied in this project were determined by establishing a molar index for each animal and by correlating the molar index to age, using the relationships given by Kirkpatrick (1965b).

Method.

The head of each grey kangaroo was placed in a cheesecloth bag with an identification tag and allowed to macerate in water for two months. The macerated skulls were scrubbed, washed and allowed to dry.

The molar index was defined as the number of molar teeth rostral to a transverse line drawn between the rostral borders of the suborbital spaces. The molar index was determined to 0.1 of a tooth with the aid of a perspex ageing plate as illustrated in Figure 21. This technique is based on the fact that the molar teeth move rostrally in the maxilla with increasing age.

To determine the molar index, it is necessary to be able to distinguish premolars from molars and this may be achieved in the following manner. Firstly, inspect the labial line of the cheek teeth. If this line is broken, then the tooth out of alignment will be premolar four and the adjacent caudal tooth molar one. Figure 22 B illustrates this case. Having identified the first molar, and with the use of the perspex ageing grid, the molar index to one-tenth of a tooth can be calculated.

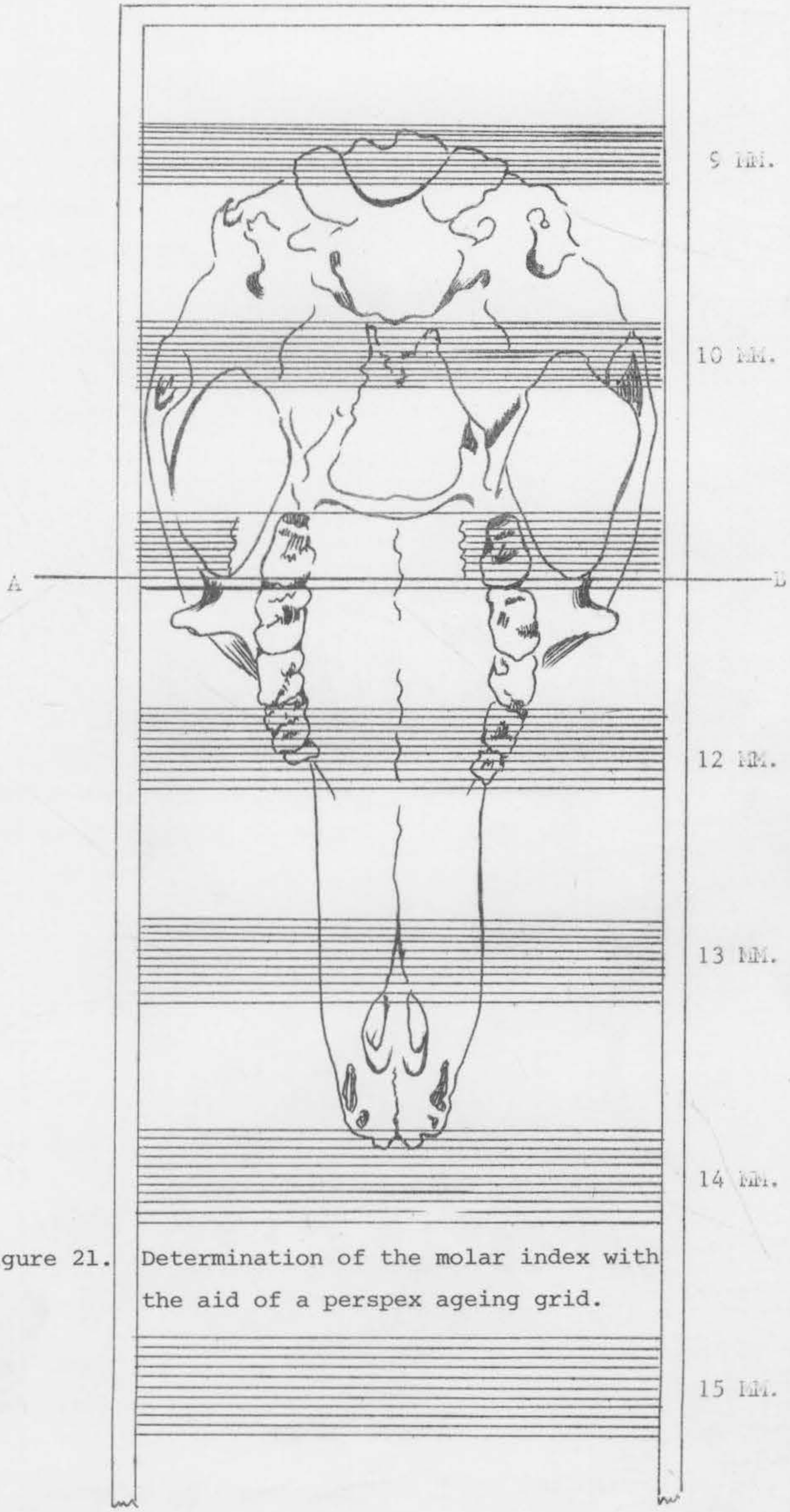

Figure 21. Determination of the molar index with the aid of a perspex ageing grid.

Molar index 1.5

Cheek teeth P_3 dP_4 M_1 M_2

Molar index 2.6

Cheek teeth P_4 M_1 M_2 M_3 (M_4)

Molar index 4.9

Cheek teeth M_3 M_4

Figure 22. Examples of three different molar indices.

If the labial tooth line is unbroken, then two possibilities arise. Firstly, premolar four may not as yet have erupted and the first two cheek teeth would be premolar three and deciduous premolar four. The second possibility is that all the premolars have been lost and the remaining cheek teeth are all molars. Figure 22 A represents the former and Figure 22 C the latter situation. To differentiate between the two possibilities, remove the first two cheek teeth and establish whether premolar four has erupted or not. The absence of premolar four (i.e. already erupted and lost with tooth progression) would confirm the remaining cheek teeth to be molars.

There are normally four (occassionally five) molar teeth in the adult grey kangaroo. However, it is possible to obtain molar indices in excess of the number of molar teeth present. Figure 22 C illustrates a molar index of 4.9. In this case, the first and second molars, as well as the premolars, have been lost as a result of the rostral progression of the teeth. The fourth molar tooth lies 0.9 times its length rostral to the line of reference used in determination of the molar index. The length of this space is added to the number of molar teeth, that is, M1 M2 (lost) M3 M4 present, to give a MI of 4.9.

For the red kangaroos, the same method of estimating molar index was used, except that readings were taken from radiographs of the skull, rather than directly off macerated skulls. The technique was altered for the red kangaroos to allow chemical estimations of total body composition to be made on these animals.

The molar indices obtained by the author were verified by Mr. George Wilson and Mr. Graham Robertson of the National Parks and Wildlife Service of N.S.W.

E. Data Analysis

Introduction.

Data were obtained from each of a series of sixty-nine animals representing five species and two sexes of the Family Macropodidae. The data were continuous within the limits of the body weight range of approximately one to sixty kilogrammes. The data were cross-sectional as each observation was made at one point only in the growth of any one animal.

The data are tabulated as Appendix II.

Statistical analyses of the data were aimed at finding mathematical expressions which would characterize the patterns of growth found within the kangaroo body and which would differentiate sex and species differences from the inherent biological variability of individual animals. Selection of a particular statistical method was based on its simplicity, mathematical accuracy and biological applicability. Implicit in the use of the following statistical methods was the assumption that the form of an animal depends on its absolute size and not on its growth rate.

The small number of wallaroos and wallabies studied limited the usefulness of the data obtained on them. Comparisons between these animals and the kangaroos were made on the basis of percentage distribution of tissue in mature animals. That is, the heaviest animals from each group were compared. The number of grey and red kangaroos studied provided sufficient data for extensive statistical analysis. The statistical methods applied to the grey and red kangaroo data developed relationships between parts and regions of the body and the body as a whole; and between individual muscles, bones and fat deposits and body, muscle, bone and fat respectively.

The two-phase linear regression of Griffiths and Miller (1973) was specifically employed to give the body weight values at which marked changes of growth intensity occurred.

Statistical Methods.

Four mathematical models were investigated as means of comparing and characterizing growth patterns found within the kangaroo body.

The mathematical model for linear regression is

$Y = \alpha + \beta X$

where Y is the sum of a random part ε and a part fixed by X

α specifies the intercept of the line

β is the slope of the line

X is the independent variable.

Huxley (1932) advocated the allometric function to give a general method of envisaging growth. The mathematical model is

$Y = \alpha X^k$

where Y is the part

X is the whole of the organism less Y

α is the fractional coefficient: it indicates the value of Y when $X = 1$ and is not biologically significant

k is the ratio of the relative growth rate of Y to X.

The mathematical model for the allometric function can be transformed into a linear regression by applying logarithms,

thus $\log Y = \log \alpha + k \log X$

The mathematical model for the second degree polynomial is

$Y = \alpha + \beta X + \delta X^2$

where α, β, δ are real numbers.

The second degree polynomial is linear in the parameters α, β, δ and can be fitted by the standard techniques of multiple linear regression.

The fourth mathematical model, the two-phase linear regression of Griffiths and Miller (1973) which is given by

$$Y = \alpha_0 + \alpha_1 (X - X_e) + \alpha_2 (X - X_e) \operatorname{sgn} (X - X_e)$$

$$\text{where } \operatorname{sgn}(s) = \begin{array}{rl} -1 & (s<0) \\ 0 & (s=0) \\ 1 & (s>0) \end{array}$$

α_1 represents the average slope of the intersecting lines

α_2 is half the differences between slopes

X_e unknown join point of the two linear regimes,

was used to find the unknown point X_e. It was expected that X_e body weight would be a body weight value at which a biological change occurred.

The procedure adopted in the application of the four models used was as follows. Plots on ordinary graph paper were made of all the pairs of variables where a relationship was to be investigated. Unless it was clear from the plot that one of the mathematical models would be unsuitable, the four models were fitted to the data. The models were fitted by the method of least squares which minimises the sum of squares of errors about the fitted regression line. Examination of the error term indicated whether the relationships adequately described the data. The model of Griffiths and Miller (1973) was fitted only to grey kangaroo data due to the limiting number of red kangaroos studied.

The inherent biological variability of animals implies that an error component must be added to the mathematical models discussed. For the purpose of statistical analysis, the error component is assumed to be normally distributed and to have equal variance. The errors are assumed additive for the linear, second-degree polynomial and two-phase linear regression but multiplicative for the allometric model. A further requirement for linear regression is that the X values be independent fixed values. A discussion of the assumptions made when using linear regression has been given by Snedecor and Cochran (1967).

On examination, the data were often found to have less variance for small data values. For simplicity of method, the data were not weighted to account for differences in variance. Further, the X values were not truly independent fixed values. These two violations of the basic assumptions for linear regression were not considered a serious restriction to the use of linear regression for the analyses of the data.

It was necessary when using the logarithmic form of the allometric equation to transform data containing zero values by the addition of one unit (X + 1, Y + 1). This was necessary as the logarithm of zero is defined as minus infinity.

The linear and logarithmic relationships were found to adequately describe the data in a majority of cases. However, in some cases, the second-degree polynomial was superior. To maintain simplicity, especially in the comparisons of differences between species and sexes, the linear and logarithmic relationships were used routinely, and the second-degree polynomial function where increased accuracy justified its use. The two-phase piecewise linear regression was utilized to define changes in growth intensity insomuch as the body or organ weight at which they occurred and the magnitude of the change. The body weights obtained from this function for a series of tissue relationships were then examined for patterns of growth.

Discussion of Methods.

Problems involved with the field collection of wild animals for body composition studies have been discussed by Tribe and Peel (1963), Ledger (1963), Ledger and Smith (1964), Sachs (1967) and by Ledger (1968). Problems associated with the methods used in quantitative anatomical studies have been discussed in detail by Butterfield (1963a) and Bryden (1967).

Kangaroos are protected fauna in N.S.W. The regulations of the Fauna Protection Act (1948) are administered by the National Parks and Wildlife Service of N.S.W. and permits must be obtained before any protected fauna may be captured or killed. The author was issued with a Section 26 Permit, which allowed the collection of specimens for scientific purposes. The experiment required animals to be collected over as wide a body weight range as possible and it became obvious that far more animals would have to be shot than those actually used in the study. This was a particular problem when a good spread of animals of differing weights had been obtained and animals of specific weight were required to fill in remaining weight gaps. From a conservation and aesthetic point of view, the author was reluctant to slaughter any more animals than necessary, and very few animals were collected using the Section 26 Permit.

Graziers with kangaroos present on their properties in pest numbers, may apply for a Section 25 Permit, which will authorize the destruction of a given number of animals. Commercial kangaroo shooters are then contracted to do the culling. It is not uncommon for a commercial shooter to take fifty or so animals in a night's shooting and this was considered as an excellent source of animals for this study. It was possible to obtain a wide selection of body weights and animals used were those requiring culling. The bulk of the animals used in this study were collected in this way and the successful collection of specimens was due to the bushcraft and marksmanship of Mr. D. Davis and Mr. R. McMillan.

A characteristic of the kangaroo carcasses studied was the small amount of fat present. The absence of a subcutaneous insulatory layer of fat allowed rapid dehydration of the superficial carcass musculature in stored carcasses and it was essential that carcasses held in storage were wrapped in air-tight plastic bags. However, the absence of significant amounts of carcass fat made the identification and dissection of individual muscles relatively easy, compared with the same procedure in sheep or cattle.

The effectiveness of the statistical analyses used for this study ultimately depends on the experimental design. Two undesirable features present in the experimental design were comparisons made between animals taken over different body weight ranges and in different numbers. Regressions developed for comparisons between the two sexes within a species were based on animals of widely different empty body weight range. Sexual dimorphism occurs in the kangaroo, where the male kangaroo may grow to two to three times the body weight of the female. An alternative experimental design would be to compare females with only those males within the female weight range. This approach however, would have the even less desireable feature of comparing mature females with immature males.

Comparisons made between individual specimens must be interpreted cautiously, due to the possibility of bias from individual animal variation. In fact, similar results were obtained when grey and red kangaroos were compared on a percentage basis or by regression.

CHAPTER 4

REGIONAL GROWTH PATTERNS

"Growth is a complicated and highly integrated process and it has been known for centuries that all parts of the body do not develop equally fast or at the same time."

R.A. McCance (1962)

"The growth of the whole (animal body) is the resultant of differential growth of the constituent parts."

C.P. McMeekan (1940)

"The details of relative growth patterns are dependent on the changing functional significance of different organs and parts during life, and the relative growth changes which occur in one species cannot be assumed to be the same as changes which occur in another, particularly if there are marked differences in habitat and mode of life."

M. Bryden (1967)

INTRODUCTION.

Studies on body composition include such major works as Hammond (1920, 1921, 1922, 1932), Palsson (1939, 1940, 1955), McMeekan (1940, 1941), Palsson and Verges (1952), Wilson (1952, 1954, 1955, 1960), Butterfield (1963), Fourie (1965), Bryden (1967), Lohse (1971) and Warren (1974).

A review of the principles of growth and development which emerge from these works will provide necessary background information to an investigation into the growth and development of the kangaroo. However, as pointed out by Bryden (1967) extrapolation of growth principles from one species to another must be made in awareness of differences in morphology, habitat and mode of life.

The concept of differential growth is well established in growth and development literature. Two patterns of differential growth have emerged from studies on quadrapedal domestic animals. A centripetal growth force acts within the limbs producing greater development of the structures of the distal limb early in development. Concomitantly, a craniocaudal growth force acts within the trunk producing a greater development of the structures of the head early in development. Both the magnitude of the differential growth forces and the body weights at which body regions change their growth impetus are less clearly defined and vary between the domestic animals. A clear statement of the absolute values of the growth forces acting within any one species is difficult to prepare. Growth is complex and highly integrated; individual research works often present different treatments of data; and studies often contain animals classed according to age and weight with the classes overlapping ages or weights of biological importance such as birth, weaning, sexual maturity and tissue maturity.

Exceptions to the craniocaudal growth force pattern are stated to exist. Butterfield (1963) found that the muscles of the loin were no later developing than any other part of the spinal musculature. Butterfield (1963) pointed out that Hammond's conclusion that the loin was late developing was based on dissection data which included abdominal wall muscle with the loin. In fact, Hammond was demonstrating the late maturity in the abdominal wall musculature. Though Hammond's statement was not well based in anatomy, the statement in itself may have been true. The loin may have been later developing than the more cranial spinal components and yet still obtained its final mature growth impetus pattern at a body weight below the weight range of Butterfield's (1963) study. Visual inspection of an early ox or sheep embryo would confirm that the cranial region of the spinal column develops earlier than the caudal region. This "exception" to the general rule is in reality only a statement that in animals of the weight studied by Butterfield (1963), the change in growth force had already occurred and the loin had reached tissue maturity. Thus any broad statement that a body region is early or late maturing must be qualified by a statement of the body weight range of the study, as it is possible for a body region to possess either a monophasic, biphasic or triphasic growth pattern through the body weight span of the species.

Differential growth forces acting on regions of the body produce changes in body form which characterize the immature and mature forms of female and male animals. Body regions themselves are composed of several tissues and differential growth has been demonstrated between the body tissues. Between body tissues, nervous tissue is early maturing, followed by bone, then muscle, with fat being the latest maturing body tissue. Within tissues, both bone and muscle have been demonstrated to have differential growth patterns. Fat growth is variable as a number of factors influence fat deposition. However, Warren (1974), was able to demonstrate differential growth patterns for fat in merino sheep.

Growth and development studies have been carried out in birds and wild animals. In the domestic fowl, Wilson (1952, 1954) was able to demonstrate the presence of definite growth gradients. He demonstrated centripetal growth in the body extremities and cranio-caudal growth in the trunk. In the Southern Elephant Seal (Mirounga leonina) Bryden (1967) found departures from centripetal muscle growth and from fat being a late maturing tissue. In fact, he found the rate of growth of subcutaneous fat during early post-natal growth, exceeded that of the other tissues. He attributed the differences found in the seals to their habitat.

This section of the study investigates the growth and development of the body regions of the kangaroo. Species are compared.

METHODS AND MATERIALS.

The general methods and materials used are described in Chapters 2 and 3.

Regional growth patterns are investigated with fifteen measurements made on the head and forequarter, fourteen measurements on the hindquarter and tail and with one full body length measurement. Relationships are established between the measurements and empty body weight, dressed weight and half-carcass weight.

RESULTS.

The results are presented in the following format.

A figure of the data plot for each relationship investigated is presented together with the functions fitted to the data. The functions are compared to establish differences, if any, between the two sexes and species of the grey and red kangaroo. In the grey kangaroo, where a change in growth impetus occurs, the estimated point (X_e Y_e) of the change and its magnitude (bl, b2) are given, based on the two-phase linear function described by Griffiths and Miller (1973).

In conjunction with the mathematical presentation of the results, a brief written summary of the differences found between the grey and red kangaroos is presented. Lengths and weights of the various body regions are predicted from the functions fitted to the data and presented in Table 5. For the grey kangaroo, the empty body weights at which growth impetus changes occur in the body regions, are presented in Table 7.

Finally, a table of the relative proportions of the various body regions for the five species of macropod studied is presented.

Symbols used in the text are:

Y	dependent variable
X	independent variable
X_e, Y_e	estimated point of change in the growth impetus
log	logarithm of
a	allometric function: is the fractional coefficient
k	ratio of the relative growth of Y to X
b, b1, b2	rates of growth of Y to X
n	number of observations
r	correlation coefficient
SE	standard error
NS	not significant at the 5% level
*	significant at the 5% level
**	significant at the 1% level
***	significant at the 0.1% level

The forequarter and tail of both sexes of the red kangaroo were relatively larger than those of the corresponding sex of the grey kangaroo. In the hindquarter, the converse was true. However, significant differences were not demonstrated between the same sexes of the grey and red kangaroo when ear length, head length, head weight and thoracic vertebral length were compared. Between males of the two species, significant differences could not be demonstrated in neck weight, chest circumference, antebrachium length, antebrachium circumference, antebrachium weight and manus weight. Both sexes of the grey kangaroo had significantly longer neck length and the female grey kangaroo had a significantly greater chest circumference than the female red kangaroo. Significant differences were not demonstrated between female grey and red kangaroos for pelvic width and between males for lumbar vertebral length, abdominal wall muscle weight, crus length and pes length. Female red kangaroos were significantly heavier in abdominal wall muscle and longer in lumbar vertebral and crural length than female grey kangaroos.

Forequarter weights (Figure 23) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, forequarter weights were significantly greater for males.

FOREQUARTER

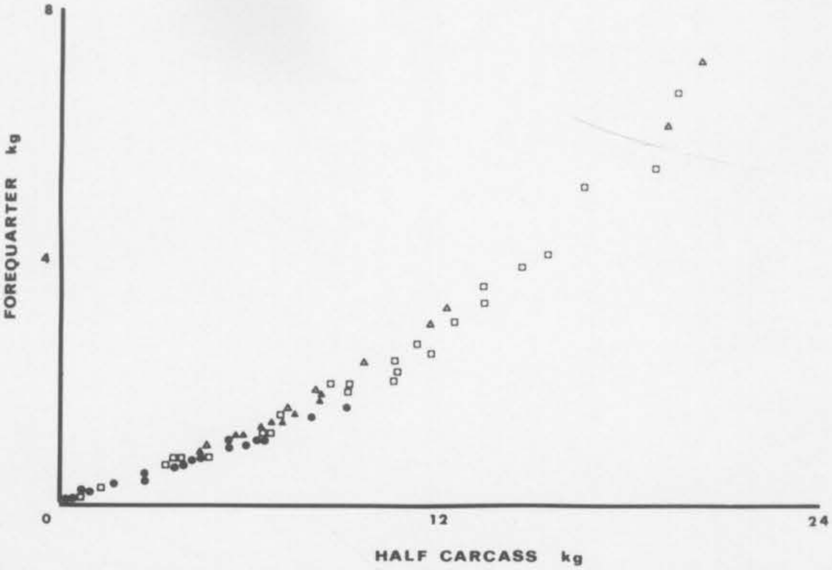

Figure 23 Relationship of forequarter weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.654 + .850 \log X$
$n = 19$ $r = .997$ SE $k = .015$ P ***

□ Male Grey Kangaroo $\log Y = -.703 + 1.066 \log X$
$n = 25$ $r = .983$ SE $k = .042$ P ***

▲ Female Red Kangaroo $\log Y = -.825 + 1.158 \log X$
$n = 9$ $r = .989$ SE $k = .065$ P ***

△ Male Red Kangaroo $\log Y = -.960 + 1.361 \log X$
$n = 8$ $r = .996$ SE $k = .047$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	*	-
Female Grey/Female Red	**	-
Male Grey/Male Red	*	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (11.0kg, 2.3kg)
SE $X_e = 0.6$ SE Y_e 0.2

Estimated slopes $b1 = 0.21$ $b2 = 0.47$
SE $b1 = 0.02$ SE $b2 = 0.03$

Hindquarter weights (Figure 24) were significantly greater for both sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, hindquarter weights were significantly greater for females.

HINDQUARTER

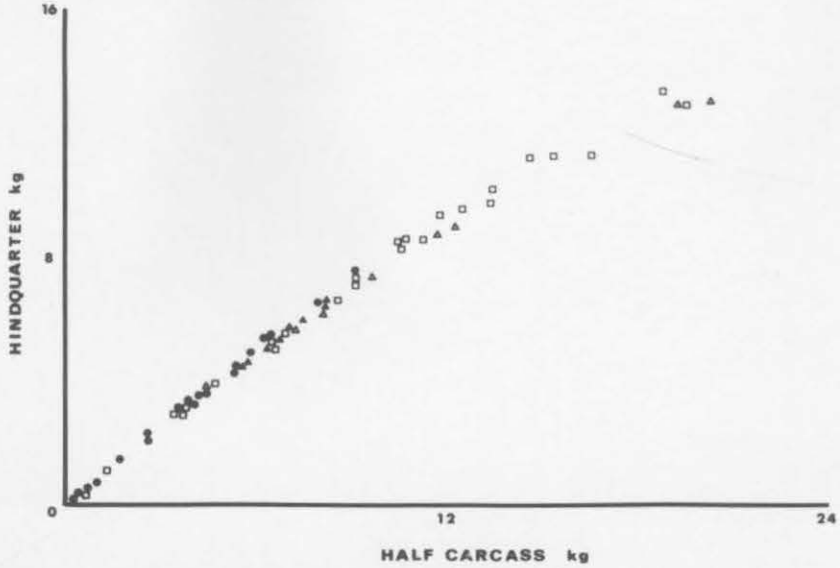

Figure 24 Relationship of hindquarter weight to half carcass weight in grey and red kangaroos.

●	Female Grey Kangaroo	$\log Y = -.112 + 1.042 \log X$ $n = 19 \quad r = 1.000 \quad SE\ k = .005 \quad P$ ***
□	Male Grey Kangaroo	$\log Y = -.095 + .979 \log X$ $n = 25 \quad r = .998 \quad SE\ k = .014 \quad P$ ***
▲	Female Red Kangaroo	$\log Y = -.072 + .967 \log X$ $n = 9 \quad r = .998 \quad SE\ k = .020 \quad P$ ***
△	Male Red Kangaroo	$\log Y = .012 + .857 \log X$ $n = 8 \quad r = .998 \quad SE\ k = .023 \quad P$ ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	*	-
Female Grey/Female Red	*	-
Male Grey/Male Red	**	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (11.8kg, 9.3kg)

$SE\ X_e = 0.3 \quad SE\ Y_e = 0.2$

Estimated slopes $b1 = 0.78 \quad b2 = 0.51$

$SE\ b1 = 0.02 \quad SE\ b2 = 0.03$

FOREQUARTER

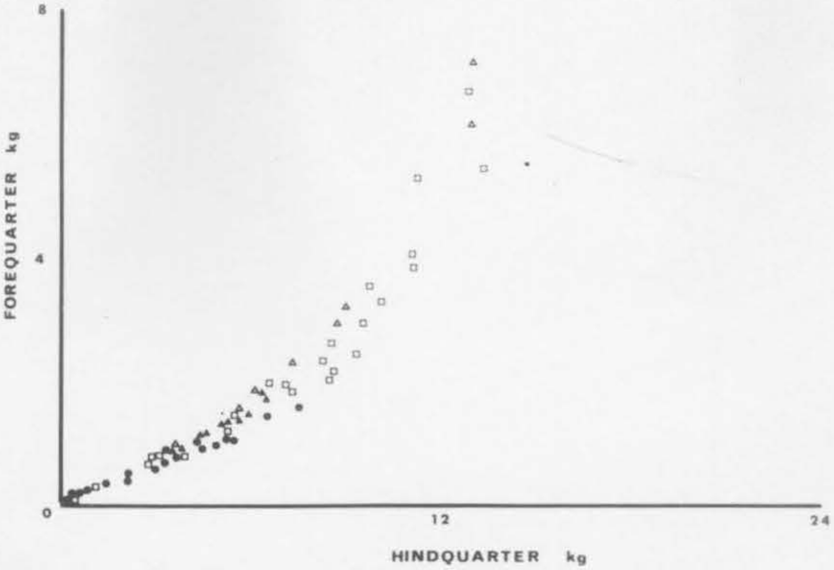

Figure 25 Relationship of forequarter weight to hindquarter weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.562 + .815 \log X$
$n = 19$ $r = .996$ SE $k = .018$ P ***

□ Male Grey Kangaroo $\log Y = -.585 + 1.072 \log X$
$n = 25$ $r = .969$ SE $k = .057$ P ***

▲ Female Red Kangaroo $\log Y = -.730 + 1.186 \log X$
$n = 9$ $r = .981$ SE $k = .088$ P ***

△ Male Red Kangaroo $\log Y = -.965 + 1.572 \log X$
$n = 8$ $r = .989$ SE $k = .096$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	–
Female Red/Male Red	*	–
Female Grey/Female Red	*	–
Male Grey/Male Red	*	–

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (8.8kg, 2.4kg)
SE $X_e = .5$ SE $Y_e = .3$

Estimated slopes $b1 = .28$ $b2 = .87$
SE $b1 = .04$ SE $b2 = .10$

Body lengths (Figure 26) were not significantly different between sexes or species in the grey and red kangaroo.

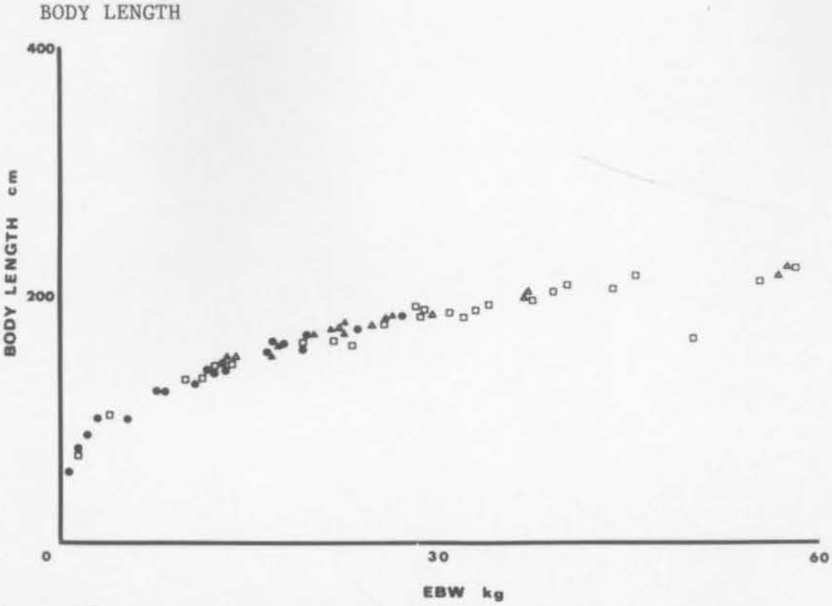

Figure 26 Relationship of body length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.814 + .306 \log X$
$n = 19$ $r = .991$ SE $k = .010$ P ***

□ Male Grey Kangaroo $\log Y = 1.819 + .298 \log X$
$n = 25$ $r = .973$ SE $k = .015$ P ***

▲ Female Red Kangaroo $\log Y = 1.765 + .350 \log X$
$n = 9$ $r = .960$ SE $k = .038$ P ***

△ Male Red Kangaroo $\log Y = 1.868 + .272 \log X$
$n = 8$ $r = .993$ SE $k = .013$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = 1.819 + .302 \log X$
Two Sexes and Species $n = 61$ $r = .986$ SE $k = .007$ P ***

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (6.7kg, 138.0cm)
SE $X_e = 2.8$ SE $Y_e = 8.2$

Estimated slopes $b1 = 13.08$ $b2 = 1.70$
SE $b1 = 7.59$ SE $b2 = 0.21$

Ear lengths (Figure 27) were not significantly different between the same sexes of the grey and red kangaroo. Between sexes within species, the ear lengths were significantly greater for the female grey kangaroo but not significantly different in the red kangaroo.

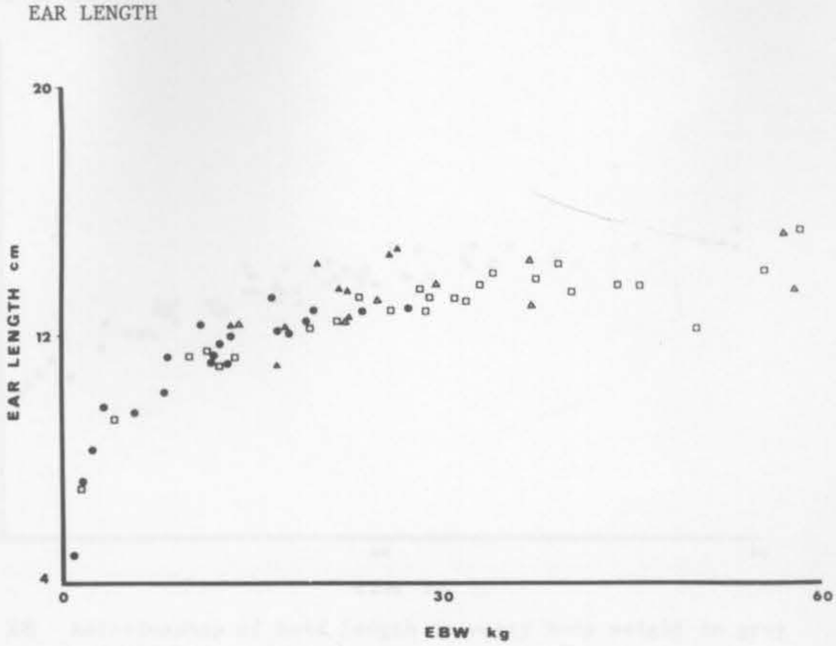

Figure 27 Relationship of ear length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .803 + .238 \log X$
$n = 19$ $r = .949$ SE $k = .019$ P ***

□ Male Grey Kangaroo $\log Y = .854 + .179 \log X$
$n = 25$ $r = .954$ SE $k = .012$ P ***

▲ Female Red Kangaroo $\log Y = .682 + .334 \log X$
$n = 9$ $r = .739$ SE $k = .115$ P *

△ Male Red Kangaroo $\log Y = .957 + .114 \log X$
$n = 8$ $r = .762$ SE $k = .040$ P *

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	*	–
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (3.2kg, 10.2cm)
SE $X_e = 0.4$ SE $Y_e = 0.4$

Estimated slopes $b1 = 2.07$ $b2 = 0.14$
SE $B1 = 0.38$ SE $b2 = 0.02$

B. Male

Estimated point of change (X_e, Y_e) (6.4kg, 11.4cm)
SE $X_e = 1.8$ SE $Y_e = 0.3$

Estimated slopes $b1 = 0.88$ $b2 = 0.06$
SE $b1 = 0.37$ SE $b2 = 0.01$

Head lengths (Figure 28) were not significantly different between sexes or species in the grey and red kangaroo.

HEAD LENGTH

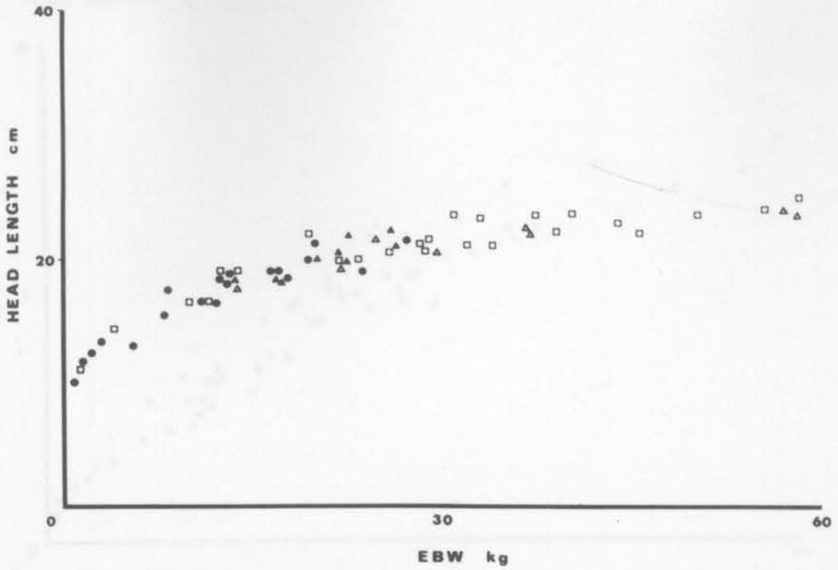

Figure 28 Relationship of head length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.016 + .215 \log X$
$n = 18$ $r = .972$ SE $k = .013$ P ***

□ Male Grey Kangaroo $\log Y = 1.025 + .209 \log X$
$n = 25$ $r = .971$ SE $k = .011$ P ***

▲ Female Red Kangaroo $\log Y = .873 + .327 \log X$
$n = 9$ $r = .870$ SE $k = .070$ P **

△ Male Red Kangaroo $\log Y = 1.015 + .208 \log X$
$n = 8$ $r = .951$ SE $k = .028$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = 1.019 + .211 \log X$
Two Sexes and Species $n = 60$ $r = .974$ SE $k = .007$ P ***

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change	(X_e, Y_e) (3.9kg, 14.8cm) SE $X_e = 1.4$ SE $Y_e = 0.9$
Estimated slopes	$b1 = 1.45$ $b2 = 0.31$ SE $b1 = 0.69$ SE $b2 = 0.05$

B. Male

Estimated point of change	(X_e, Y_e) (7.1kg, 17.9cm) SE $X_e = 2.8$ SE $Y_e = 0.7$
Estimated slopes	$b1 = 1.16$ $b2 = 0.15$ SE $b1 = 0.60$ SE $b2 = 0.02$

Head weights (Figure 29) were not significantly different between the same sexes of the grey and red kangaroo. Between sexes within species, the head weights were not significantly different in the grey kangaroo but were significantly greater for the female red kangaroo.

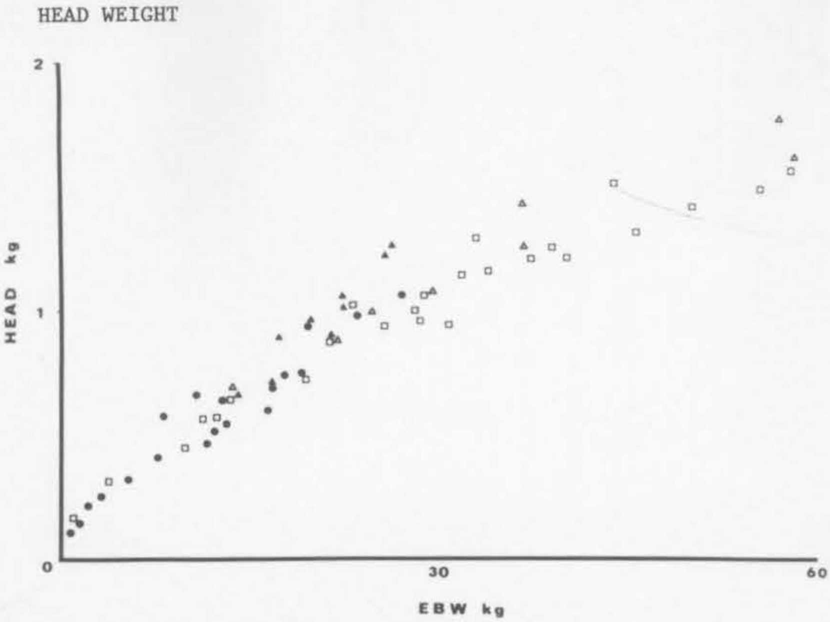

Figure 29 Relationship of head weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.908 + .587 \log X$
$n = 19$ $r = .840$ SE $k = .092$ P ***

□ Male Grey Kangaroo $\log Y = -.964 + .654 \log X$
$n = 25$ $r = .904$ SE $k = .064$ P ***

▲ Female Red Kangaroo $\log Y = -1.316 + .987 \log X$
$n = 9$ $r = .947$ SE $k = .126$ P ***

△ Male Red Kangaroo $\log Y = -.920 + .657 \log X$
$n = 8$ $r = .986$ SE $k = .046$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	*	-
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = -.946 + .653 \log X$
Two Sexes and Species $n = 61$ $r = .906$ SE $k = .040$ P ***

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (13.7kg, 0.6kg)
SE $X_e = 6.8$ SE $Y_e = 0.2$

Estimated slopes $b1 = 0.04$ $b2 = 0.02$
SE $b1 = 0.01$ SE $b2 = 0.003$

Cervical vertebral lengths (Figure 30) were significantly greater for both the sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, the cervical vertebral lengths were not significantly different.

CERVICAL VERTEBRAL LENGTH

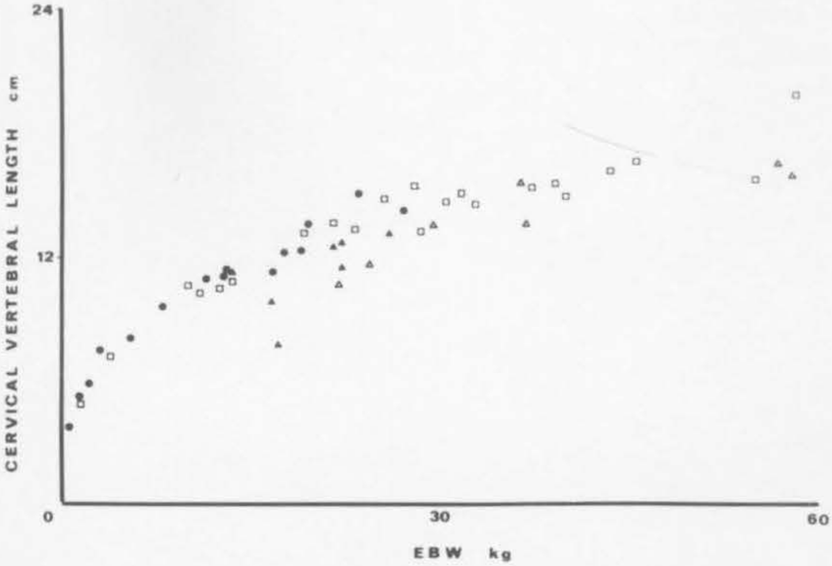

Figure 30 Relationship of cervical vertebral length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .641 + .366 \log X$
$n = 15$ $r = .992$ SE $k = .013$ P ***

◻ Male Grey Kangaroo $\log Y = .644 + .348 \log X$
$n = 22$ $r = .983$ SE $k = .014$ P ***

▲ Female Red Kangaroo $\log Y = .503 + .418 \log X$
$n = 7$ $r = .502$ SE $k = .322$ P *

△ Male Red Kangaroo $\log Y = .489 + .418 \log X$
$n = 7$ $r = .927$ SE $k = .075$ P **

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	**
Male Grey/Male Red	NS	***

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (6.3kg, 9.2cm)
SE $X_e = 1.2$ SE $Y_e = .6$

Estimated slopes $b1 = .87$ $b2 = .27$
SE $b1 = .15$ SE $b2 = .03$

B. Male

Estimated point of change (X_e, Y_e) (7.7kg, 10.5cm)
SE $X_e = 3.6$ SE $Y_e = 0.7$

Estimated slopes $b1 = 0.92$ $b2 = 0.16$
SE $b1 = 0.54$ SE $b2 = 0.01$

Neck weights (Figure 31) were not significantly different between the same sexes of the grey and red kangaroo. Between sexes within the grey kangaroos, neck weights were significantly greater in the male. Predicted neck weights for male red kangaroos were non-significantly greater than those for females (Table5).

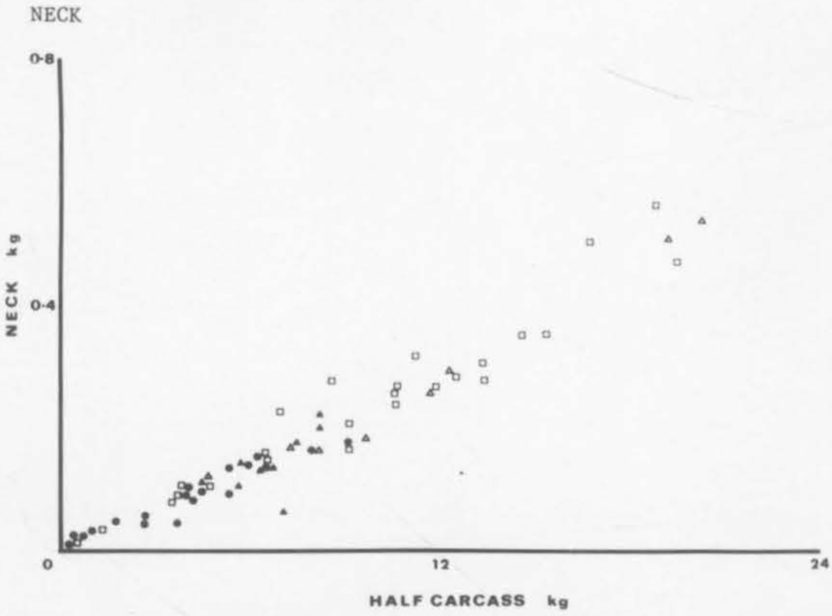

Figure 31 Relationship of neck weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo log Y = -1.507 + .755 log X
n = 19 r = .963 SE k = .051 P ***

□ Male Grey Kangaroo log Y = -1.517 + .905 log X
n = 25 r = .982 SE k = .037 P ***

▲ Female Red Kangaroo log Y = -1.580 + .870 log X
n = 9 r = .446 SE k = .661 P NS

△ Male Red Kangaroo log Y = -1.702 + 1.066 log X
n = 8 r = .975 SE k = .099 P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	*	-
Male Grey/Male Red	NS	NS

Overall Equation log Y = -1.533 + .881 log X
Two Sexes and Species n = 61 r = .963 SE k = .032 P ***

Chest circumferences (Figure 32) were significantly greater for the female grey kangaroo but not significantly different between males, when the same sex of the grey and red kangaroo were compared. Between sexes within species, the chest circumferences were not significantly different.

CHEST CIRCUMFERENCE

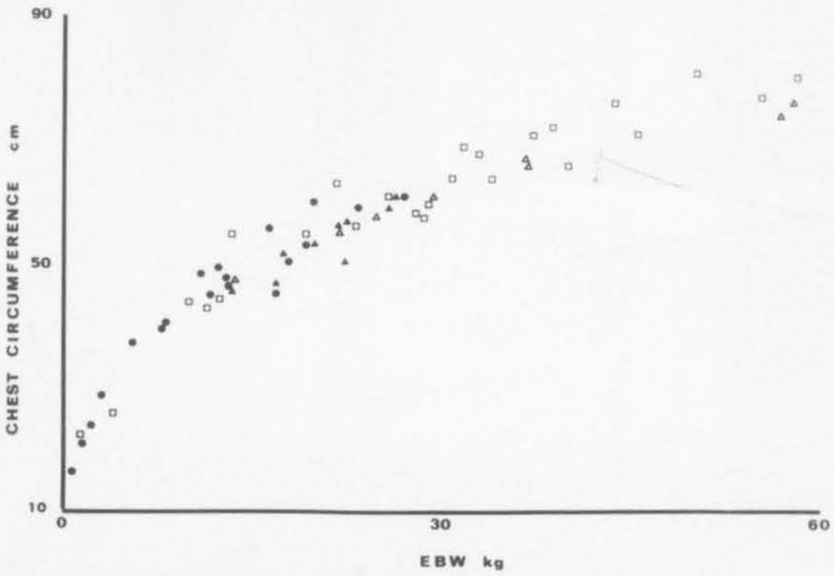

Figure 32 Relationship of chest circumference to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.261 + .373 \log X$
$n = 19$ $r = .988$ SE $k = .014$ P ***

□ Male Grey Kangaroo $\log Y = 1.255 + .370 \log X$
$n = 25$ $r = .979$ SE $k = .016$ P ***

▲ Female Red Kangaroo $\log Y = 1.174 + .420 \log X$
$n = 9$ $r = .894$ SE $k = .080$ P **

△ Male Red Kangaroo $\log Y = 1.305 + .325 \log X$
$n = 8$ $r = .997$ SE $k = .010$ P ***

<u>Comparison of differences between the two sexes and species</u>

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = 1.265 + .360 \log X$
Two Sexes and Species $n = 61$ $r = .985$ SE $k = .008$ P ***

<u>Change in the Growth Impetus in the Grey Kangaroo</u>

A. Female

Estimated point of change (X_e, Y_e) (5.8kg, 39.3cm)
SE $X_e = 1.1$ SE $Y_e = 2.4$

Estimated slopes $b1 = 4.33$ $b2 = 1.09$
SE $b1 = 0.82$ SE $b2 = 0.15$

B. Male

Estimated point of change (X_e, Y_e) (14.4kg, 52.5cm)
SE $X_e = 1.6$ SE $Y_e = 2.5$

Estimated slopes $b1 = 2.45$ $b2 = 0.66$
SE $b1 = 0.31$ SE $b2 = 0.07$

Chest depths (Figure 33) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, the chest depths were not significantly different.

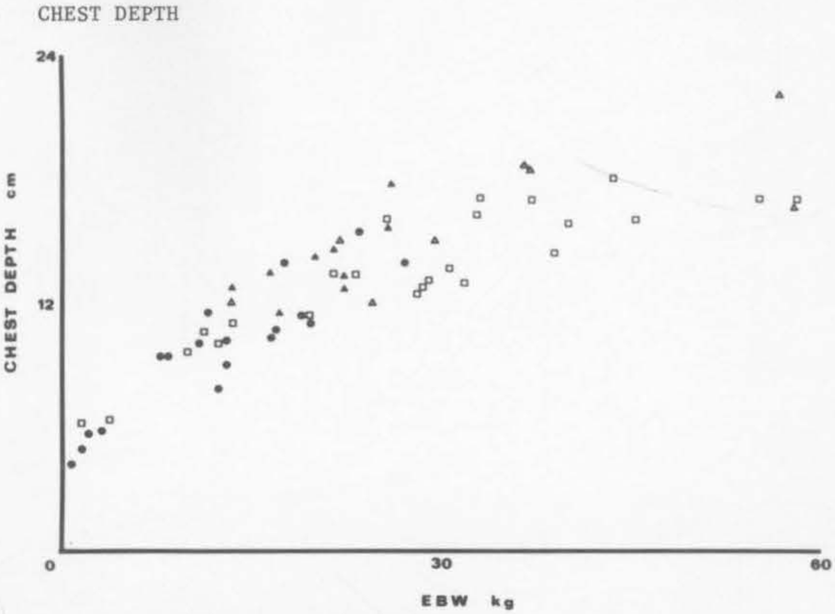

Figure 33 Relationship of chest depth to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .639 + .342 \log X$
$n = 18$ $r = .949$ SE $k = .028$ P ***

□ Male Grey Kangaroo $\log Y = .682 + .319 \log X$
$n = 24$ $r = .951$ SE $k = .022$ P ***

▲ Female Red Kangaroo $\log Y = .620 + .400 \log X$
$n = 9$ $r = .681$ SE $k = .163$ P *

△ Male Red Kangaroo $\log Y = .661 + .362 \log X$
$n = 8$ $r = .818$ SE $k = .104$ P *

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	*

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (4.6kg, 7.2cm)
SE $X_e = 5.9$ SE $Y_e = 2.3$

Estimated slopes $b1 = 0.73$ $b2 = 0.35$
SE $b1 = 0.78$ SE $b2 = 0.06$

B. Male

Estimated point of change (X_e, Y_e) (17.5kg, 12.7cm)
SE $X_e = 4.1$ SE $Y_e = 0.9$

Estimated slopes $b1 = 0.42$ $b2 = 0.13$
SE $b1 = 0.11$ SE $b2 = 0.03$

Thoracic vertebral lengths (Figure 34) were not significantly different between sexes or species in the grey and red kangaroo. Predicted thoracic vertebral lengths were non-significantly greater for the red kangaroo (Table 5).

THORACIC VERTEBRAL LENGTH

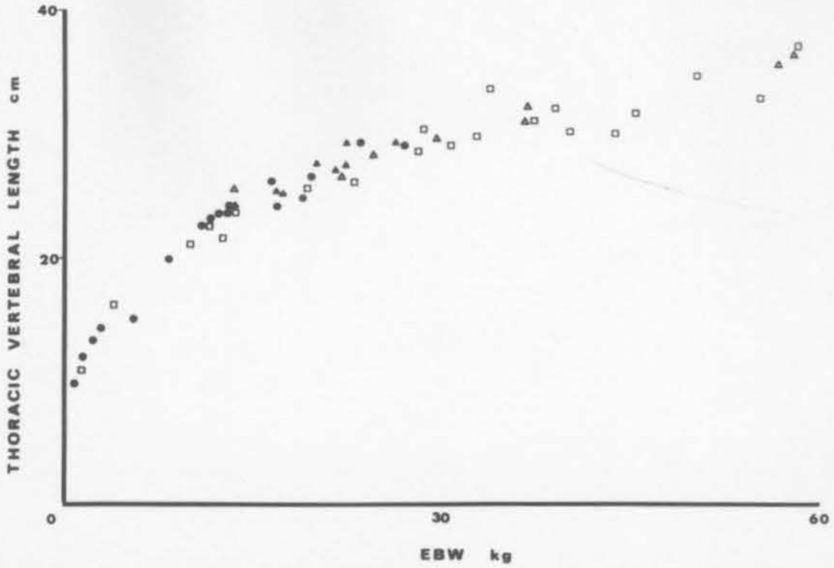

Figure 34 Relationship of thoracic vertebral length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.008 + .321 \log X$
$n = 17$ $r = .989$ SE $k = .013$ P ***

◘ Male Grey Kangaroo $\log Y = 1.009 + .307 \log X$
$n = 21$ $r = .986$ SE $k = .012$ P ***

▲ Female Red Kangaroo $\log Y = 1.048 + .292 \log X$
$n = 9$ $r = .923$ SE $k = .046$ P ***

△ Male Red Kangaroo $\log Y = 1.100 + .256 \log X$
$n = 8$ $r = .974$ SE $k = .024$ P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = 1.017 + .308 \log X$
Two Sexes and Species $n = 55$ $r = .987$ SE $k = .007$ P ***

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (12.4kg, 23.3cm)
SE $X_e = 0.4$ SE $Y_e = 0.6$

Estimated slopes $b1 = 1.09$ $b2 = 0.41$
SE $b1 = 0.09$ SE $b2 = 0.09$

B. Male

Estimated point of change (X_e, Y_e) (14.6kg, 25.0cm)
SE $X_e = 1.8$ SE $Y_e = 1.1$

Estimated slopes $b1 = 0.97$ $b2 = 0.25$
SE $b1 = 0.14$ SE $b2 = 0.03$

Thorax weights (Figure 35) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, thorax weights were significantly greater for male grey kangaroos but were not significantly different in the red kangaroo.

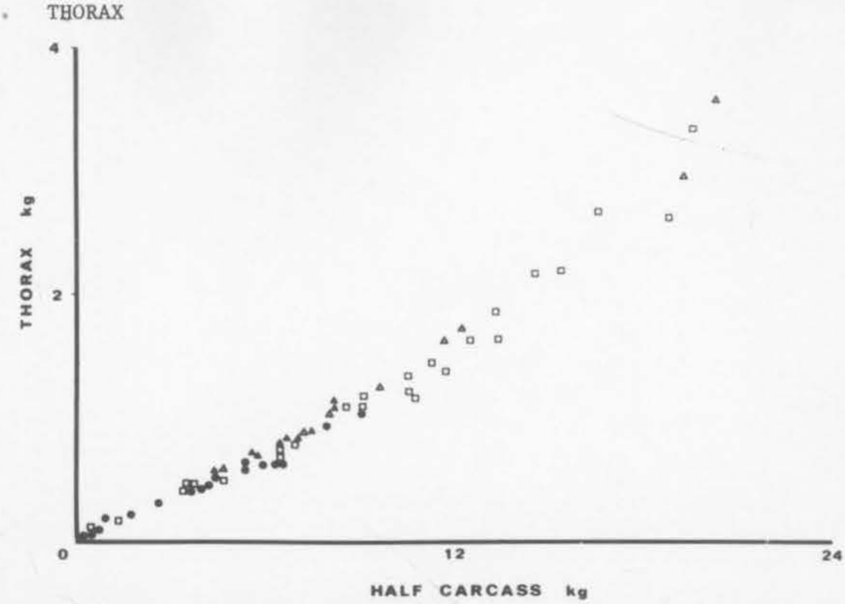

Figure 35 Relationship of thoracic weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.883 + .893 \log X$
$n = 19$ $r = .998$ SE $k = .012$ P ***

□ Male Grey Kangaroo $\log Y = -.931 + 1.037 \log X$
$n = 25$ $r = .991$ SE $k = .029$ P ***

▲ Female Red Kangaroo $\log Y = -1.025 + 1.147 \log X$
$n = 9$ $r = .977$ SE $k = .095$ P ***

△ Male Red Kangaroo $\log Y = -1.090 + 1.225 \log X$
$n = 8$ $r = .995$ SE $k = .049$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	*	-
Male Grey/Male Red	*	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (11.7kg, 1.4kg)
SE $X_e = 1.1$ SE $Y_e = 0.2$

Estimated slopes $b1 = 0.12$ $b2 = 0.22$
SE $b1 = 0.01$ SE $b2 = 0.01$

Lumbar vertebral lengths (Figure 36) were significantly greater for female red kangaroos but not significantly different between males when the same sexes of grey and red kangaroos were compared. Between sexes within species, the lumbar vertebral lengths were not significantly different in the grey kangaroo but were significantly greater for female red kangaroos.

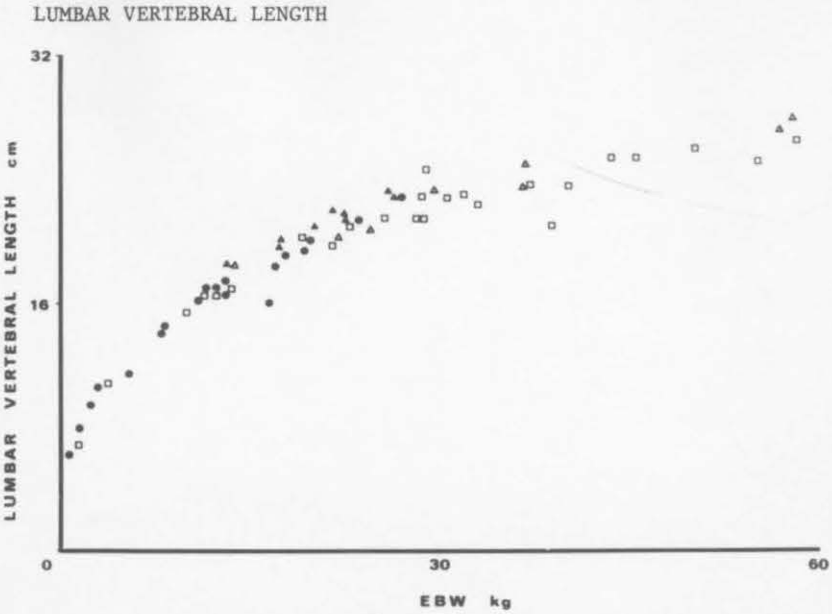

Figure 36 Relationship of lumbar vertebral length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .840 + .348 \log X$
$n = 19$ $r = .992$ SE $k = .011$ P ***

◘ Male Grey Kangaroo $\log Y = .817 + .356 \log X$
$n = 25$ $r = .986$ SE $k = .012$ P ***

▲ Female Red Kangaroo $\log Y = .885 + .336 \log X$
$n = 9$ $r = .979$ SE $k = .027$ P ***

△ Male Red Kangaroo $\log Y = .903 + .306 \log X$
$n = 8$ $r = .990$ SE $k = .018$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	***
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

A. Female
Estimated point of change (X_e, Y_e) (4.0kg, 12.3cm)
SE $X_e = 0.9$ SE $Y_e = 0.7$

Estimated slopes $b1 = 1.82$ $b2 = 0.46$
SE $b1 = 0.50$ SE $b2 = 0.04$

B. Male
Estimated point of change (X_e, Y_e) (7.6kg, 16.6cm)
SE $X_e = 2.4$ SE $Y_e = 0.8$

Estimated slopes $b1 = 1.60$ $b2 = 0.22$
SE $b1 = 0.67$ SE $b2 = 0.02$

Loin weights (Figure 37) were not significantly different between the same sexes of the grey and red kangaroo. Between sexes within species, loin weights were significantly greater for the female grey kangaroo but there were no significant differences between the red kangaroos.

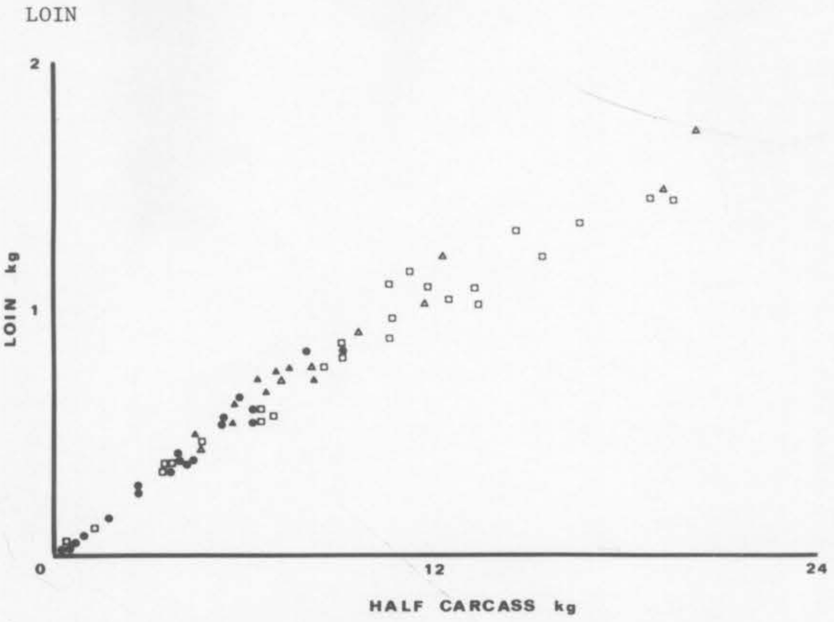

Figure 37 Relationship of loin weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.055 + 1.052 \log X$
$n = 19$ $r = .996$ SE $k = .022$ P ***

☐ Male Grey Kangaroo $\log Y = -1.044 + .986 \log X$
$n = 25$ $r = .993$ SE $k = .025$ P ***

▲ Female Red Kangaroo $\log Y = -.777 + .735 \log X$
$n = 9$ $r = .919$ SE $k = .119$ P ***

△ Male Red Kangaroo $\log Y = -.916 + .878 \log X$
$n = 8$ $r = .991$ SE $k = .049$ P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	*
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (11.2kg, 1.0kg)
SE $X_e = 0.3$ SE $Y_e = 0.03$

Estimated slopes $b1 = 0.09$ $b2 = 0.05$
SE $b1 = 0.004$ SE $b2 = 0.006$

Abdominal wall muscle weights (Figure 38) were significantly greater for female red kangaroos but were not significantly different for males, when the same sexes of grey and red kangaroo were compared. Between sexes within species, abdominal wall muscle weights were significantly greater for females.

ABDOMINAL WALL MUSCLE

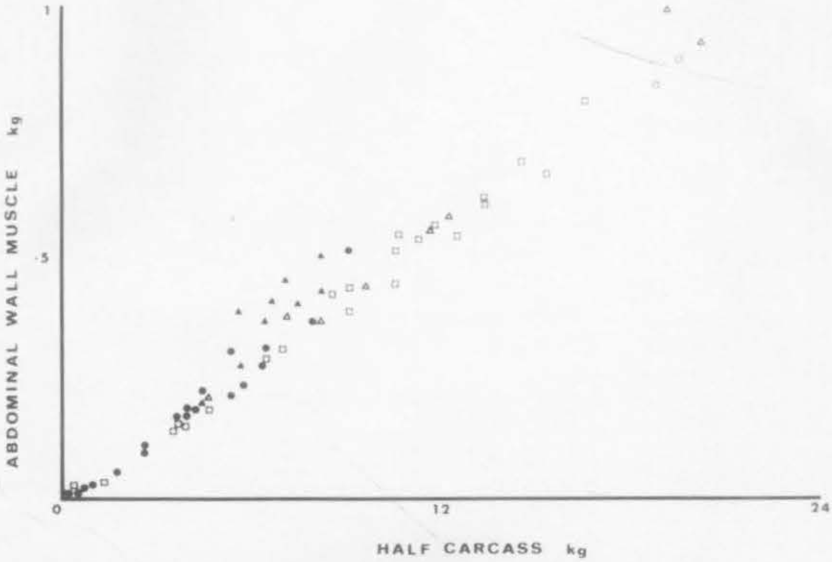

Figure 38 Relationship of abdominal wall muscle weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.490 + 1.203 \log X$
$n = 19$ $r = .996$ SE $k = .026$ P ***

▢ Male Grey Kangaroo $\log Y = -1.497 + 1.145 \log X$
$n = 25$ $r = .997$ SE $k = .019$ P ***

▲ Female Red Kangaroo $\log Y = -1.487 + 1.280 \log X$
$n = 9$ $r = .892$ SE $k = .245$ P **

△ Male Red Kangaroo $\log Y = -1.377 + 1.046 \log X$
$n = 8$ $r = .994$ SE $k = .046$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	**
Female Red/Male Red	NS	**
Female Grey/Female Red	NS	**
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Female

Estimated point of change (X_e, Y_e) (4.9kg, 0.2kg)
SE $X_e = 0.1$ SE $Y_e = 0.02$

Estimated slopes $b1 = 0.05$ $b2 = 0.06$
SE $b1 = 0.002$ SE $b2 = 0.003$

Pelvic widths (Figure 39) were not significantly different between females but were significantly different between males, when the same sexes of grey and red kangaroo were compared. Between sexes within species, the pelvic widths were not significantly different.

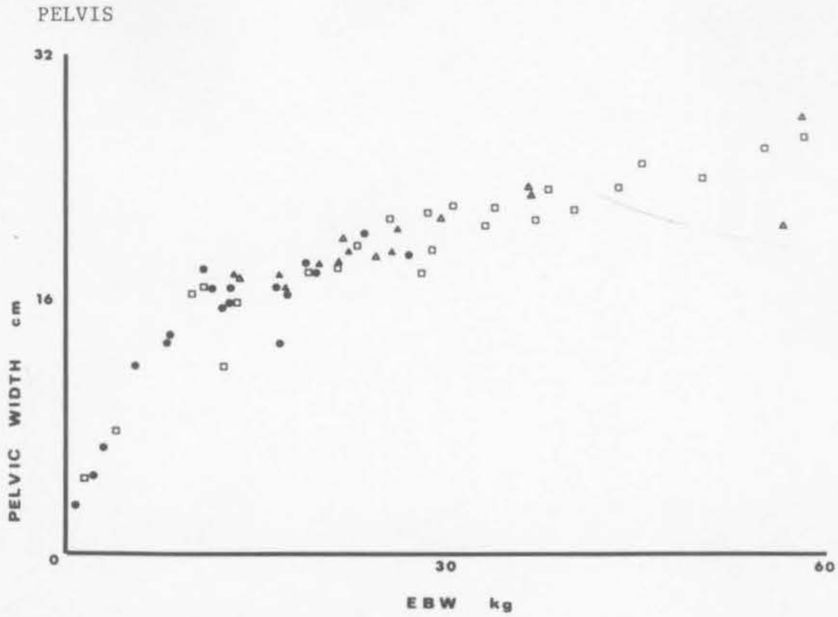

Figure 39 Relationship of pelvic width to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .605 + .525 \log X$
$n = 18$ $r = .957$ SE $k = .040$ P ***

□ Male Grey Kangaroo $\log Y = .670 + .439 \log X$
$n = 24$ $r = .965$ SE $k = .026$ P ***

▲ Female Red Kangaroo $\log Y = .945 + .253 \log X$
$n = 9$ $r = .756$ SE $k = .083$ P *

△ Male Red Kangaroo $\log Y = .974 + .240 \log X$
$n = 8$ $r = .806$ SE $k = .072$ P *

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	*	-

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (6.9kg, 14.5cm)
SE $X_e = 1.2$ SE $Y_e = 0.9$

Estimated slopes $b1 = 1.97$ $b2 = 0.26$
SE $b1 = 0.40$ SE $b2 = 0.07$

B. Male

Estimated point of change (X_e, Y_e) (9.9kg, 15.7cm)
SE $X_e = 0.2$ SE $Y_e = 0.7$

Estimated slopes $b1 = 1.31$ $b2 = 0.24$
SE $b1 = 0.16$ SE $b2 = 0.03$

Butt weights (Figure 40) were significantly greater for both sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, the butt weights were significantly greater for females.

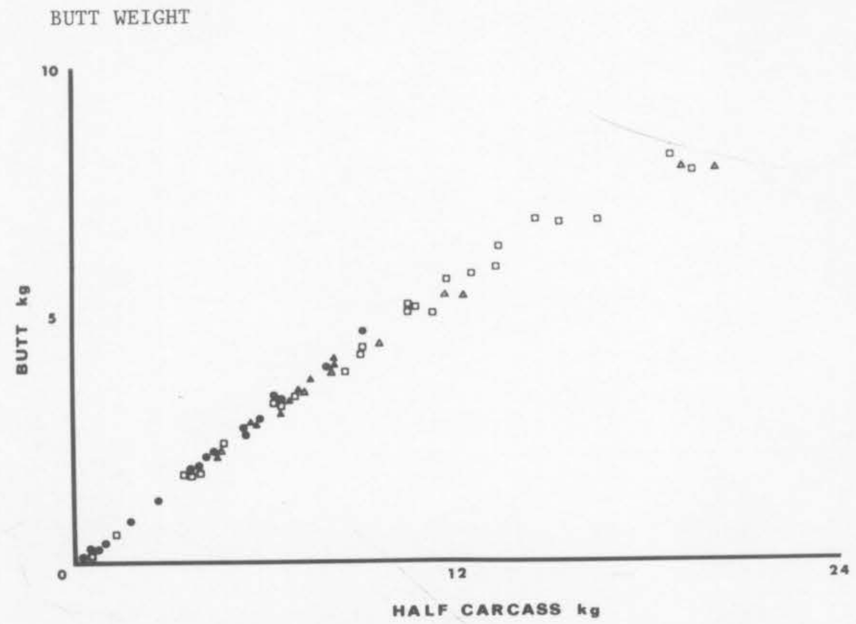

Figure 40 Relationship of butt weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.382 + 1.120 \log X$
$n = 19$ $r = .999$ SE $k = .011$ P ***

□ Male Grey Kangaroo $\log Y = -.361 + 1.027 \log X$
$n = 25$ $r = .996$ SE $k = .019$ P ***

▲ Female Red Kangaroo $\log Y = -.341 + 1.037 \log X$
$n = 9$ $r = .997$ SE $k = .032$ P ***

△ Male Red Kangaroo $\log Y = -.209 + .860 \log X$
$n = 8$ $r = .998$ SE $k = .024$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	**	-
Female Grey/Female Red	NS	**
Male Grey/Male Red	**	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (12.3kg, 5.8kg)

SE $X_e = 0.9$ SE $Y_e = 0.4$

Estimated slopes $b1 = 0.47$ $b2 = 0.32$

SE $b1 = 0.01$ SE $b2 = 0.03$

Tail lengths (Figure 41) were not significantly different between sexes or species for the grey and red kangaroo. Predicted tail lengths were non-significantly greater for the red kangaroo.

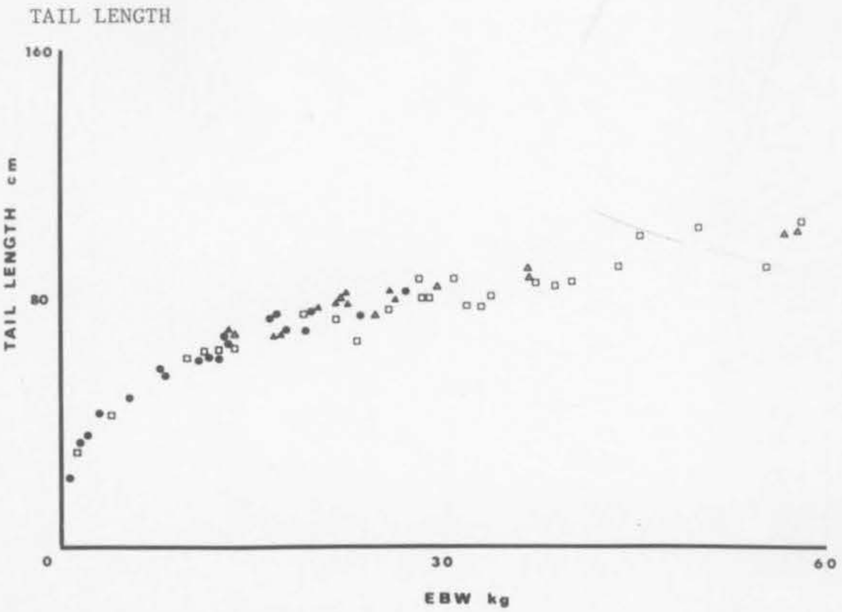

Figure 41 Relationship of tail length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.436 + .338 \log X$
$n = 19 \quad r = .989 \quad SE\ k = .012 \quad P$ ***

□ Male Grey Kangaroo $\log Y = 1.445 + .316 \log X$
$n = 25 \quad r = .979 \quad SE\ k = .014 \quad P$ ***

▲ Female Red Kangaroo $\log Y = 1.472 + .313 \log X$
$n = 9 \quad r = .879 \quad SE\ k = .064 \quad P$ **

△ Male Red Kangaroo $\log Y = 1.519 + .275 \log X$
$n = 8 \quad r = .980 \quad SE\ k = .023 \quad P$ ***

<u>Comparison of differences between the two sexes and species</u>

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = 1.449 + .320 \log X$
Two Sexes and Species $n = 61 \quad r = .984 \quad SE\ k = .007 \quad P$ ***

<u>Change in the Growth Impetus in the Grey Kangaroo</u>

A. Female

Estimated point of change (X_e, Y_e) (3.8kg, 50.1cm)
$SE\ X_e = 0.6 \quad SE\ Y_e = 2.3$

Estimated slopes $b1 = 8.58 \quad b2 = 1.48$
$SE\ b1 = 1.89 \quad SE\ b2 = 0.14$

B. Male

Estimated point of change (X_e, Y_e) (7.8kg, 60.9cm)
$SE\ X_e = 3.5 \quad SE\ Y_e = 3.9$

Estimated slopes $b1 = 4.84 \quad b2 = 0.86$
$SE\ b1 = 2.69 \quad SE\ b2 = 0.08$

Tail circumferences (Figure 42) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, the tail circumferences were not significantly different.

TAIL CIRCUMFERENCE

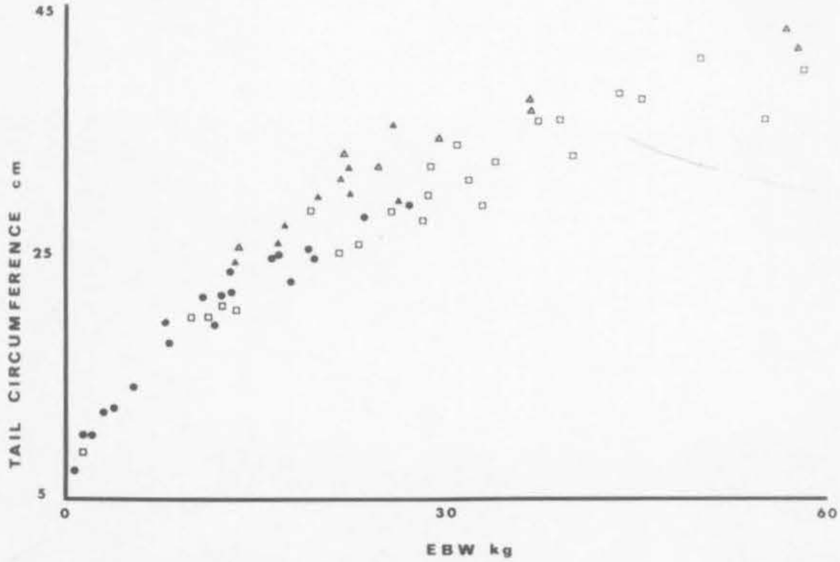

Figure 42 Relationship of tail circumference to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .901 + .388 \log X$
$n = 19$ $r = .990$ SE $k = .014$ P ***

□ Male Grey Kangaroo $\log Y = .857 + .423 \log X$
$n = 25$ $r = .986$ SE $k = .015$ P ***

▲ Female Red Kangaroo $\log Y = .877 + .447 \log X$
$n = 9$ $r = .867$ SE $k = .097$ P **

△ Male Red Kangaroo $\log Y = 1.040 + .336 \log X$
$n = 8$ $r = .981$ SE $k = .027$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	***

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (9.3kg, 19.9cm)
SE $X_e = 1.2$ SE $Y_e = 1.03$

Estimated slopes $b1 = 1.37$ $b2 = 0.51$
SE $b1 = 0.14$ SE $b2 = 0.06$

B. Male

Estimated point of change (X_e, Y_e) (17.8kg, 25.8cm)
SE $X_e = 3.4$ SE $Y_e = 1.8$

Estimated slopes $b1 = 0.99$ $b2 = 0.37$
SE $b1 = 0.19$ SE $b2 = 0.04$

Tail weights (Figure 43) were significantly greater for both the sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, tail weights were significantly greater for male grey kangaroos but not significantly different in red kangaroos. Predicted tail weights for male red kangaroos were non-significantly greater than those for female red kangaroos (Table 5).

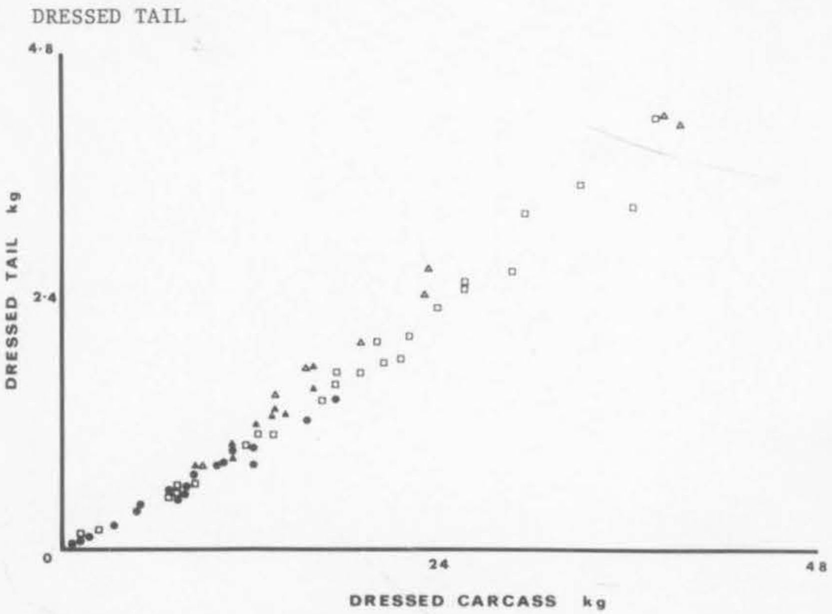
DRESSED TAIL

Figure 43 Relationship of dressed tail weight to dressed carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.134 + 1.032 \log X$
$n = 19$ $r = .998$ SE $k = .016$ P ***

◘ Male Grey Kangaroo $\log Y = -1.202 + 1.131 \log X$
$n = 25$ $r = .997$ SE $k = .017$ P ***

▲ Female Red Kangaroo $\log Y = -1.226 + 1.192 \log X$
$n = 9$ $r = .970$ SE $k = .113$ P ***

△ Male Red Kangaroo $\log Y = -1.064 + 1.073 \log X$
$n = 8$ $r = .992$ SE $k = .054$ P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	***

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (13.5kg, 1.1kg)
SE $X_e = 4.2$ SE $Y_e = .4$

Estimated slopes $b1 = .08$ $b2 = .12$
SE $b1 = .01$ SE $b2 = .01$

Omobrachium weights (Figure 44) were significantly greater for both the sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, the omobrachium weights were significantly greater for males.

OMOBRACHIUM

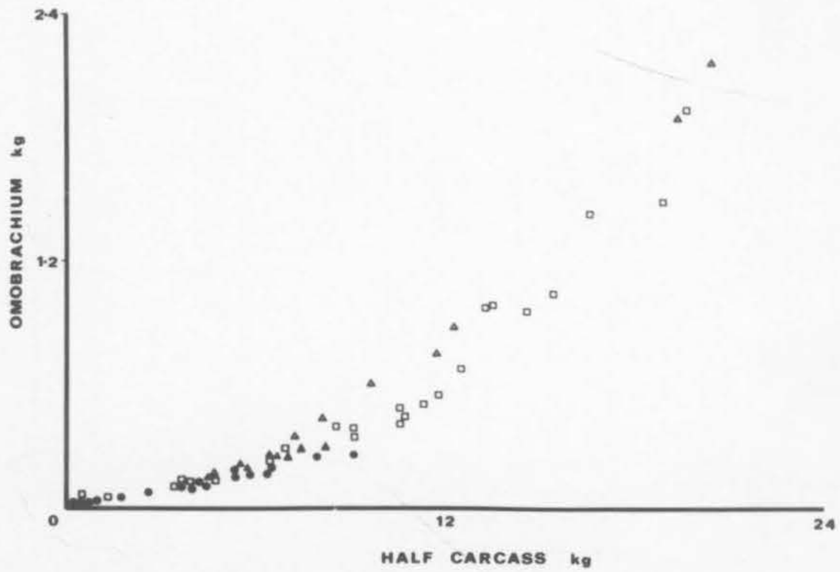

Figure 44 Relationship of omobrachial weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.448 + .848 \log X$
$n = 19$ $r = .990$ SE $k = .029$ P ***

◘ Male Grey Kangaroo $\log Y = -1.489 + 1.194 \log X$
$n = 25$ $r = .960$ SE $k = .073$ P ***

▲ Female Red Kangaroo $\log Y = -1.585 + 1.178 \log X$
$n = 9$ $r = .980$ SE $k = .090$ P ***

▲ Male Red Kangaroo $\log Y = -1.958 + 1.744 \log X$
$n = 8$ $r = .999$ SE $k = .027$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	***	-
Female Grey/Female Red	NS	***
Male Grey/Male Red	*	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change	(X_e, Y_e) (10.4kg, 0.4kg) SE $X_e = 0.8$ SE $Y_e = 0.1$
Estimated slopes	$b1 = 0.04$ $b2 = 0.15$ SE $b1 = 0.01$ SE $b2 = 0.01$

Antebrachium lengths (Figure 45) were significantly greater for female red kangaroos but not significantly different between males, when the same sexes of grey and red kangaroo were compared. Between sexes within species, the antebrachium lengths were significantly greater for male grey kangaroos but significantly greater for female red kangaroos.

ANTEBRACHIAL LENGTH

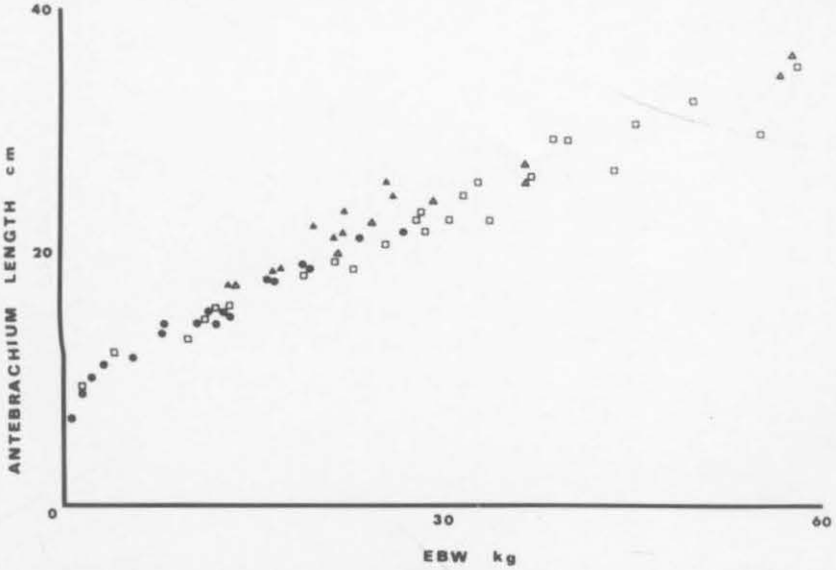

Figure 45 Relationship of antebrachial length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .888 + .294 \log X$
$n = 19$ $r = .980$ SE $k = .014$ P ***

◘ Male Grey Kangaroo $\log Y = .824 + .374 \log X$
$n = 25$ $r = .957$ SE $k = .024$ P ***

▲ Female Red Kangaroo $\log Y = .570 + .586 \log X$
$n = 9$ $r = .953$ SE $k = .070$ P ***

△ Male Red Kangaroo $\log Y = .665 + .494 \log X$
$n = 8$ $r = .986$ SE $k = .035$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	**	-
Female Red/Male Red	NS	*
Female Grey/Female Red	**	-
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (1.4kg, 10.0cm)
SE $X_e = .7$ SE $Y_e = .5$

Estimated slopes $b1 = 5.09$ $b2 = .50$
SE $b1 = 5.63$ SE $b2 = .02$

B. Male

Estimated point of change (X_e, Y_e) (2.3kg, 11.4cm)
SE $X_e = 9.7$ SE $Y_e = 4.2$

Estimated slopes $b1 = 2.55$ $b2 = .42$
SE $b1 = 26.05$ SE $b2 = .02$

Antebrachium circumferences (Figure 46) were significantly greater for female red kangaroos but not significantly different between males when the same sexes of grey and red kangaroo were compared. Between sexes within species, antebrachium circumferences were significantly greater for males.

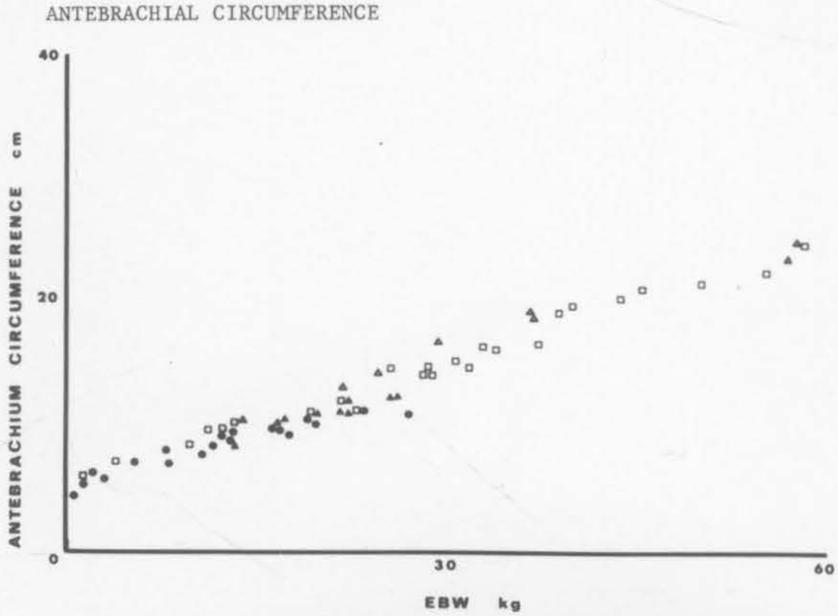

Figure 46 Relationship of antebrachial circumference to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .672 + .259 \log X$
$n = 19$ $r = .973$ SE $k = .015$ P ***

☐ Male Grey Kangaroo $\log Y = .590 + .411 \log X$
$n = 25$ $r = .945$ SE $k = .030$ P ***

▲ Female Red Kangaroo $\log Y = .374 + .514 \log X$
$n = 9$ $r = .957$ SE $k = .059$ P ***

▲ Male Red Kangaroo $\log Y = .351 + .591 \log X$
$n = 8$ $r = .996$ SE $k = .023$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	–
Female Red/Male Red	NS	***
Female Grey/Female Red	**	–
Male Grey/Male Red	NS	NS

Antebrachium weights (Figure 47) were significantly greater for female red kangaroos but not significantly different between males when the same sexes of grey and red kangaroo were compared. Between sexes within species, antebrachium weights were significantly greater for males.

ANTEBRACHIAL WEIGHT

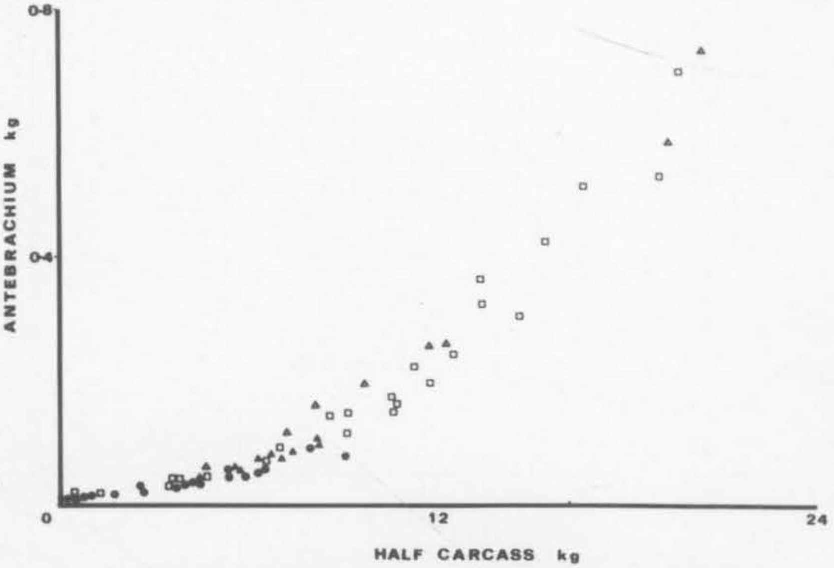

Figure 47 Relationship of antebrachial weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.851 + .726 \log X$
$n = 19$ $r = .982$ SE $k = .033$ P ***

□ Male Grey Kangaroo $\log Y = -1.930 + 1.182 \log X$
$n = 25$ $r = .944$ SE $k = .086$ P ***

▲ Female Red Kangaroo $\log Y = -2.274 + 1.394 \log X$
$n = 9$ $r = .980$ SE $k = .106$ P ***

△ Male Red Kangaroo $\log Y = -2.326 + 1.642 \log X$
$n = 8$ $r = .996$ SE $k = .058$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	NS	***
Female Grey/Female Red	**	-
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (10.3kg, 0.1kg)
SE $X_e = 0.7$ SE $Y_e = 0.03$

Estimated slopes $b1 = 0.02$ $b2 = 0.05$
SE $b1 = 0.003$ SE $b2 = 0.003$

Manus weights (Figure 48) were significantly different between females but not significantly different between males, when the same sexes of grey and red kangaroo were compared. Between sexes within species, the manus weights were significantly greater for males.

MANUS

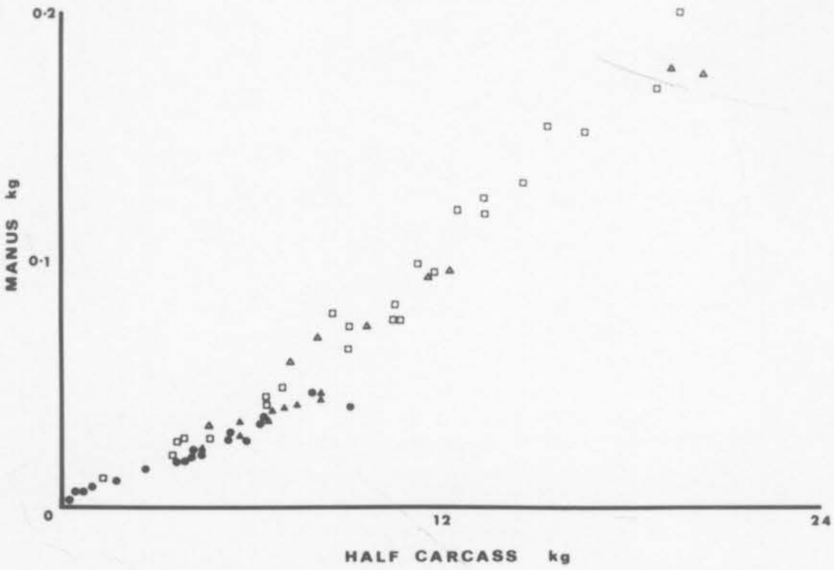

Figure 48 Relationship of manus weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -2.097 + .734 \log X$
$n = 19$ $r = .989$ SE $k = .027$ P ***

◻ Male Grey Kangaroo $\log Y = -2.112 + 1.020 \log X$
$n = 25$ $r = .981$ SE $k = .042$ P ***

▲ Female Red Kangaroo $\log Y = -2.314 + 1.064 \log X$
$n = 9$ $r = .967$ SE $k = .106$ P ***

△ Male Red Kangaroo $\log Y = -2.228 + 1.132 \log X$
$n = 8$ $r = .995$ SE $k = .045$ P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	NS	***
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (6.4kg, .04kg)
SE $X_e = 1.6$ SE $Y_e = .02$

Estimated slopes $b1 = .01$ $b2 = .01$
SE $b1 = .001$ SE $b2 = .001$

Crus lengths (Figure 49) were significantly greater for female red kangaroos but were not significantly different between males, when the same sexes of grey and red kangaroo were compared. Between sexes within species, the crus lengths were not significantly different.

CRUS LENGTH

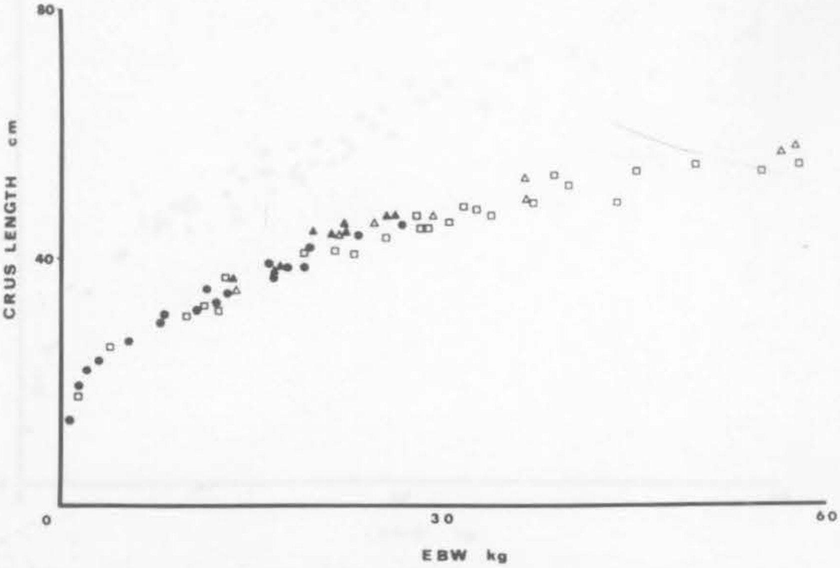

Figure 49 Relationship of crus length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = 1.207 + .304 \log X$	
	$n = 19$ $r = .991$ SE $k = .010$	P ***
◘ Male Grey Kangaroo	$\log Y = 1.194 + .314 \log X$	
	$n = 25$ $r = .990$ SE $k = .010$	P ***
▲ Female Red Kangaroo	$\log Y = 1.081 + .418 \log X$	
	$n = 9$ $r = .952$ SE $k = .051$	P ***
△ Male Red Kangaroo	$\log Y = 1.185 + .329 \log X$	
	$n = 8$ $r = .981$ SE $k = .027$	P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change	(X_e, Y_e) (2.6kg, 24.6cm) SE $X_e = 0.4$ SE $Y_e = 0.8$
Estimated slopes	$b1 = 5.46$ $b2 = 0.91$ SE $b1 = 1.20$ SE $b2 = 0.05$

B. Male

Estimated point of change	(X_e, Y_e) (6.0kg, 32.2cm) SE $X_e = 1.9$ SE $Y_e = 1.6$
Estimated slopes	$b1 = 3.16$ $b2 = 0.51$ SE $b1 = 1.37$ SE $b2 = 0.04$

Crus circumferences (Figure 50) were significantly greater for both sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, crus circumferences were significantly different.

CRUS CIRCUMFERENCE

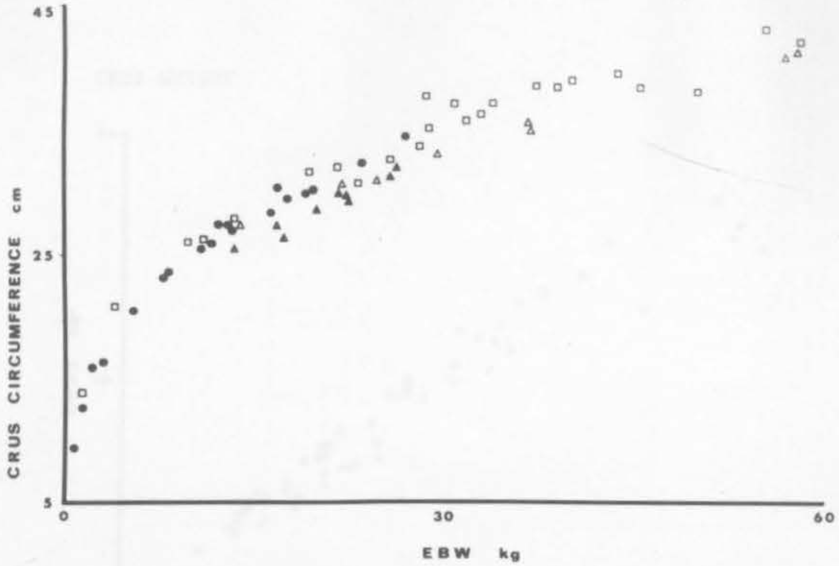

Figure 50 Relationship of crus circumference to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.046 + .346 \log X$
$n = 19$ $r = .996$ SE $k = .008$ P ***

◻ Male Grey Kangaroo $\log Y = 1.117 + .292 \log X$
$n = 25$ $r = .989$ SE $k = .009$ P ***

▲ Female Red Kangaroo $\log Y = 1.010 + .345 \log X$
$n = 9$ $r = .971$ SE $k = .032$ P ***

△ Male Red Kangaroo $\log Y = 1.098 + .289 \log X$
$n = 8$ $r = .994$ SE $k = .013$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	–
Female Red/Male Red	NS	*
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	***

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (4.4kg, 21.5cm)
SE $X_e = 0.5$ SE $Y_e = 0.6$

Estimated slopes $b1 = 3.16$ $b2 = 0.60$
SE $b1 = 0.50$ SE $b2 = 0.04$

B. Male

Estimated point of change (X_e, Y_e) (5.9kg, 26.3cm)
SE $X_e = 1.3$ SE $Y_e = 1.0$

Estimated slopes $b1 = 2.80$ $b2 = 0.34$
SE $b1 = 0.94$ SE $b2 = 0.03$

Crus weights (Figure 51) were significantly greater for both sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, the crus weights were not significantly different.

CRUS WEIGHT

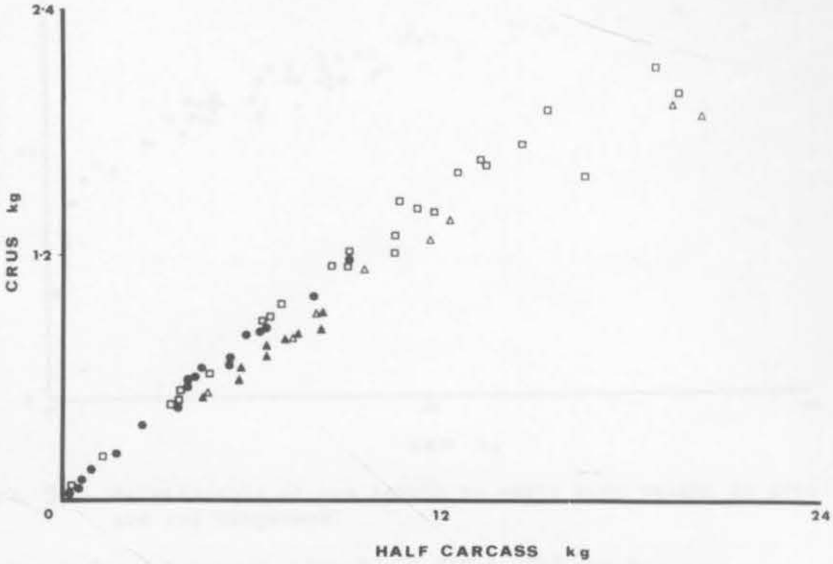

Figure 51 Relationship of crus weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.811 + .917 \log X$
$n = 19$ $r = .999$ SE $k = .011$ P ***

◻ Male Grey Kangaroo $\log Y = -.788 + .882 \log X$
$n = 25$ $r = .996$ SE $k = .016$ P ***

▲ Female Red Kangaroo $\log Y = -.892 + .918 \log X$
$n = 9$ $r = .970$ SE $k = .086$ P ***

△ Male Red Kangaroo $\log Y = -.849 + .884 \log X$
$n = 8$ $r = .994$ SE $k = .041$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	***

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (9.9kg, 1.3kg)
SE $X_e = 1.8$ SE $Y_e = 0.2$

Estimated slopes $b1 = 0.13$ $b2 = 0.08$
SE $b1 = 0.01$ SE $b2 = 0.01$

Pes lengths (Figure 52) were significantly greater for female grey kangaroos but not significantly different between males, when the same sexes of grey and red kangaroos were compared. Between sexes within species, pes lengths were significantly greater for males.

PES LENGTH

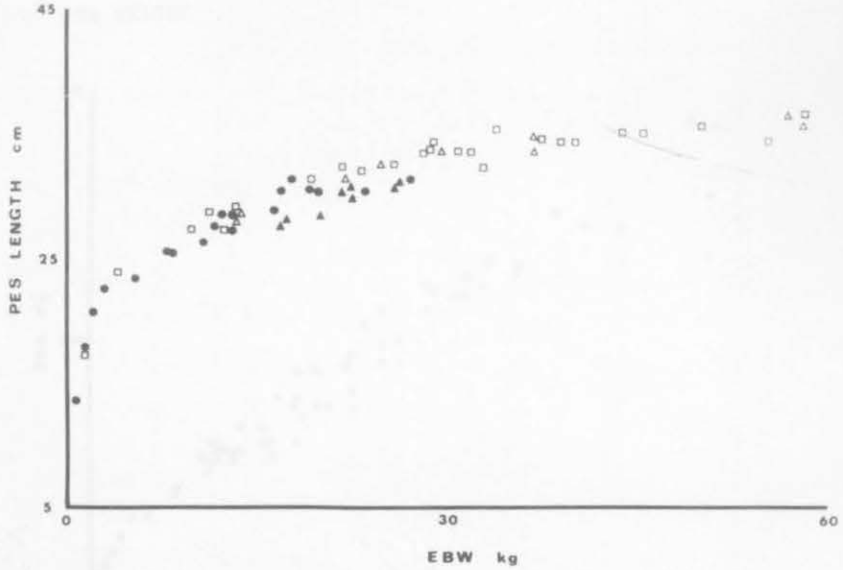

Figure 52 Relationship of pes length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.210 + .213 \log X$
$n = 19$ $r = .977$ SE $k = .011$ P ***

☐ Male Grey Kangaroo $\log Y = 1.253 + .181 \log X$
$n = 25$ $r = .978$ SE $k = .008$ P ***

▲ Female Red Kangaroo $\log Y = 1.224 + .186 \log X$
$n = 9$ $r = .868$ SE $k = .040$ P **

△ Male Red Kangaroo $\log Y = 1.290 + .154 \log X$
$n = 8$ $r = .969$ SE $k = .016$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	*	–
Female Red/Male Red	NS	**
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (2.8kg, 23.5cm)
SE $X_e = 0.4$ SE $Y_e = 0.6$

Estimated slopes $b1 = 4.78$ $b2 = 0.39$
SE $b1 = 1.05$ SE $b2 = 0.04$

B. Male

Estimated point of change (X_e, Y_e) (6.0kg, 28.7cm)
SE $X_e = 1.2$ SE $Y_e = 0.6$

Estimated slopes $b1 = 2.36$ $b2 = 0.17$
SE $b1 = 0.71$ SE $b2 = 0.02$

Pes weights (Figure 53) were significantly greater for both sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, pes weights were significantly greater for males.

PES WEIGHT

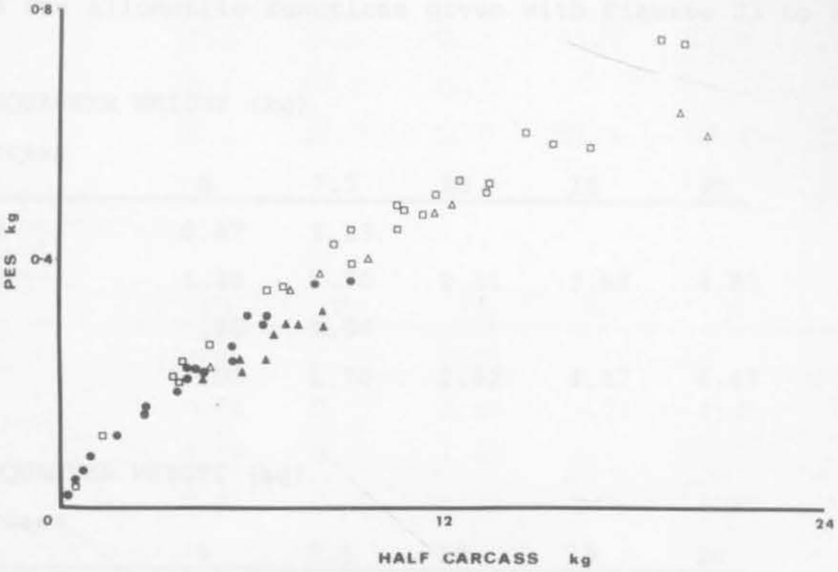

Figure 53 Relationship of pes weight to half carcass weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = -1.124 + .746 \log X$ $n = 19$ $r = .996$ SE $k = .016$	P ***
□ Male Grey Kangaroo	$\log Y = -1.071 + .717 \log X$ $n = 25$ $r = .992$ SE $k = .019$	P ***
▲ Female Red Kangaroo	$\log Y = -1.137 + .677 \log X$ $n = 9$ $r = .913$ SE $k = .114$	P ***
△ Male Red Kangaroo	$\log Y = -1.054 + .665 \log X$ $n = 8$ $r = .983$ SE $k = .051$	P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	**
Female Red/Male Red	NS	***
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	*

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (3.0kg, 0.2kg)

SE $X_e = 1.65$ SE $Y_e = 0.04$

Estimated slopes $b1 = 0.08$ $b2 = 0.03$

SE $b1 = 0.04$ SE $b2 = 0.001$

TABLE 5

Predicted regional body values for grey and red kangaroos. Values predicted from the allometric functions given with Figures 23 to 53.

PREDICTED FOREQUARTER WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.87	1.23			
Male Grey	1.10	1.70	2.31	3.55	4.83
Female Red	.96	1.54			
Male Red	.98	1.70	2.52	4.37	6.47

PREDICTED HINDQUARTER WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	4.13	6.31			
Male Grey	3.88	5.78	7.66	11.39	15.09
Female Red	4.02	5.95			
Male Red	4.08	5.78	7.40	10.47	13.40

PREDICTED BODY LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	149.2	163.0	184.5			
Male Grey	147.7	161.0	181.6	197.9	211.5	217.6
Female Red	150.2	166.1	191.4			
Male Red	154.1	166.7	186.1	201.3	213.9	219.5

PREDICTED EAR LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	12.1	13.0	14.3			
Male Grey	11.6	12.2	13.1	13.8	14.4	14.6
Female Red	11.9	13.1	15.0			
Male Red	12.3	12.7	13.3	13.8	14.1	14.3

PREDICTED HEAD LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	18.6	19.8	21.2			
Male Grey	18.7	19.8	21.3	22.9	24.0	24.5
Female Red	18.1	19.9	22.7			
Male Red	18.2	19.3	21.0	22.3	23.4	23.8

PREDICTED HEAD WEIGHT (kg)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	0.61	0.72	0.91			
Male Grey	0.64	0.77	1.01	1.21	1.40	1.49
Female Red	0.70	0.93	1.39			
Male Red	0.71	0.86	1.12	1.36	1.57	1.67

PREDICTED CERVICAL VERTEBRAL LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	11.8	13.1	15.2			
Male Grey	11.3	12.5	14.4	15.9	17.2	17.8
Female Red	9.9	11.1	13.2			
Male Red	9.6	10.8	12.8	14.4	15.8	16.5

PREDICTED NECK WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.10	0.14			
Male Grey	0.13	0.19	0.24	0.35	0.46
Female Red	0.11	0.15			
Male Red	0.11	0.17	0.23	0.36	0.48

PREDICTED CHEST CIRCUMFERENCE (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	50.1	55.8	64.9			
Male Grey	49.0	54.5	63.3	70.4	76.5	79.2
Female Red	46.6	52.5	62.3			
Male Red	48.7	53.4	61.0	66.9	72.0	74.2

PREDICTED CHEST DEPTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	11.0	12.1	13.9			
Male Grey	11.4	12.5	14.2	15.6	16.7	17.3
Female Red	12.3	13.8	16.2			
Male Red	12.2	13.6	15.7	17.4	18.9	19.5

PREDICTED THORACIC VERTEBRAL LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	24.3	26.6	30.3			
Male Grey	23.4	25.6	29.0	31.7	33.9	34.9
Female Red	24.6	26.8	30.2			
Male Red	25.2	27.1	30.1	32.4	34.3	35.1

PREDICTED THORAX WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.55	0.79			
Male Grey	0.62	0.95	1.28	1.94	2.62
Female Red	0.60	0.95			
Male Red	0.58	0.96	1.36	2.24	3.19

PREDICTED LUMBAR VERTEBRAL LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	17.8	19.6	22.6			
Male Grey	17.2	19.1	22.0	24.4	26.4	27.3
Female Red	19.0	21.0	24.1			
Male Red	18.3	20.0	22.6	24.7	26.5	27.3

PREDICTED LUMBAR WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.48	0.73			
Male Grey	0.44	0.66	0.87	1.31	1.73
Female Red	0.55	0.73			
Male Red	0.50	0.71	0.92	1.31	1.68

PREDICTED ABDOMINAL WALL MUSCLE WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.22	0.37			
Male Grey	0.20	0.32	0.44	0.71	0.98
Female Red	0.26	0.43			
Male Red	0.23	0.35	0.47	0.71	0.96

PREDICTED PELVIC WIDTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	16.7	19.4	24.0			
Male Grey	15.4	17.4	20.8	23.6	26.1	27.2
Female Red	17.5	18.8	20.8			
Male Red	18.0	19.3	21.3	22.8	24.1	24.6

PREDICTED BUTT WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	2.52	3.96			
Male Grey	2.27	3.45	4.63	7.03	9.44
Female Red	2.42	3.69			
Male Red	2.47	3.50	4.48	6.35	8.13

PREDICTED TAIL LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	68.2	75.1	86.2			
Male Grey	65.6	71.8	81.6	89.4	95.9	98.8
Female Red	69.2	75.7	86.0			
Male Red	69.6	75.3	84.2	91.1	96.9	99.5

PREDICTED TAIL CIRCUMFERENCE (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	22.8	25.5	29.8			
Male Grey	22.6	25.5	30.3	34.3	37.6	39.2
Female Red	25.3	28.7	34.5			
Male Red	27.2	30.0	34.4	37.9	40.8	42.1

PREDICTED DRESSED TAIL WEIGHT (kg)

at Dressed Carcass Weight (kg)	8	12	16	20	30	40
Female Grey	0.63	0.95	1.28			
Male Grey	0.66	1.04	1.44	1.86	2.94	4.07
Female Red	0.71	1.15	1.62			
Male Red	0.80	1.24	1.69	2.15	3.32	4.52

PREDICTED OMOBRACHIUM WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.14	0.20			
Male Grey	0.22	0.36	0.51	0.82	1.16
Female Red	0.17	0.28			
Male Red	0.18	0.37	0.61	1.24	2.05

PREDICTED ANTEBRACHIUM LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	17.1	18.6	21.0			
Male Grey	18.4	20.4	23.8	26.5	28.8	29.8
Female Red	18.2	21.5	27.3			
Male Red	17.6	20.3	24.8	28.6	31.9	33.5

PREDICTED ANTEBRACHIUM CIRCUMFERENCE (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	9.5	10.2	11.3			
Male Grey	11.8	13.3	15.7	17.7	19.4	20.2
Female Red	9.5	11.0	13.6			
Male Red	11.1	13.2	16.7	19.9	22.7	24.0

PREDICTED ANTEBRACHIUM WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.05	0.06			
Male Grey	0.08	0.13	0.18	0.29	0.41
Female Red	0.05	0.09			
Male Red	0.07	0.13	0.21	0.40	0.65

PREDICTED MANUS WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.03	0.04			
Male Grey	0.04	0.06	0.08	0.12	0.16
Female Red	0.03	0.04			
Male Red	0.04	0.06	0.08	0.13	0.18

PREDICTED CRUS LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	36.7	40.0	45.3			
Male Grey	36.6	40.0	45.5	49.8	53.4	55.0
Female Red	37.4	42.2	49.9			
Male Red	37.3	41.0	46.9	51.5	55.5	57.2

PREDICTED CRUS CIRCUMFERENCE (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	28.4	31.3	36.1			
Male Grey	28.9	31.4	35.3	38.4	41.0	42.2
Female Red	26.0	28.8	33.1			
Male Red	27.4	29.8	33.5	36.4	38.8	39.9

PREDICTED CRUS WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.68	0.98			
Male Grey	0.67	0.96	1.24	1.78	2.29
Female Red	0.56	0.82			
Male Red	0.59	0.84	1.08	1.55	2.00

PREDICTED FOOT LENGTH (cm)

at Empty Body Weight (kg)	15	20	30	40	50	55
Female Grey	28.9	30.7	33.5			
Male Grey	29.2	30.8	33.1	34.9	36.4	37.0
Female Red	27.7	29.2	31.5			
Male Red	29.6	30.9	32.9	34.4	35.6	36.1

PREDICTED FOOT WEIGHT (kg)

at Half Carcass Weight (kg)	5	7.5	10	15	20
Female Grey	0.25	0.34			
Male Grey	0.27	0.36	0.44	0.59	0.73
Female Red	0.22	0.29			
Male Red	0.26	0.34	0.41	0.53	0.65

TABLE 6

Comparisons between the relative proportions of the various body regions of grey kangaroos (*Macropus giganteus*), red kangaroos (*Megaleia rufa*), Wallaroos (*Macropus robustus*), red neck wallabies (*Macropus rufogriseus*) and swamp wallabies (*Wallabia bicolour*). Comparisons relative to the grey kangaroo = 100 and based on mature animals.

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Forequarter weight % Half Carcass Weight	Female	100	121	99	98	108
	Male	100	106	86		
Hindquarter Weight % Half Carcass Weight	Female	100	95	101	100	96
	Male	100	96	108		
Forequarter Weight % Hindquarter Weight	Female	100	127	98	98	112
	Male	100	111	79		
Body length on Empty Body Weight	Female	100	99	173	177	133
	Male	100	100	242		
Ear length on Empty Body Weight	Female	100	112	145	176	133
	Male	100	97	210		
Head length on Empty Body Weight	Female	100	104	171		156
	Male	100	95	236		
Head Weight % Empty Body Weight	Female	100	118	111	76	120
	Male	100	110	121		

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Cervical Vertebral Length on Empty Body Weight	Female	100	87		134	116
	Male	100	90	173		
Neck Weight % Half Carcass Weight	Female	100	127	51	88	107
	Male	100	98	72		
Chest Circumference on Empty Body Weight	Female	100	97	166	174	138
	Male	100	94	245		
Chest Depth on Empty Body Weight	Female	100	110	144	142	122
	Male	100	113	234		
Thoracic Vertebral Length on Empty Body Weight	Female	100	95	172	164	126
	Male	100	102	245		
Thorax Weight % Half Carcass Weight	Female	100	119	98	106	104
	Male	100	106	98		
Lumbar Vertebral Length on Empty Body Weight	Female	100	102	174	169	131
	Male	100	106	254		
Loin Weight % Half Carcass Weight	Female	100	93	104	107	104
	Male	100	108	120		
Abdominal Wall Muscle Weight % Half Carcass Weight	Female	100	109	125	121	113
	Male	100	108	114		

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Pelvic Width on Empty Body Weight	Female	100	99	176	175	131
	Male	100	91	235		
Butt Weight % Half Carcass Weight	Female	100	98	96	98	97
	Male	100	95	104		
Tail length on Empty Body Weight	Female	100	101	202	206	135
	Male	100	103	268		
Tail Circumference on Empty Body Weight	Female	100	111	151	154	119
	Male	100	112	200		
Dressed Tail Weight % Dressed Carcass Weight	Female	100	128	95	95	91
	Male	100	107	74		
Omobrachium Weight % Half Carcass Weight	Female	100	121	135	88	119
	Male	100	115	76		
Antebrachium Length on Empty Body Weight	Female	100	114	138	144	120
	Male	100	107	172		
Antebrachium Circumference on Empty Body Weight	Female	100	109	191	149	144
	Male	100	102	226		
Antebrachium Weight % Half Carcass Weight	Female	100	124	98	72	107
	Male	100	104	76		

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Manus Weight % Half Carcass Weight	Female	100	106	102	71	113
	Male	100	93	77		
Crus Length on Empty Body Weight	Female	100	102	133	144	124
	Male	100	104	173		
Crus Circumference on Empty Body Weight	Female	100	92	152	153	120
	Male	100	96	197		
Crus Weight % Half Carcass Weight	Female	100	84	85	81	82
	Male	100	90	89		
Foot Length on Empty Body Weight	Female	100	96	149	161	128
	Male	100	100	224		
Foot Weight % Half Carcass Weight	Female	100	86	101	85	95
	Male	100	92	121		

TABLE 7

Regional growth impetus patterns in the grey kangaroo. Estimated empty body weights at which growth impetus changes occur and the direction of the change (increase in impetus = +, decrease in impetus = -).

FEMALE

Regional Measurement	Empty Body Weight X_e kg	SE X_e	Direction of change
Antebrachium length	1.4	0.7	-
Crus length	2.6	0.4	-
Pes length	2.8	0.4	-
Ear length	3.2	0.4	-
Tail length	3.8	0.6	-
Head length	3.9	1.4	-
Lumbar vertebral length	4.0	0.9	-
Crus circumference	4.4	0.5	-
Chest depth	4.6	5.9	-
Chest circumference	5.8	1.1	-
Cervical vertebral length	6.3	1.2	-
Pelvic width	6.9	1.2	-
Tail circumference	9.3	1.2	-
Thoracic vertebral length	12.4	0.4	-

TABLE 7 (CONT.)

MALE

Regional Measurement	Empty Body Weight X_e kg	SE X_e	Half-Carcass Weight X_e kg	SE X_e	Direction of change
Antebrachium length	2.3	9.7	...	...	-
Crus circumference	5.9	1.3	...	...	-
Pes length	6.0	1.2	...	...	-
Crus length	6.0	1.9	...	...	-
Ear length	6.4	1.8	...	...	-
Body length	6.7	2.8	...	...	-
Head length	7.1	2.8	...	...	-
Lumbar vertebral length	7.6	2.4	...	...	-
Cervical vertebral length	7.7	3.6	...	...	-
Tail length	7.8	3.5	...	...	-
Pelvic width	9.9	0.2	...	...	-
Chest circumference	14.4	1.6	...	...	-
Thoracic vertebral length	14.6	1.8	...	...	-
Chest depth	17.5	4.1	...	...	-
Tail circumference	17.8	3.4	...	...	-
Pes weight	*9.2	...	3.0	1.7	-

TABLE 7 (CONT.)

MALE

Regional Measurement	Empty Body Weight X_e kg	SE X_e	Half-Carcass Weight X_e kg	SE X_e	Direction of change
Head weight	*13.7	6.8	...	...	–
Crus weight	*29.7	...	9.9	1.8	–
Loin weight	*33.5	...	11.2	0.3	–
Hindquarter weight	*35.0	...	11.8	0.3	–
Butt weight	*36.4	...	12.3	0.9	–
Manus weight	*19.4	...	6.4	1.6	+
Antebrachium weight	*30.6	...	10.3	0.7	+
Omobrachium weight	*31.1	...	10.4	0.8	+
Forequarter weight	*32.7	...	11.0	0.6	+
Thorax weight	*34.7	...	11.7	1.1	+

* Empty body weight predicted from log EBW = log a + k log half carcass weight

= .501 + .975 log half carcass weight

$n = 25$ $r = .998$ SE k ± 0.013

The remaining relationships investigated were significantly different with those relationships developed between forequarter tissues being greater in the red kangaroo and those for hindquarter tissues being greater in the grey kangaroo.

Female Grey Kangaroos.

Monophasic growth patterns were found for head weight and antebrachium circumference on empty body weight; and forequarter weight, neck weight, thorax weight, loin weight, butt weight, omobrachium weight, antebrachium weight, manus weight and crus weight on half-carcass dressed weight; and for dressed tail weight on dressed carcass weight.

Biphasic growth patterns were evident in the remaining relationships studied. No triphasic growth patterns were found. Females were studied in the empty body weight range 1 to 30 kg. From the data presented in Figure 13 correlating age to weight, and assuming this data is an adequate sample of the population, it is unlikely that female grey kangaroos, apart from exceptional individuals, exceed 30 kg empty body weight. Triphasic growth patterns may have been found, however, if animals less than 1 kg empty body weight were to have been included in the study.

All the linear measurements made on the various body regions, exhibiting biphasic growth, were characterized by a decrease in growth impetus during the second growth phase. The earliest maturing linear measure relationship was antebrachial length. A ten-fold decrease in growth impetus occurred at 1.4 (±0.7) kg empty body weight. In the hindlimb, growth impetus decreased in pes length, crus length and crus circumference at 2.8 (±0.4), 2.6 (±0.4) and 4.4 (±0.5) kg empty body weight respectively. Along the body axis, growth impetus decreased in ear length, head length and cervical vertebral length at 3.2 (±0.4), 3.9 (±1.4) and 6.3 (±1.2) kg empty body weight respectively. In a caudo-cranial direction, growth impetus decreased in tail length and lumbar vertebral length at 3.8 (±0.6) and 4.0 (±0.9) kg empty body weight respectively. The latest maturing linear measure relationship on the body axis was thoracic vertebral length, where growth impetus decrease did not occur till 12.4 (±0.4) kg empty body weight.

The weight of body regions was characterized by monophasic growth patterns.

Male Grey Kangaroos.

Monophasic growth patterns were less common among males than females. The relationships of neck weight and abdominal wall muscle weight on half carcass weight; and antebrachium circumference on empty body weight were monophasic in growth pattern.

Biphasic growth patterns were evident in the remaining relationships investigated. In the empty body weight range of the study, 1 - 60 kg, no triphasic growth patterns were found. Triphasic growth patterns may have been encountered if animals less than 1 kg or greater than 60 kg were included in the study.

Similarly to the females, all linear measurements made on various body regions exhibiting biphasic growth, were characterized by a decrease in growth impetus during the second growth phase. The earliest maturing linear measure relationship was antebrachial length. A five-fold decrease in growth impetus occurred at 2.3 (±9.7) kg empty body weight. In the hindlimb, pes length, crus length and crus circumference showed growth impetus decrease at 6.0 (±1.2), 6.0 (±1.9) and 5.9 (±1.3) kg empty body weight respectively. Along the body axis, growth impetus decreased in ear length, head length and cervical vertebral length at 6.4 (±1.8), 7.1 (±2.8) and 7.7 (±3.6) kg empty body weight respectively. In a caudo-cranial direction, growth impetus decreased in tail length and lumbar vertebral length at 7.8 (±3.5) and 7.6 (±2.4) kg empty body weight respectively. The latest maturing linear measure relationship on the body axis was thoracic vertebral length, where growth impetus decrease did not occur till 14.6 (±1.8) kg empty body weight.

Regional body weights were characterized by a biphasic growth pattern in which the second growth phase was an impetus increase in the forequarter regions and an impetus decrease in the hindquarter regions. In the forelimb, growth impetus increase occurred in the manus weight, antebrachium weight, omobrachium weight and thorax weight at 19.4, 30.6, 31.1 and 34.7 kg empty body weight respectively. In the hindlimb, growth impetus decrease occurred in the pes weight, crus weight and butt weight at 9.2, 29.7 and 36.4 kg empty body weight respectively. The forequarter as a whole, showed growth impetus increase at 32.7 kg empty body weight and the hindquarter showed growth impetus decrease at 35.0 kg empty body weight.

Species Differences.

The species differences discussed are based on female animals and are extracted from Table 6.

Forequarter development is least emphasized in the red neck wallaby, followed by the swamp wallaby, grey kangaroo, wallaroo and most developed in the red kangaroo. Hindquarter development is least emphasized in the red kangaroo and wallaroo.

Hindquarter development in the grey kangaroo, red neck wallaby and swamp wallaby is approximately the same on a proportionate basis.

When the five species were compared on a body weight basis, the wallabies consistently had relatively greater linear measurements than the grey and red kangaroo.

An attempt to classify the red neck wallaby and swamp wallaby as resembling the grey or red kangaroo in regional body composition, was not successful. In many characteristics, the proportions of the wallaroo resembled the red kangaroo.

DISCUSSION.

Grey Kangaroo Growth Patterns

The form of the newly born kangaroo bears little resemblance to that of the adult. Figure 1 is a photograph taken of a newly born kangaroo. This specimen was prepared by the alizarin bone stain technique described by Culling (1974) and demonstrates the striking development of the head and forelimbs, with the comparatively poor development of hindlimbs and tail in the newly born kangaroo.

Specimen F102, a female grey kangaroo of 791g empty body weight was the smallest specimen fully dissected for this study. Figure 54 is an approximate form outline for this animal.

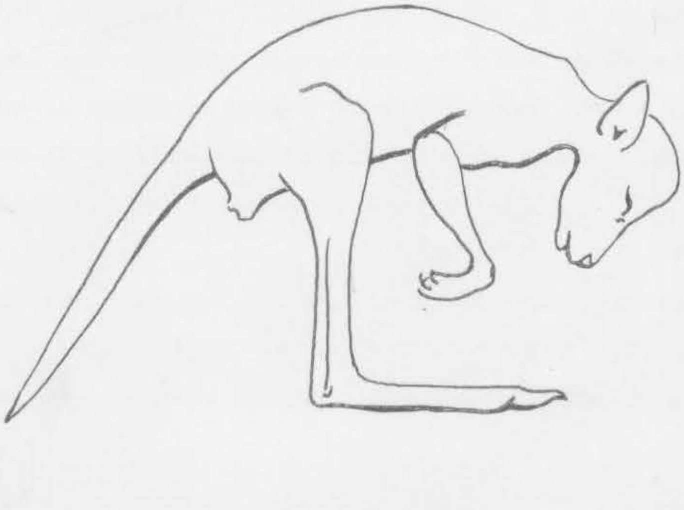

Figure 54. Outline sketch of the body form of specimen F102.

Comparison of Figure 1 and Figure 54 is a basis for speculation that a large number of growth impetus changes have occurred in the body weight range below the lower body weight limit of this study. Although Sharman et al (1964) and Kirkpatrick (1964a) have studied the growth of the pouch young of the kangaroo, their studies have been biased towards methods of estimating the age of pouch young. An interesting extension of this present study would be to carry out a quantitative anatomical study on pouch young from birth to 1 kg empty body weight.

Early development of the young kangaroo is a striking example of development preceeding functional requirement. Frith and Calaby (1969) described the birth and migration of the kangaroo foetus to and attachment within the pouch. Uterine development as is evident from Figure 1, has emphasized those structures necessary for the migration to the teat. The young kangaroo, having gained the teat, exhibits a shift in growth impetus to the hindlimbs and tail. Both these stages in development are independent of concurrent functional demand.

(1) Female Grey Kangaroos

The overall picture is of an animal changing from one body form (Figure 1) to a radically different one (Figure 54). Without exception, linear body measurements taken on female animals were found to follow an early maturing growth pattern (b1 > b2). With the exception of thoracic vertebral length, growth impetus decrease was distributed around 4 kg empty body weight.

Regional body weight measurements were characterized by monophasic growth patterns. Thus the body form of the older female pouch young tended to approximate the mature adult female form.

(II) Male Grey Kangaroos

The overall growth picture is that of an animal changing from one form to another, as in the female, but with a secondary reproportioning of the body weight within the conformation of the second form. The linear body measurements underwent decrease in growth impetus around 6 - 7 kg empty body weight, with the exception of antebrachial length, which was earlier maturing and thoracic vertebral length, which was later maturing. Growth impetus reproportioning of the body weight occurred, with exceptions, in the empty body weight range of 30 - 35 kg.

Examination of the allometric 'k' values produced eight relationships with 'k' values significantly greater than 1. The 'k' values for manus weight, antebrachium weight, omobrachium weight, thorax weight and forequarter weight on half-carcass weight were 1.020 (±0.042), 1.182 (±0.086), 1.194 (±0.073), 1.037 (±0.029) and 1.066 (±0.042). Dressed tail weight on carcass weight was 'k' 1.131 (±0.017). The abdominal wall muscle weight on half carcass weight with 'k' 1.145 (±0.019) probably reflected the increase in growth of gut weight in change from milk to herbivorous diet at weaning. The 'k' value greater than 1 for butt weight on half carcass weight (Figure 40) is difficult to explain, especially after visual examination of the data plot.

The grouping of 'k' values greater than 1 in the forequarter and tail is consistent with the late maturing picture (b2 > b1) for these areas given by the two phase linear regression. All the 'k' values for linear measure relationships were less than 1, again consistent with an overall picture of early maturity in conformation or bone length growth.

Centripetal and Cranio-Caudal Growth Theories

In females, centripetal growth patterns could not be demonstrated from the linear measurements taken. In the hindlimb, both the pes length and crus length exhibited growth impetus decrease at approximately the same empty body weight and in the forelimb, only one linear measurement exhibiting biphasic growth, was taken. Growth impetus patterns were demonstrated for linear measurements taken along the body axis. The thoracic vertebral length was the latest axial linear measurement to show growth impetus decrease. Head length and tail length underwent impetus decrease at 3.9 (±1.4) and 3.8 (±0.6) kg empty body weight respectively. An indistinct, yet demonstrable wave of growth impetus decrease appears to spread from head and tail along the vertebral column to end in the thoracic region.

If the tail were to be classed as a limb, then its growth impetus pattern could be termed centripetal. In fact, *Dorcopsulus macleayi* uses its tail like an extra limb. If the tail were to be considered part of the vertebral column, which in reality it is, then clearly a cranio-caudal growth pattern does not exist. Rather, two waves of growth occur in the macropod vertebral column, a cranio-thoracic and a caudo-thoracic wave of growth impetus decrease.

Body weight measurements in females exhibited monophasic growth and no growth impetus patterns could be demonstrated in the empty body weight range studied.

In males, centripetal growth patterns could not be demonstrated from the linear measurements taken. In the hindlimb, both the pes length and crus length exhibited growth impetus decrease at the same empty body weight. In the forelimb, only one linear measurement exhibiting biphasic growth was taken. Centripetal growth patterns however, were well established from measurements of regional body weights. In the hindlimb, a wave of decreasing growth impetus began in the pes at 9.2 kg and reached the butt by 36.4 kg empty body weight. In the forelimb, a wave of growth impetus increase began in the manus at 19.4 kg and reached the thorax by 34.7 kg empty body weight. In the male eastern grey kangaroo, a theory of centripetal growth force is found to hold irrespective of whether the force is one of positive or negative growth impetus.

Linear measurements along the body axis follow a similar pattern to that observed in females. The thoracic vertebral length is the last region to undergo growth impetus decrease at 14.6 (±1.8) kg empty body weight. A clear gradient of growth impetus decrease in a cranio-thoracic and caudo-thoracic direction is not demonstrable due to overlap in the standard errors for the body weights at which the growth impetus is estimated to change. Weight measurements along the trunk were consistent with the thorax, being the latest maturing region of the trunk. Whereas the head and lumbar weights were undergoing growth impetus decrease at 13.7 (±6.8) and 33.5 kg respectively, the thorax weight exhibited growth impetus increase at 34.7 kg empty body weight.

Points of biological interest may be found in the growth patterns discussed. Body form is seen to be early maturing (females around 4 kg empty body weight, males around 6 kg empty body weight). It would appear that pouch growth involves the change from one body form (the newly born form) to another quite different one (adult form) and that the change occurs predominantly before the end of pouch life. A second major change is evident in males only, and around 30 - 35 kg empty body weight. This change involves a redistribution of the body weight, without phasic growth changes in the regional length measurements. This reallocation of body proportions is associated with the onset of sexual maturity in the male.

Where biphasic growth occurred in the same relationship for both females and males, without exception, the males were found to be later maturing.

The startling differences in body form of female and male grey kangaroos are no more than would be expected from the differences present in the growth impetus patterns of their component tissues.

CHAPTER 5

MUSCLE GROWTH PATTERNS

"Development preceeds function."

Anon.

".... the most important factor in determining the differential increase or decrease of weight of muscles during changes of body weight is their functional significance at the time."

M. Bryden (1967)

".... all cattle have a basically similar muscle weight distribution ....."

R.M. Butterfield (1963)

".... changes which are observed in muscle weights are quite independent of age and are highly total muscle weight dependent."

Berg and Butterfield (1976)

GENERAL INTRODUCTION.

Muscle is that tissue of the body which is responsible for movement. Detailed reviews of the microscopic and ultrastructure of muscle can be found in the texts of Ham and Leeson (1961), Bloom and Fawcett (1962) and Le Gros Clark (1965). The development of the different histochemical types of muscle fibres has been discussed by Ashmore *et al* (1972) in pigs, lambs and calves, Davies (1972) in pigs and Suzuki (1973) in sheep.

Descriptions of the gross structure of skeletal muscle have been given in the texts of Cunningham (1931), Sisson and Grossman (1953), and Miller, Christensen and Evans (1964). A description of the carcass and tail musculature of the grey kangaroo (*Macropus giganteus*) is given in Appendix I.

The concept of relative growth has been established in Chapter 4. Specific studies of a quantitative nature on the growth and development of skeletal muscle may be obtained from the following references. In cattle, Hammond (1920), Walker (1961), Butterfield (1962; 1963a, b; 1965a; 1966b), Tulloh (1963a; 1964), Yeates (1964), Ledger (1965, 1966), Butterfield and Berg (1966a, b; 1972), Butterfield, Pryor and Berg (1966), Harte (1967, 1968), Butterfield and Johnson (1968, 1971), Berg and Butterfield (1968, 1976), Mukhoty (1969, 1971), Suess, Tyler and Brungardt (1969), Berg and Mukhoty (1970) and Brännäng (1971). In sheep, Hammond (1921, 1932, 1960), Palsson (1939, 1940, 1955), Palsson and Verges (1952), Kirton, Ulyatt and Barton (1959), Fourie (1965), Jackson (1967), Russel and Barton (1967) and Lohse, Moss and Butterfield (1971). In goats, Wilson (1958, 1960), Kirton (1970). In pigs, Hammond (1922), McMeekan (1940, 1941), Cuthbertson and Pomeroy (1962), Lawrie and Gatherum (1964), Doornenbal (1971) and Nielson (1973). In the domestic fowl, Wilson (1952, 1954) and Moss (1967). In wild or feral animals, Ledger (1963, 1968) in East African mammals, Tribe and Peel (1963) in Macropus spp, Ledger and Smith (1964) in the Uganda kob, Sachs and Smith (1967) in wildlife of semi-arid tropical areas, Sachs (1967) in Serengeti game animals, Bryden (1967, 1969a, b, c, 1973)in the Elephant Seal, Charles, Johnson and Butterfield (1970) in the buffalo and Hakonson and Whicker (1971) in the mule deer. In rats and mice, Jackson and Lowry (1912), Kochakian and Stettner (1948), Kochakian, Tillotson and Endahl (1956) and Rowe (1968).

From the literature cited, it is evident that relative growth is a feature of the growth process in the musculature of the quadrapedal domestic animals. McMeekan (1940) found evidence of centripetal and cranio-caudal growth forces occurring in the musculature of the pig. Lohse (1971) stated that centripetal growth "... probably reflects a common quadruped mode of locomotion.....". He noted that in the merino sheep, all muscles within a body region did not necessarily have the same relative growth impetus. Wilson (1958, 1960) found evidence of centripetal growth forces in limb weights of the East African Dwarf Goat. He demonstrated that muscle was later maturing than bone, though earlier maturing than fat. Butterfield (1963a) found evidence of centripetal growth in the limb musculature but not of cranio-caudal growth in spinal musculature of steers slaughtered from birth to maturity. He found that muscles of the abdominal wall made the most rapid post-natal gain of all muscles. Distal limb muscles were relatively more developed at birth and the forelimb musculature was more early maturing than that of the hindlimb. Muscles intrinsic to the neck and thorax and muscles attaching the foreleg to the trunk, were found to be late developing. Fourie (1965) was unable to demonstrate cranio-caudal growth forces in the spinal musculature of the sheep.

In birds and wild animals, growth impetus patterns have been shown to occur in the musculature. Wilson (1952, 1954) in the domestic fowl, demonstrated growth forces acting from the extremities towards the trunk. The muscle of the leg was shown to be early maturing. Bryden (1967) found that, though some signs of centripetal growth may be demonstrated in the Elephant Seal, the development of the musculature is overridingly influenced by the necessity for the pups to adapt to an aquatic environment. He was able to demonstrate that at birth, the forelimb muscle was better developed than that of the hindlimb.

This section of the study investigates the growth and development of the musculature of the kangaroo. Species are compared.

METHODS AND MATERIALS.

The general methods and materials used are described in Chapters 2 and 3.

Investigation of the muscle growth patterns is based on weights recorded from approximately one hundred individual muscles.

RESULTS.

The results are presented in the following format. A figure of the data plot for the relationship of each muscle group to half-carcass muscle, is presented together with the functions fitted to the data. The functions are compared to establish differences, if any, between the two sexes and species of the grey and red kangaroo. In the male grey kangaroo, where a change in growth impetus occurs in the musculature, the estimated point (X_e Y_e) of the change and its magnitude (bl, b2) are given, based on the two phase linear function described by Griffiths and Miller (1973). In conjunction with the mathematical presentation of the relationships of each muscle group to half-carcass muscle, a brief written summary of the differences found between the grey and red kangaroo is presented. Muscle group weights are predicted from the functions fitted to the data and presented in Table 9.

The relationship of individual muscles to half-carcass muscle, together with comparisons between the two sexes and species of the grey and red kangaroo are presented in Table 8. In the male grey kangaroo, where a change in growth impetus occurs in individual muscles relative to half-carcass muscle, the estimated point (X_e Y_e) of the change and its magnitude (bl, b2) are presented in Table 11. The muscle growth impetus patterns for both individual muscles and muscle groups are related to empty body weight and the estimated empty body weights at which growth impetus changes occur, and the direction of the change, are presented in Table 12.

Finally, the relative proportions of the muscle groups for the five species of macropod studied are presented in Table M10.

Symbols used in the text are:-

Y	dependent variable
X	independent variable
X_e, Y_e	estimated point of change in the growth impetus
log	logarithm of
a	allometric function: is the fractional coefficient
k	ratio of the relative growth of Y to X
b, $b1$, $b2$	rates of growth of Y to X
n	number of observations
r	correlation coefficient
SE	standard error
NS	not significant at the 5% level
*	significant at the 5% level
**	significant at the 1% level
***	significant at the 0.1% level

Female Grey Kangaroo

Monophasic growth was the characteristic growth pattern in the musculature of the female grey kangaroo. A triphasic growth pattern was evident in the growth of abdominal wall muscle.

Male Grey Kangaroo

Biphasic growth was the characteristic growth pattern in the musculature of the male grey kangaroo.

In the forequarter, the second growth phase was characterized by an increase in growth rate. Forequarter muscle as a whole, exhibited increased growth rate at 31.8 kg empty body weight. Within the forequarter, growth impetus increase occurred in the distal forelimb muscle, proximal forelimb muscle, thorax-foreleg muscle, neck-foreleg muscle and intrinsic neck and thorax muscle at 28.3, 31.8, 30.2, 51.7

Forequarter muscle weights (Figure 55) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, the forequarter muscle weights were significantly greater for males.

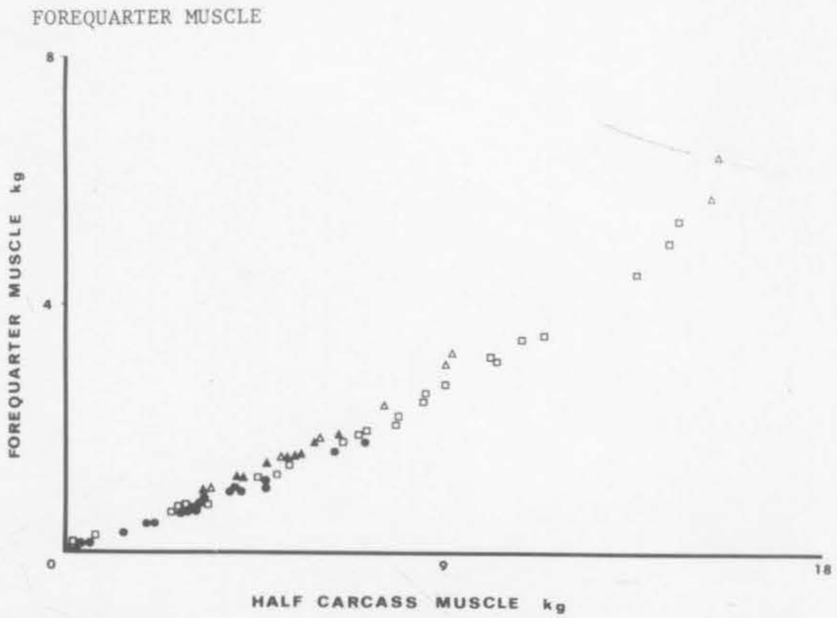

Figure 55 Relationship of forequarter muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.597 + .955 \log X$
$n = 19$ $r = .998$ SE $k = .015$ P ***

□ Male Grey Kangaroo $\log Y = -.584 + 1.046 \log X$
$n = 25$ $r = .994$ SE $k = .024$ P ***

▲ Female Red Kangaroo $\log Y = -.543 + 1.000 \log X$
$n = 9$ $r = .997$ SE $k = .031$ P ***

△ Male Red Kangaroo $\log Y = -.683 + 1.227 \log X$
$n = 8$ $r = .998$ SE $k = .030$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	**	–
Female Red/Male Red	**	–
Female Grey/Female Red	NS	***
Male Grey/Male Red	*	–

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (8.0kg, 2.2kg)
SE $X_e = 0.8$ SE $Y_e = 0.3$

Estimated slopes $b1 = 0.28$ $b2 = 0.47$
SE $b1 = 0.01$ SE $b2 = 0.01$

Hindquarter muscle weights (Figure 56) were significantly greater for both sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, hindquarter muscle weights were significantly greater for females.

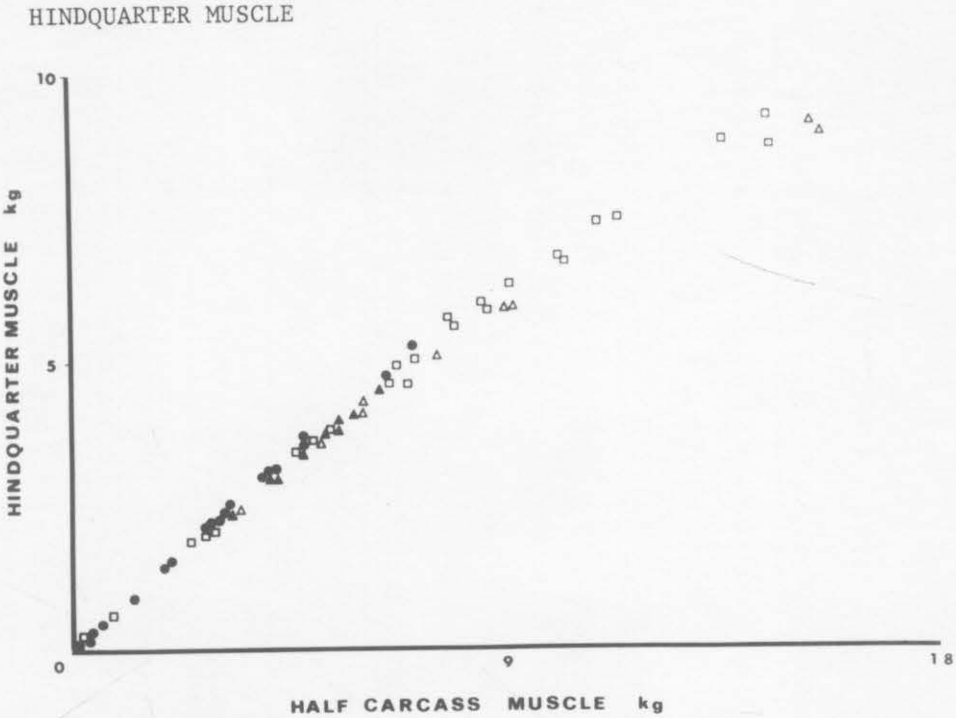

Figure 56 Relationship of hindquarter muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = -.160 + 1.059 \log X$ $n = 19 \quad r = 1.000 \quad SE\ k = .005$	P ***
▣ Male Grey Kangaroo	$\log Y = -.154 + .993 \log X$ $n = 25 \quad r = .998 \quad SE\ k = .012$	P ***
▲ Female Red Kangaroo	$\log Y = -.139 + .984 \log X$ $n = 9 \quad r = .999 \quad SE\ k = .019$	P ***
△ Male Red Kangaroo	$\log Y = -.059 + .862 \log X$ $n = 8 \quad r = .999 \quad SE\ k = .018$	P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	**	-
Female Grey/Female Red	NS	***
Male Grey/Male Red	**	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (9.3kg, 6.6kg)

$SE\ X_e = .6 \quad SE\ Y_e = .4$

Estimated slopes $b1 = .70 \quad b2 = .49$

$SE\ b1 = .01 \quad SE\ b2 = .03$

Proximal hindlimb muscle weights (Figure 57) were significantly greater for both sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, the proximal hindlimb muscle weights were significantly greater for females.

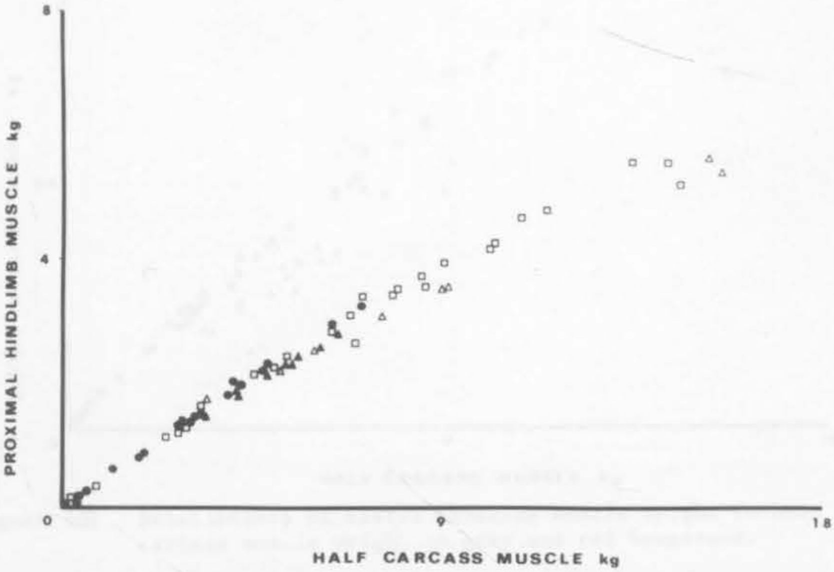
PROXIMAL HINDLIMB MUSCLE

Figure 57 Relationship of proximal hindlimb muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.366 + 1.052 \log X$
$n = 19$ $r = 1.000$ SE $k = .007$ P ***

◘ Male Grey Kangaroo $\log Y = -.367 + .995 \log X$
$n = 25$ $r = .997$ SE $k = .016$ P ***

▲ Female Red Kangaroo $\log Y = -.347 + .972 \log X$
$n = 9$ $r = .997$ SE $k = .027$ P ***

△ Male Red Kangaroo $\log Y = -.284 + .866 \log X$
$n = 8$ $r = .998$ SE $k = .020$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	**	–
Female Red/Male Red	*	–
Female Grey/Female Red	NS	***
Male Grey/Male Red	*	–

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (13.1kg, 5.6kg)
SE $X_e = .2$ SE $Y_e = .1$

Estimated slopes $b1 = .42$ $b2 = -.17$
SE $b1 = .01$ SE $b2 = .11$

Distal hindlimb muscle weights (Figure 58) were significantly greater for both sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, the distal hindlimb muscle weights were significantly greater for female grey kangaroos, but not significantly different between the red kangaroos.

DISTAL HINDLIMB MUSCLE

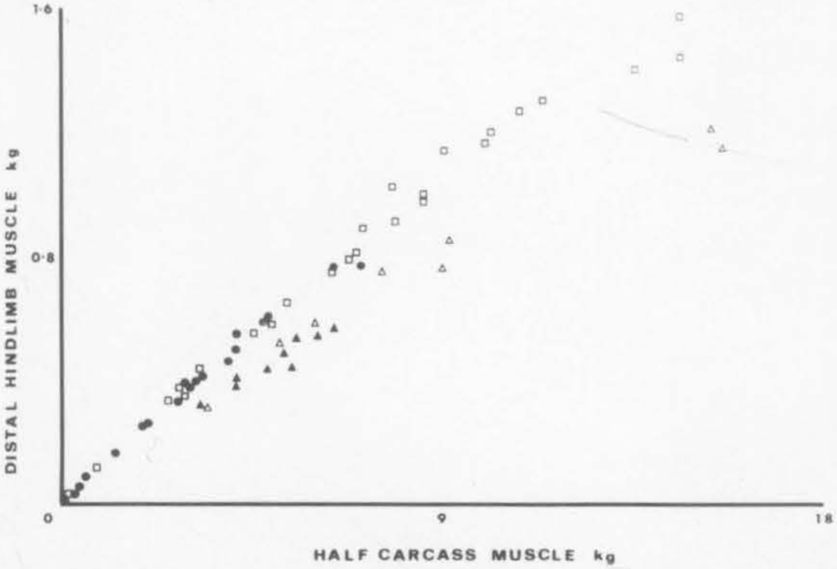

Figure 58 Relationship of distal hindlimb muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.887 + .961 \log X$
$n = 19$ $r = .999$ SE $k = .012$ P ***

◘ Male Grey Kangaroo $\log Y = -.865 + .925 \log X$
$n = 25$ $r = .998$ SE $k = .012$ P ***

▲ Female Red Kangaroo $\log Y = -.955 + .875 \log X$
$n = 9$ $r = .964$ SE $k = .091$ P ***

▲ Male Red Kangaroo $\log Y = -.906 + .840 \log X$
$n = 8$ $r = .985$ SE $k = .060$ P ***

<u>Comparison of differences between the two sexes and species</u>

Comparison	k	log a
Female Grey/Male Grey	*	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	***

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (9.8kg, 1.2kg)
SE $X_e = 1.1$ SE $Y_e = .1$

Estimated slopes $b1 = .12$ $b2 = .07$
SE $b1 = .003$ SE $b2 = .01$

Spinal muscle weights (Figure 59) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, spinal muscle weights were significantly greater for female grey kangaroos but not significantly different between the red kangaroos.

SPINAL MUSCLE

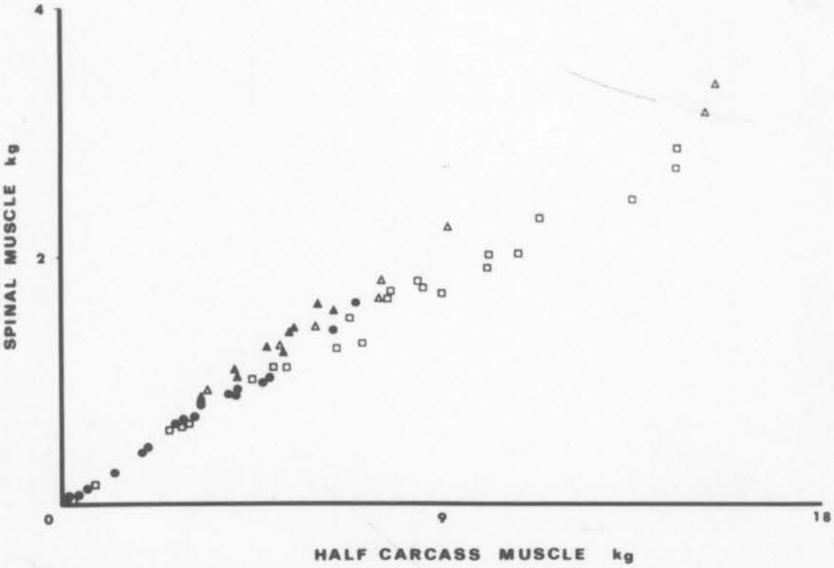

Figure59 Relationship of spinal muscle weight to half carcass muscle weight in grey and red kangaroos.

●	Female Grey Kangaroo	log Y = -.675 + 1.041 log X n = 19 r = .999 SE k = .011 P ***
☐	Male Grey Kangaroo	log Y = -.671 + .975 log X n = 25 r = .997 SE k = .016 P ***
▲	Female Red Kangaroo	log Y = -.571 + .961 log X n = 9 r = .981 SE k = .071 P ***
▲	Male Red Kangaroo	log Y = -.495 + .855 log X n = 8 r = .998 SE k = .025 P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	**	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	*	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (5.8kg, 1.3kg)

SE X_e = 3.0 SE Y_e = .6

Estimated slopes b1 = .22 b2 = .17

SE b1 = .03 SE b2 = .02

Abdominal wall muscle weights (Figure 60) were not significantly different for females but were significantly different for males when the same sex of grey and red kangaroo were compared. Between sexes within species, abdominal muscle weights were significantly greater for females.

ABDOMINAL MUSCLE

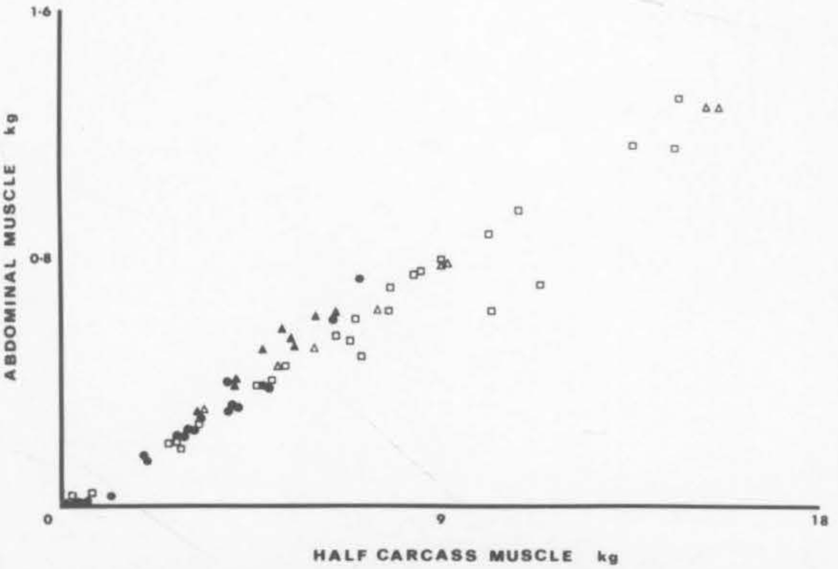

Figure 60 Relationship of abdominal muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.374 + 1.464 \log X$
$n = 19$ $r = .976$ SE $k = .080$ P ***

□ Male Grey Kangaroo $\log Y = -1.315 + 1.249 \log X$
$n = 25$ $r = .990$ SE $k = .038$ P ***

▲ Female Red Kangaroo $\log Y = -1.107 + 1.139 \log X$
$n = 9$ $r = .981$ SE $k = .084$ P ***

△ Male Red Kangaroo $\log Y = -1.028 + .955 \log X$
$n = 8$ $r = .999$ SE $k = .015$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	*	–
Female Red/Male Red	*	–
Female Grey/Female Red	NS	NS
Male Grey/Male Red	*	–

Proximal forelimb muscle weights (Figure 61) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, proximal forelimb muscle weights were significantly greater for males.

PROXIMAL FORELIMB MUSCLE

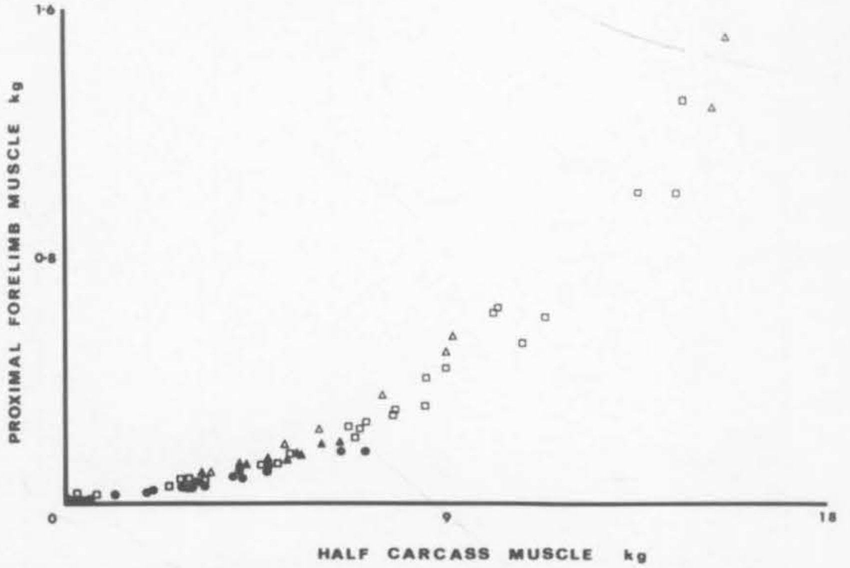

Figure 61 Relationship of proximal forelimb muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.528 + .796 \log X$
$n = 19$ $r = .988$ SE $k = .031$ P ***

□ Male Grey Kangaroo $\log Y = -1.505 + 1.151 \log X$
$n = 25$ $r = .954$ SE $k = .075$ P ***

▲ Female Red Kangaroo $\log Y = -1.711 + 1.244 \log X$
$n = 9$ $r = .988$ SE $k = .074$ P ***

△ Male Red Kangaroo $\log Y = -1.991 + 1.782 \log X$
$n = 8$ $r = .998$ SE $k = .045$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	–
Female Red/Male Red	***	–
Female Grey/Female Red	*	–
Male Grey/Male Red	*	–

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (8.0kg, .3kg)
SE $X_e = .7$ SE $Y_e = .1$

Estimated slopes $b1 = .04$ $b2 = .13$
SE $b1 = .01$ SE $b2 = .02$

Distal forelimb muscle weights (Figure 62) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, distal forelimb muscle weights were significantly greater for males.

DISTAL FORELIMB MUSCLE

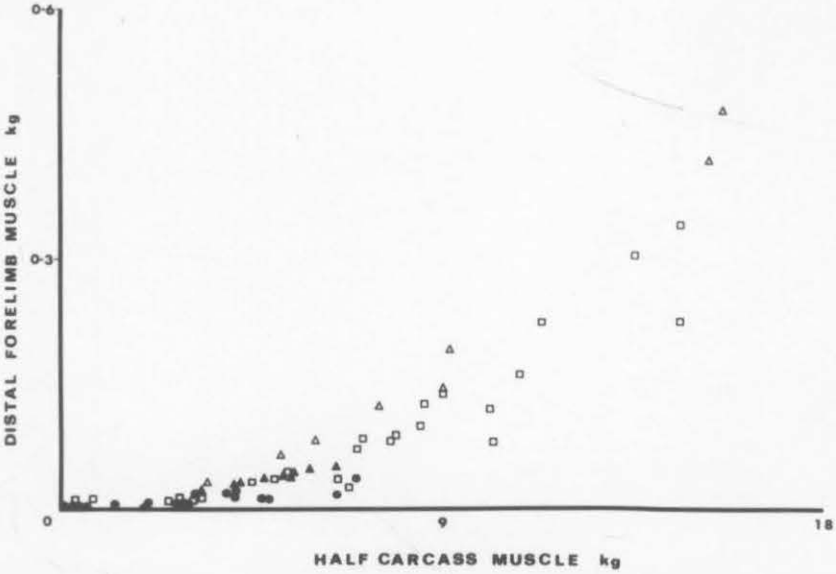

Figure 62 Relationship of distal forelimb muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -2.457 + .799 \log X$
$n = 19$ $r = .921$ SE $k = .082$ P ***

◻ Male Grey Kangaroo $\log Y = -2.340 + 1.368 \log X$
$n = 25$ $r = .905$ SE $k = .134$ P ***

▲ Female Red Kangaroo $\log Y = -2.530 + 1.525 \log X$
$n = 9$ $r = .991$ SE $k = .080$ P ***

△ Male Red Kangaroo $\log Y = -2.493 + 1.803 \log X$
$n = 8$ $r = .998$ SE $k = .052$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	*	-
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	*

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (7.1kg, .1kg)
SE $X_e = .7$ SE $Y_e = .01$

Estimated slopes $b1 = .01$ $b2 = .04$
SE $b1 = .002$ SE $b2 = .002$

Thorax-forelimb muscle weights (Figure 63) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, thorax-forelimb muscle weights were significantly greater for males.

THORAX-FORELEG MUSCLE

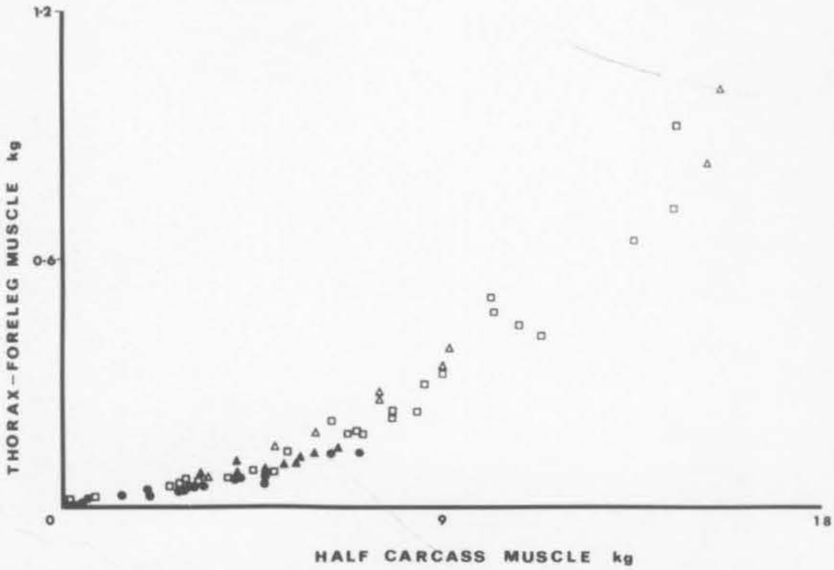

Figure 63 Relationship of thorax-foreleg muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.661 + .779 \log X$
$n = 19$ $r = .982$ SE $k = .037$ P ***

□ Male Grey Kangaroo $\log Y = -1.673 + 1.189 \log X$
$n = 25$ $r = .959$ SE $k = .073$ P ***

▲ Female Red Kangaroo $\log Y = -1.704 + 1.025 \log X$
$n = 9$ $r = .906$ SE $k = .182$ P ***

△ Male Red Kangaroo $\log Y = -2.065 + 1.703 \log X$
$n = 8$ $r = .998$ SE $k = .045$ P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	**	-
Female Grey/Female Red	NS	***
Male Grey/Male Red	*	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (7.6kg, .2kg)
SE $X_e = .5$ SE $Y_e = .03$

Estimated slopes $b1 = .03$ $b2 = .09$
SE $b1 = .01$ SE $b2 = .01$

Neck-forelimb muscle weights (Figure 64) were significantly greater for female red kangaroos, but not significantly different for males, when the same sex of grey and red kangaroo were compared. Between sexes within species, neck-forelimb muscle weights were significantly greater for males.

NECK-FORELEG MUSCLE

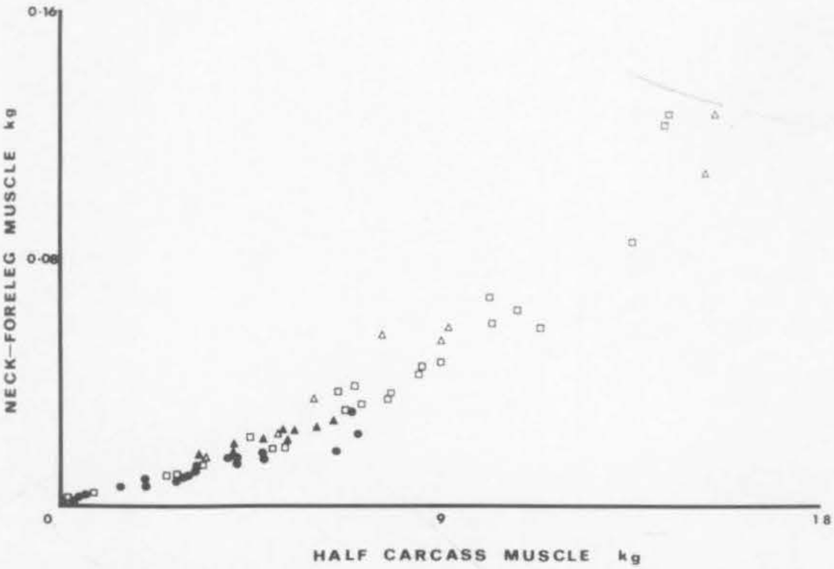

Figure 64 Relationship of neck-foreleg muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -2.315 + .732 \log X$
$n = 19$ $r = .991$ SE $k = .024$ P ***

◘ Male Grey Kangaroo $\log Y = -2.352 + 1.073 \log X$
$n = 25$ $r = .974$ SE $k = .052$ P ***

▲ Female Red Kangaroo $\log Y = -2.256 + .839 \log X$
$n = 9$ $r = .945$ SE $k = .109$ P ***

△ Male Red Kangaroo $\log Y = -2.555 + 1.373 \log X$
$n = 8$ $r = .990$ SE $k = .081$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	–
Female Red/Male Red	**	–
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (13.2kg, .07kg)
SE $X_e = .5$ SE $Y_e = .01$

Estimated slopes $b1 = .01$ $b2 = .04$
SE $b1 = .0003$ SE $b2 = .003$

Intrinsic neck-thorax muscle weights (Figure 65) were significantly greater for female red kangaroos, but not significantly different for males, when the same sex of red and grey kangaroo were compared. Between sexes within species, intrinsic neck-thorax muscle weights were significantly greater for male grey kangaroos, but not significantly different between red kangaroos.

INTRINSIC NECK AND THORAX MUSCLE

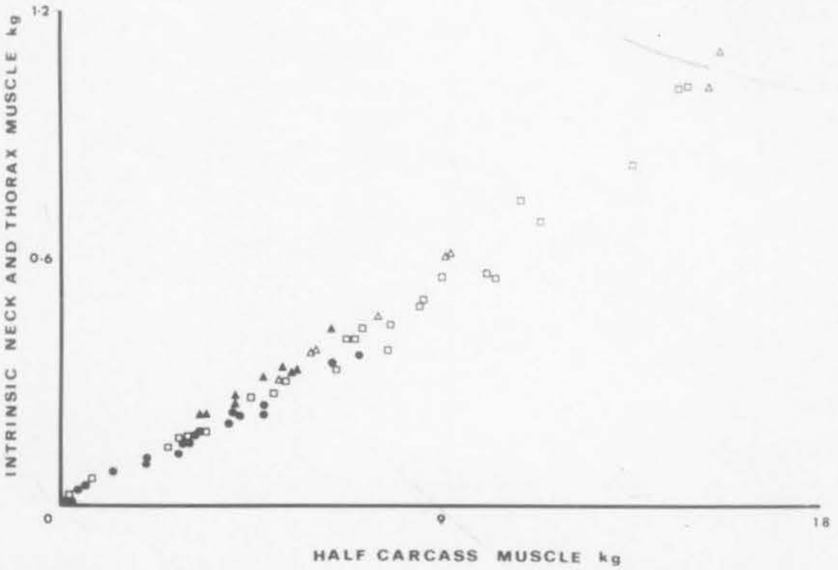

Figure 65 Relationship of intrinsic neck and thorax muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.223 + .893 \log X$
$n = 19$ $r = .987$ SE $k = .035$ P ***

☐ Male Grey Kangaroo $\log Y = -1.181 + .938 \log X$
$n = 25$ $r = .990$ SE $k = .028$ P ***

▲ Female Red Kangaroo $\log Y = -1.187 + .972 \log X$
$n = 9$ $r = .975$ SE $k = .084$ P ***

△ Male Red Kangaroo $\log Y = -1.260 + 1.074 \log X$
$n = 8$ $r = .997$ SE $k = .033$ P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	**
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	**
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (10.2kg, .6kg)
SE $X_e = .3$ SE $Y_e = .02$

Estimated slopes $b1 = .06$ $b2 = .10$
SE $b1 = .002$ SE $b2 = .01$

Tail muscle weights (Figure 66) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, tail muscle weights were significantly greater for male grey kangaroos, but not significantly different between the red kangaroos.

TOTAL TAIL MUSCLE

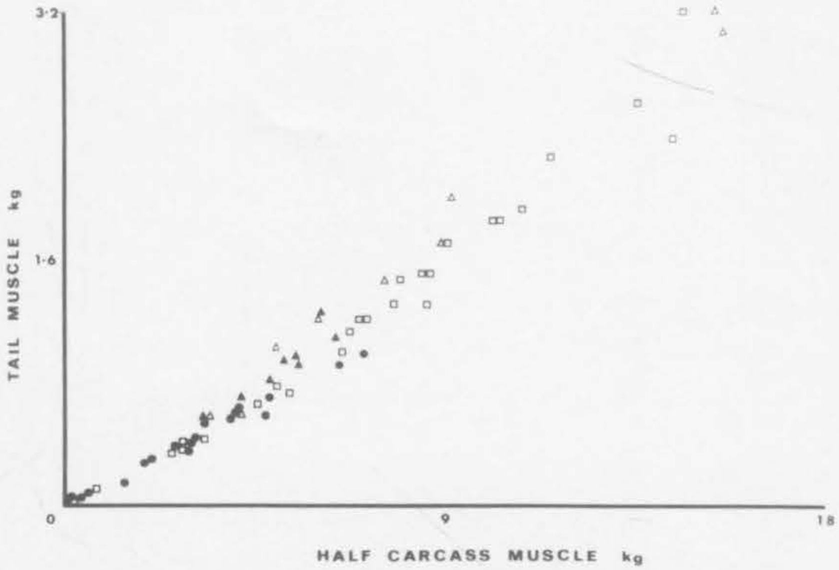

Figure 66 Relationship of total tail muscle weight to half carcass muscle weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = -.852 + .989 \log X$ $n = 19 \quad r = .997 \quad SE\ k = .018 \quad P$ ***
□ Male Grey Kangaroo	$\log Y = -.879 + 1.116 \log X$ $n = 25 \quad r = .995 \quad SE\ k = .024 \quad P$ ***
▲ Female Red Kangaroo	$\log Y = -.932 + 1.232 \log X$ $n = 9 \quad r = .953 \quad SE\ k = .148 \quad P$ ***
△ Male Red Kangaroo	$\log Y = -.817 + 1.120 \log X$ $n = 8 \quad r = .992 \quad SE\ k = .058 \quad P$ ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	**

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (4.5kg, .6kg)

$SE\ X_e = 2.5 \quad SE\ Y_e = .5$

Estimated slopes $b1 = .13 \quad b2 = .22$

$SE\ b1 = .03 \quad SE\ b2 = .01$

TABLE 8

Allometric relationships and comparisons between sexes and species of the grey and red kangaroo for individual muscles on half-carcass muscle.

TABLE M1

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
1*	Female Grey	-.207	.908	.298	17	.619	**	Female Grey/Male Grey	NS	NS
	Male Grey	-.399	1.061	.116	24	.890	***			
	Female Red	-.281	.700	1.105	9	.233	NS			
	Male Red	.083	.438	.357	8	.448	NS			
2	Female Grey	1.778	1.101	.018	19	.998	***	Female Grey/Male Grey	***	-
	Male Grey	1.784	.988	.021	25	.995	***	Female Red/Male Red	NS	***
	Female Red	1.833	.826	.051	9	.987	***	Female Grey/Female Red	*	-
	Male Red	1.804	.792	.040	8	.993	***	Male Grey/Male Red	**	-

* A key to the muscle code numbers, together with a description of the individual muscles, is given in Appendix I.

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
3	Female Grey	1.362	1.097	.044	19	.987	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.390	1.000	.025	25	.993	***	Female Red/Male Red	NS	NS
	Female Red	1.635	.867	.144	9	.916	***	Female Grey/Female Red	NS	**
	Male Red	1.694	.748	.051	8	.986	***	Male Grey/Male Red	**	–
4	Female Grey	1.527	1.074	.021	19	.997	***	Female Grey/Male Grey	*	–
	Male Grey	1.540	.991	.027	25	.992	***	Female Red/Male Red	NS	NS
	Female Red	1.556	1.003	.151	9	.929	***	Female Grey/Female Red	NS	NS
	Male Red	1.744	.730	.075	8	.970	***	Male Grey/Male Red	**	–
5	Female Grey	1.112	1.135	.047	19	.986	***	Female Grey/Male Grey	NS	**
	Male Grey	1.043	1.076	.043	25	.982	***	Female Red/Male Red	NS	NS
	Female Red	1.130	.837	.312	9	.712	*	Female Grey/Female Red	NS	***
	Male Red	1.167	.793	.123	8	.934	***	Male Grey/Male Red	NS	**
6	Female Grey	1.694	1.027	.015	19	.998	***	Female Grey/Male Grey	*	–
	Male Grey	1.686	.961	.023	25	.994	***	Female Red/Male Red	NS	NS
	Female Red	1.596	.989	.131	9	.943	***	Female Grey/Female Red	NS	***
	Male Red	1.765	.754	.041	8	.991	***	Male Grey/Male Red	**	–

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE K	n	r	P			
7	Female Grey	1.001	.975	.026	19	.994	***	Female Grey/Male Grey	NS	NS
	Male Grey	.961	1.036	.029	25	.991	***	Female Red/Male Red	NS	NS
	Female Red	.855	1.154	.182	9	.923	***	Female Grey/Female Red	NS	NS
	Male Red	.999	.920	.056	8	.989	***	Male Grey/Male Red	NS	**
8	Female Grey	1.555	1.133	.014	19	.999	***	Female Grey/Male Grey	**	-
	Male Grey	1.558	1.068	.018	25	.997	***	Female Red/Male Red	NS	NS
	Female Red	1.669	.953	.078	9	.977	***	Female Grey/Female Red	NS	NS
	Male Red	1.700	.899	.038	8	.995	***	Male Grey/Male Red	**	-
9	Female Grey	.634	1.099	.039	19	.990	***	Female Grey/Male Grey	NS	NS
	Male Grey	.605	1.129	.042	25	.984	***	Female Red/Male Red	NS	NS
	Female Red	1.006	.883	.244	9	.807	**	Female Grey/Female Red	NS	***
	Male Red	.748	1.154	.066	8	.990	***	Male Grey/Male Red	NS	***
10	Female Grey	.263	1.064	.035	19	.991	***	Female Grey/Male Grey	NS	NS
	Male Grey	.275	1.007	.051	25	.971	***	Female Red/Male Red	NS	NS
	Female Red	.331	1.121	.256	9	.856	**	Female Grey/Female Red	NS	**
	Male Red	.478	.854	.118	8	.947	***	Male Grey/Male Red	NS	NS

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
11	Female Grey	.478	.922	.028	19	.992	***	Female Grey/Male Grey	NS	NS
	Male Grey	.492	.916	.042	25	.977	***	Female Red/Male Red	NS	NS
	Female Red	.418	1.153	.148	9	.947	***	Female Grey/Female Red	NS	***
	Male Red	.636	.896	.061	8	.987	***	Male Grey/Male Red	NS	***
12	Female Grey	.567	.954	.020	19	.996	***	Female Grey/Male Grey	NS	NS
	Male Grey	.597	.928	.021	25	.994	***	Female Red/Male Red	NS	**
	Female Red	.380	.998	.189	9	.894	**	Female Grey/Female Red	NS	***
	Male Red	.579	.866	.076	8	.978	***	Male Grey/Male Red	NS	***
13	Female Grey	.602	.989	.033	19	.991	***	Female Grey/Male Grey	NS	NS
	Male Grey	.594	1.018	.049	25	.974	***	Female Red/Male Red	NS	NS
	Female Red	.693	.910	.384	9	.667	*	Female Grey/Female Red	NS	NS
	Male Red	.737	.974	.165	8	.924	**	Male Grey/Male Red	NS	*
14	Female Grey	1.339	1.017	.016	19	.998	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.337	1.001	.020	25	.996	***	Female Red/Male Red	NS	NS
	Female Red	1.333	.955	.137	9	.935	***	Female Grey/Female Red	NS	**
	Male Red	1.410	.848	.028	8	.997	***	Male Grey/Male Red	*	–

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
15	Female Grey	.672	1.007	.044	19	.984	***	Female Grey/Male Grey	NS	*
	Male Grey	.591	1.012	.044	25	.979	***	Female Red/Male Red	NS	NS
	Female Red	.806	.873	.213	9	.840	**	Female Grey/Female Red	NS	NS
	Male Red	.788	.850	.087	8	.970	***	Male Grey/Male Red	NS	NS
16	Female Grey	1.318	1.064	.018	19	.998	***	Female Grey/Male Grey	*	–
	Male Grey	1.317	1.003	.016	25	.997	***	Female Red/Male Red	NS	NS
	Female Red	1.233	1.173	.124	9	.963	***	Female Grey/Female Red	NS	NS
	Male Red	1.358	.951	.046	8	.993	***	Male Grey/Male Red	NS	NS
18	Female Grey	1.014	1.064	.025	19	.995	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.078	1.001	.025	25	.993	***	Female Red/Male Red	NS	NS
	Female Red	1.160	.941	.182	9	.890	**	Female Grey/Female Red	NS	*
	Male Red	1.193	.937	.049	8	.992	***	Male Grey/Male Red	NS	**
19	Female Grey	.902	.976	.030	19	.992	***	Female Grey/Male Grey	NS	NS
	Male Grey	.913	1.024	.028	25	.992	***	Female Red/Male Red	NS	NS
	Female Red	.818	1.138	.106	9	.971	***	Female Grey/Female Red	NS	NS
	Male Red	.899	1.025	.067	8	.988	***	Male Grey/Male Red	NS	NS

Muscle Code Number		Allometric Relationships						Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
20	Female Grey	1.329	.988	.021	19	.996	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.320	.970	.025	25	.992	***	Female Red/Male Red	NS	NS
	Female Red	1.216	1.034	.157	9	.928	***	Female Grey/Female Red	NS	***
	Male Red	1.321	.929	.047	8	.992	***	Male Grey/Male Red	NS	NS
21	Female Grey	.308	.884	.024	19	.994	***	Female Grey/Male Grey	NS	NS
	Male Grey	.323	.871	.025	25	.991	***	Female Red/Male Red	NS	NS
	Female Red	.441	.689	.249	9	.722	*	Female Grey/Female Red	NS	NS
	Male Red	.256	.983	.079	8	.981	***	Male Grey/Male Red	NS	NS
22	Female Grey	.787	1.102	.027	17	.996	***	Female Grey/Male Grey	*	-
	Male Grey	.769	1.014	.028	23	.992	***	Female Red/Male Red	NS	NS
	Female Red	1.505	.786	.111	9	.936	***	Female Grey/Female Red	NS	***
	Male Red	1.457	.880	.050	8	.990	***	Male Grey/Male Red	NS	***
23	Female Grey	.291	.892	.032	19	.989	***	Female Grey/Male Grey	NS	NS
	Male Grey	.365	.847	.041	24	.976	***	Female Red/Male Red	NS	NS
	Female Red	.162	1.053	.371	9	.731	*	Female Grey/Female Red	NS	NS
	Male Red	.194	.962	.090	8	.975	***	Male Grey/Male Red	NS	*

Muscle Code Number		Allometric Relationships						Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
24	Female Grey	1.707	1.034	.014	19	.998	***	Female Grey/Male Grey	**	–
	Male Grey	1.719	.960	.018	24	.996	***	Female Red/Male Red	NS	NS
	Female Red	1.489	.987	.087	9	.974	***	Female Grey/Female Red	NS	***
	Male Red	1.579	.870	.041	8	.993	***	Male Grey/Male Red	NS	***
25	Female Grey	1.536	1.037	.018	19	.997	***	Female Grey/Male Grey	**	–
	Male Grey	1.566	.953	.017	25	.996	***	Female Red/Male Red	NS	NS
	Female Red	1.504	.916	.110	9	.953	***	Female Grey/Female Red	NS	***
	Male Red	1.571	.871	.052	8	.989	***	Male Grey/Male Red	NS	***
26	Female Grey	1.631	.956	.021	19	.996	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.644	.936	.014	25	.997	***	Female Red/Male Red	NS	NS
	Female Red	1.568	.808	.105	9	.945	***	Female Grey/Female Red	NS	***
	Male Red	1.520	.888	.073	8	.980	***	Male Grey/Male Red	NS	***
27	Female Grey	1.187	.978	.018	19	.997	***	Female Grey/Male Grey	*	–
	Male Grey	1.237	.916	.018	25	.996	***	Female Red/Male Red	NS	NS
	Female Red	1.130	.786	.181	9	.854	**	Female Grey/Female Red	NS	***
	Male Red	1.149	.830	.078	8	.974	***	Male Grey/Male Red	NS	***

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
28	Female Grey	.515	.886	.018	19	.996	***	Female Grey/Male Grey	NS	NS
	Male Grey	.518	.925	.019	25	.995	***	Female Red/Male Red	NS	NS
	Female Red	.315	1.007	.093	9	.971	***	Female Grey/Female Red	NS	***
	Male Red	.518	.777	.081	8	.969	***	Male Grey/Male Red	*	-
29	Female Grey	1.382	.908	.022	19	.995	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.405	.893	.016	25	.996	***	Female Red/Male Red	NS	NS
	Female Red	1.252	1.011	.083	9	.977	***	Female Grey/Female Red	NS	**
	Male Red	1.451	.737	.084	8	.963	***	Male Grey/Male Red	*	-
30	Female Grey	-.003	.378	.030	19	.951	***	Female Grey/Male Grey	NS	*
	Male Grey	-.005	.436	.043	25	.903	***	Male Grey/Male Red	NS	NS
	Female Red	.077	.246	.289	9	.307	NS			
	Male Red	-.083	.476	.074	8	.935	***			
31	Female Grey	.943	.864	.018	19	.996	***	Female Grey/Male Grey	NS	NS
	Male Grey	.963	.860	.016	25	.996	***	Female Red/Male Red	NS	NS
	Female Red	.980	.666	.147	9	.863	**	Female Grey/Female Red	NS	***
	Male Red	.925	.808	.084	8	.969	***	Male Grey/Male Red	NS	***

Muscle Code Number		Allometric Relationships						Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
32	Female Grey	.846	.977	.015	19	.998	***	Female Grey/Male Grey	NS	**
	Male Grey	.880	.972	.016	25	.997	***	Female Red/Male Red	NS	NS
	Female Red	.694	1.144	.154	9	.942	***	Female Grey/Female Red	NS	*
	Male Red	.877	.955	.058	8	.989	***	Male Grey/Male Red	NS	NS
33	Female Grey	.088	.876	.035	19	.986	***	Female Grey/Male Grey	NS	NS
	Male Grey	.114	.912	.048	25	.970	***	Female Red/Male Red	NS	NS
	Female Red	-.030	1.318	.254	9	.891	**	Female Grey/Female Red	NS	***
	Male Red	.200	.947	.130	8	.948	***	Male Grey/Male Red	NS	**
34	Female Grey	.608	1.099	.025	19	.996	***	Female Grey/Male Grey	NS	NS
	Male Grey	.604	1.030	.044	25	.980	***	Female Red/Male Red	NS	**
	Female Red	.748	1.151	.311	9	.814	**	Female Grey/Female Red	NS	***
	Male Red	.710	1.025	.064	8	.988	***	Male Grey/Male Red	NS	**
35	Female Grey	.107	1.144	.109	14	.950	***	Female Grey/Male Grey	NS	NS
	Male Grey	.131	1.054	.095	21	.931	***	Female Red/Male Red	*	-
	Female Red	-.334	1.699	.349	9	.878	**	Female Grey/Female Red	NS	NS
	Male Red	.156	.862	.131	8	.938	***	Male Grey/Male Red	NS	*

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
36	Female Grey	-.375	.859	.065	19	.954	***	Female Grey/Male Grey	NS	**
	Male Grey	-.298	.982	.054	24	.968	***	Female Red/Male Red	NS	NS
	Female Red	-.161	.978	.362	9	.714	*	Female Grey/Female Red	NS	***
	Male Red	-.078	.892	.214	8	.862	**	Male Grey/Male Red	NS	**
37	Female Grey	1.151	1.064	.028	19	.994	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.134	1.052	.031	25	.990	***	Female Red/Male Red	NS	*
	Female Red	1.062	1.225	.313	9	.828	**	Female Grey/Female Red	NS	NS
	Male Red	1.042	1.119	.121	8	.967	***	Male Grey/Male Red	NS	NS
38	Female Grey	1.153	.989	.015	19	.998	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.168	.971	.017	25	.996	***	Female Red/Male Red	NS	NS
	Female Red	1.193	1.056	.141	9	.943	***	Female Grey/Female Red	NS	***
	Male Red	1.246	.966	.026	8	.998	***	Male Grey/Male Red	NS	***
39	Female Grey	.396	1.005	.040	19	.987	***	Female Grey/Male Grey	NS	NS
	Male Grey	.434	.966	.030	25	.989	***	Female Red/Male Red	NS	NS
	Female Red	.081	1.452	.309	9	.871	**	Female Grey/Female Red	NS	NS
	Male Red	.329	1.100	.043	8	.995	***	Male Grey/Male Red	NS	NS

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
40	Female Grey	.562	.865	.035	18	.987	***	Female Grey/Male Grey	NS	NS
	Male Grey	.544	.868	.032	25	.984	***	Female Red/Male Red	NS	NS
	Female Red	.540	.911	.215	9	.848	**	Female Grey/Female Red	NS	NS
	Male Red	.631	.780	.070	8	.976	***	Male Grey/Male Red	NS	NS
41	Female Grey	.885	1.009	.021	18	.996	***	Female Grey/Male Grey	NS	NS
	Male Grey	.903	.987	.019	25	.996	***	Female Red/Male Red	NS	NS
	Female Red	.807	1.024	.189	9	.899	***	Female Grey/Female Red	NS	**
	Male Red	.929	.908	.035	8	.996	***	Male Grey/Male Red	NS	**
42	Female Grey	1.616	1.108	.032	19	.993	***	Female Grey/Male Grey	*	-
	Male Grey	1.637	.947	.050	25	.970	***	Female Red/Male Red	NS	NS
	Female Red	1.929	.801	.141	9	.907	***	Female Grey/Female Red	NS	***
	Male Red	2.029	.713	.040	8	.991	***	Male Grey/Male Red	NS	***
43	Female Grey	1.424	1.035	.016	19	.998	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.415	1.015	.018	25	.996	***	Female Red/Male Red	NS	NS
	Female Red	1.422	1.021	.122	9	.954	***	Female Grey/Female Red	NS	NS
	Male Red	1.491	.903	.082	8	.976	***	Male Grey/Male Red	NS	NS

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
44	Female Grey	.713	.889	.101	19	.905	***	Female Grey/Male Grey	NS	*
	Male Grey	.789	.956	.047	25	.973	***	Female Red/Male Red	NS	NS
	Female Red	.743	1.017	.215	9	.872	**	Female Grey/Female Red	NS	NS
	Male Red	.856	.862	.201	8	.868	**	Male Grey/Male Red	NS	NS
45	Female Grey	.707	.934	.046	19	.980	***	Female Grey/Male Grey	NS	NS
	Male Grey	.719	.976	.023	25	.994	***	Female Red/Male Red	**	-
	Female Red	-.169	2.208	.354	9	.921	***	Female Grey/Female Red	**	-
	Male Red	.729	.932	.132	8	.945	***	Male Grey/Male Red	NS	NS
46	Female Grey	.858	1.040	.034	19	.991	***	Female Grey/Male Grey	NS	NS
	Male Grey	.822	1.100	.033	25	.990	***	Female Red/Male Red	NS	***
	Female Red	.720	1.249	.139	9	.959	***	Female Grey/Female Red	NS	NS
	Male Red	.686	1.169	.042	8	.996	***	Male Grey/Male Red	NS	**
47	Female Grey	.765	1.081	.052	19	.981	***	Female Grey/Male Grey	NS	NS
	Male Grey	.801	.986	.050	25	.972	***	Female Red/Male Red	NS	NS
	Female Red	.724	1.206	.151	9	.949	***	Female Grey/Female Red	NS	NS
	Male Red	1.048	.761	.126	8	.927	***	Male Grey/Male Red	NS	NS

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
48	Female Grey	1.788	1.103	.017	19	.998	***	Female Grey/Male Grey	**	-
	Male Grey	1.786	1.003	.024	25	.993	***	Female Red/Male Red	NS	NS
	Female Red	1.906	.936	.076	9	.977	***	Female Grey/Female Red	NS	NS
	Male Red	1.936	.879	.052	8	.990	***	Male Grey/Male Red	NS	*
49	Female Grey	1.267	.865	.032	19	.988	***	Female Grey/Male Grey	*	-
	Male Grey	1.265	.953	.021	25	.995	***	Female Red/Male Red	NS	NS
	Female Red	1.255	1.027	.098	9	.969	***	Female Grey/Female Red	NS	***
	Male Red	1.364	.865	.030	8	.996	***	Male Grey/Male Red	NS	NS
50	Female Grey	-.550	1.556	.243	14	.880	***	Female Grey/Male Grey	NS	**
	Male Grey	-.929	1.748	.190	23	.895	***	Male Grey/Male Red	NS	*
	Female Red	-.224	1.242	.526	9	.666	NS			
	Male Red	-.360	1.329	.118	8	.977	***			
51	Female Grey	1.569	.714	.187	14	.741	**	Female Grey/Male Grey	*	-
	Male Grey	1.262	1.095	.038	24	.987	***	Female Red/Male Red	**	-
	Female Red	1.220	1.217	.116	9	.970	***	Female Grey/Female Red	NS	NS
	Male Red	1.505	.824	.050	8	.989	***	Male Grey/Male Red	**	-

Muscle Code Number		Allometric Relationships						Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
52	Female Grey	.817	.784	.030	19	.988	***	Female Grey/Male Grey	***	-
	Male Grey	.805	1.162	.066	25	.965	***	Female Red/Male Red	**	-
	Female Red	.504	1.383	.101	9	.982	***	Female Grey/Female Red	*	-
	Male Red	.347	1.747	.037	8	.999	***	Male Grey/Male Red	**	-
53	Female Grey	.867	.744	.061	18	.950	***	Female Grey/Male Grey	***	-
	Male Grey	.869	1.247	.096	25	.939	***	Male Grey/Male Red	NS	NS
	Female Red	1.180	.479	.389	9	.422	NS			
	Male Red	.504	1.719	.088	8	.992	***			
54	Female Grey	-.121	1.281	.119	13	.955	***	Female Grey/Male Grey	NS	**
	Male Grey	-.253	1.289	.104	19	.949	***	Female Red/Male Red	NS	*
	Female Red	.081	1.276	.325	9	.829	**	Female Grey/Female Red	NS	***
	Male Red	.145	1.010	.117	8	.962	***	Male Grey/Male Red	NS	***
55	Female Grey	1.188	.992	.056	13	.983	***	Female Grey/Male Grey	*	-
	Male Grey	1.113	1.159	.042	19	.989	***	Female Red/Male Red	NS	NS
	Female Red	1.165	1.043	.111	9	.963	***	Female Grey/Female Red	NS	NS
	Male Red	1.130	1.105	.040	8	.996	***	Male Grey/Male Red	NS	NS

Muscle Code Number		Allometric Relationships						Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
56	Female Grey	1.349	1.068	.048	13	.989	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.312	1.096	.029	24	.992	***	Female Red/Male Red	NS	***
	Female Red	1.503	.967	.088	9	.972	***	Female Grey/Female Red	NS	***
	Male Red	1.409	1.015	.038	8	.996	***	Male Grey/Male Red	NS	NS
57	Female Grey	.232	.825	.044	19	.977	***	Female Grey/Male Grey	**	-
	Male Grey	.194	1.056	.059	25	.966	***	Female Red/Male Red	NS	NS
	Female Red	.213	.977	.219	9	.860	**	Female Grey/Female Red	NS	*
	Male Red	-.061	1.389	.106	8	.983	***	Male Grey/Male Red	NS	NS
58	Female Grey	.556	.757	.028	19	.988	***	Female Grey/Male Grey	***	-
	Male Grey	.499	1.094	.046	25	.981	***	Female Red/Male Red	**	-
	Female Red	.669	.732	.148	9	.882	**	Female Grey/Female Red	NS	***
	Male Red	.286	1.353	.089	8	.987	***	Male Grey/Male Red	NS	NS
59	Female Grey	.097	.705	.031	18	.985	***	Female Grey/Male Grey	***	-
	Male Grey	.119	1.024	.071	24	.951	***	Female Red/Male Red	NS	NS
	Female Red	-.038	1.183	.362	9	.777	*	Female Grey/Female Red	NS	***
	Male Red	-.091	1.419	.242	8	.922	**	Male Grey/Male Red	NS	*

Muscle Code Number		Allometric Relationships						Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
60	Female Grey	.766	.859	.031	19	.989	***	Female Grey/Male Grey	***	–
	Male Grey	.731	1.181	.060	25	.972	***	Female Red/Male Red	NS	*
	Female Red	.548	1.330	.167	9	.949	***	Female Grey/Female Red	NS	***
	Male Red	.329	1.734	.079	8	.994	***	Male Grey/Male Red	**	–
61	Female Grey	–.392	.716	.064	18	.942	***	Female Grey/Male Grey	*	–
	Male Grey	–.355	.940	.056	23	.965	***	Female Red/Male Red	NS	**
	Female Red	–.823	1.550	.256	9	.916	***	Female Grey/Female Red	NS	*
	Male Red	–.582	1.346	.059	8	.994	***	Male Grey/Male Red	*	–
62	Female Grey	.314	.871	.032	19	.989	***	Female Grey/Male Grey	***	–
	Male Grey	.293	1.093	.053	24	.976	***	Female Red/Male Red	NS	NS
	Female Red	.256	1.084	.188	9	.909	***	Female Grey/Female Red	NS	**
	Male Red	.086	1.382	.076	8	.991	***	Male Grey/Male Red	NS	NS
63	Female Grey	.455	.628	.069	19	.912	***	Female Grey/Male Grey	*	–
	Male Grey	.457	.787	.037	25	.975	***	Male Grey/Male Red	NS	NS
	Female Red	.084	1.177	.554	9	.627	NS			
	Male Red	.280	.956	.074	7	.985	***			

Muscle Code Number		Allometric Relationships log a	k	SE k	n	r	P	Comparison between the two sexes and species	k	log a
64	Female Grey	.235	.837	.030	19	.989	***	Female Grey/Male Grey	***	–
	Male Grey	.195	1.073	.048	25	.978	***	Female Red/Male Red	NS	NS
	Female Red	.157	1.037	.279	9	.815	**	Female Grey/Female Red	NS	*
	Male Red	.170	1.131	.139	8	.957	***	Male Grey/Male Red	NS	NS
65	Female Grey	.400	.695	.060	14	.958	***	Female Grey/Male Grey	NS	NS
	Male Grey	.399	.857	.066	21	.948	***	Female Red/Male Red	NS	NS
	Female Red	.383	.738	.202	9	.811	**	Female Grey/Female Red	NS	NS
	Male Red	.197	1.007	.251	8	.854	**	Male Grey/Male Red	NS	NS
66	Female Grey	.115	.757	.435	6	.656	NS			
	Male Grey	.070	.902	.132	16	.876	***			
	Female Red	.304	.677	1.124	8	.239	NS			
	Male Red	.443	.515	.403	8	.462	NS			
67	Female Grey	.562	.927	.032	19	.990	***	Female Grey/Male Grey	NS	*
	Male Grey	.594	.988	.044	25	.978	***	Female Red/Male Red	NS	NS
	Female Red	.561	1.129	.379	9	.748	*	Female Grey/Female Red	NS	***
	Male Red	.532	1.138	.115	8	.971	***	Male Grey/Male Red	NS	*

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
68	Female Grey	1.347	.982	.016	19	.998	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.367	.927	.023	24	.993	***	Female Red/Male Red	NS	NS
	Female Red	1.512	.925	.082	9	.974	***	Female Grey/Female Red	NS	***
	Male Red	1.588	.818	.046	8	.991	***	Male Grey/Male Red	NS	***
69	Female Grey	-.268	1.035	.104	16	.936	***	Female Grey/Male Grey	NS	NS
	Male Grey	-.071	.858	.078	19	.936	***			
	Female Red	.776	-.755	1.096	7	.294	NS			
	Male Red	-.080	.633	.467	7	.518	NS			
70	Female Grey	.973	.690	.029	19	.986	***	Female Grey/Male Grey	*	-
	Male Grey	.952	.791	.028	24	.987	***	Female Red/Male Red	NS	NS
	Female Red	.990	.743	.293	9	.692	*	Female Grey/Female Red	NS	NS
	Male Red	.904	.850	.114	8	.950	***	Male Grey/Male Red	NS	NS
71	Female Grey	.967	.777	.038	19	.980	***	Female Grey/Male Grey	NS	NS
	Male Grey	.940	.849	.022	24	.993	***	Female Red/Male Red	NS	NS
	Female Red	1.051	.711	.219	9	.775	*	Female Grey/Female Red	NS	NS
	Male Red	.970	.852	.103	8	.959	***	Male Grey/Male Red	NS	NS

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
72	Female Grey	.268	.674	.061	17	.943	***	Female Grey/Male Grey	NS	NS
	Male Grey	.255	.732	.098	23	.853	***	Male Grey/Male Red	NS	NS
	Female Red	.512	.463	.446	9	.365	NS			
	Male Red	-.042	1.164	.210	8	.914	**			
73	Female Grey	-.191	.469	.131	11	.765	**	Female Grey/Male Grey	NS	NS
	Male Grey	-.113	.487	.179	14	.617	*			
	Female Red	-.277	.691	1.673	6	.202	NS			
	Male Red	-.181	.640	.432	5	.650	NS			
74	Female Grey	.259	.771	.075	16	.940	***	Female Grey/Male Grey	NS	NS
	Male Grey	.150	.905	.059	22	.960	***	Female Red/Male Red	NS	*
	Female Red	-.094	1.318	.264	9	.884	**	Female Grey/Female Red	NS	NS
	Male Red	-.444	1.575	.263	8	.926	***	Male Grey/Male Red	**	-
75	Female Grey	.385	.736	.032	16	.987	***	Female Grey/Male Grey	NS	NS
	Male Grey	.376	.792	.027	25	.987	***	Male Grey/Male Red	NS	NS
	Female Red	.639	.366	.446	8	.318	NS			
	Male Red	.381	.796	.069	8	.978	***			

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
76	Female Grey	.569	.726	.051	18	.963	***	Female Grey/Male Grey	*	-
	Male Grey	.617	.848	.033	25	.983	***	Female Red/Male Red	NS	NS
	Female Red	.232	1.297	.269	9	.877	**	Female Grey/Female Red	NS	NS
	Male Red	.574	.914	.129	8	.945	***	Male Grey/Male Red	NS	NS
77	Female Grey	.152	.766	.082	18	.920	***	Female Grey/Male Grey	NS	**
	Male Grey	.293	.802	.046	23	.968	***	Male Grey/Male Red	NS	NS
	Female Red	.483	.463	.471	9	.348	NS			
	Male Red	.093	1.090	.102	8	.975	***			
78	Female Grey	-.123	1.260	.259	8	.893	**	Female Grey/Male Grey	NS	NS
	Male Grey	-.194	1.297	.137	19	.917	***	Female Red/Male Red	NS	NS
	Female Red	.127	1.051	.363	9	.738	*	Female Grey/Female Red	NS	*
	Male Red	-.096	1.246	.151	8	.959	***	Male Grey/Male Red	NS	NS
79	Female Grey	1.565	.875	.021	18	.996	***	Female Grey/Male Grey	**	-
	Male Grey	1.564	.982	.029	25	.990	***	Female Red/Male Red	NS	NS
	Female Red	1.534	1.072	.091	9	.976	***	Female Grey/Female Red	NS	***
	Male Red	1.482	1.127	.033	8	.997	***	Male Grey/Male Red	NS	*

Muscle Code Number		Allometric Relationships						Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
80	Female Grey	.183	.853	.038	19	.983	***	Female Grey/Male Grey	***	–
	Male Grey	.267	1.234	.091	25	.943	***	Female Red/Male Red	**	–
	Female Red	.182	.989	.267	9	.813	**	Female Grey/Female Red	NS	*
	Male Red	–.257	1.931	.094	8	.993	***	Male Grey/Male Red	*	–
81	Female Grey	–1.032	.698	.132	16	.817	***	Female Grey/Male Grey	**	–
	Male Grey	–1.171	1.293	.103	23	.939	***	Male Grey/Male Red	NS	NS
	Female Red	–1.162	1.100	.475	9	.658	NS			
	Male Red	–1.401	1.672	.095	8	.991	***			
82	Female Grey	.545	.789	.031	19	.987	***	Female Grey/Male Grey	***	–
	Male Grey	.618	1.187	.087	25	.943	***	Female Red/Male Red	*	–
	Female Red	.292	1.437	.114	9	.979	***	Female Grey/Female Red	**	–
	Male Red	.131	1.894	.092	8	.993	***	Male Grey/Male Red	*	–
83	Female Grey	.437	.756	.034	19	.984	***	Female Grey/Male Grey	***	–
	Male Grey	.450	1.192	.090	25	.940	***	Female Red/Male Red	***	–
	Female Red	.347	1.112	.086	9	.980	***	Female Grey/Female Red	NS	***
	Male Red	.003	1.823	.073	8	.995	***	Male Grey/Male Red	*	–

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
84	Female Grey	-.707	.563	.064	19	.905	***	Female Grey/Male Grey	***	-
	Male Grey	-.714	.953	.079	25	.929	***	Male Grey/Male Red	*	-
	Female Red	-.218	-.045	.418	9	.041	NS			
	Male Red	-1.426	1.825	.572	8	.793	*			
85	Female Grey	.481	.815	.030	19	.988	***	Female Grey/Male Grey	***	-
	Male Grey	.523	1.129	.074	25	.954	***	Female Red/Male Red	*	-
	Female Red	.236	1.366	.089	9	.986	***	Female Grey/Female Red	*	-
	Male Red	-.041	1.805	.092	8	.992	***	Male Grey/Male Red	**	-
86	Female Grey	.424	.855	.030	19	.989	***	Female Grey/Male Grey	***	-
	Male Grey	.439	1.147	.063	25	.967	***	Female Red/Male Red	NS	*
	Female Red	.249	1.306	.106	9	.978	***	Female Grey/Female Red	*	-
	Male Red	.080	1.619	.081	8	.993	***	Male Grey/Male Red	*	-
88	Female Grey	.456	.780	.034	19	.985	***	Female Grey/Male Grey	***	-
	Male Grey	.490	1.246	.092	25	.942	***	Female Red/Male Red	**	-
	Female Red	.182	1.302	.170	9	.945	***	Female Grey/Female Red	*	-
	Male Red	-.196	2.102	.084	8	.995	***	Male Grey/Male Red	**	-

Muscle Code Number		Allometric Relationships						Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
89	Female Grey	1.020	.790	.036	19	.983	***	Female Grey/Male Grey	***	-
	Male Grey	1.024	1.068	.066	25	.959	***	Female Red/Male Red	*	-
	Female Red	.867	1.174	.112	9	.970	***	Female Grey/Female Red	NS	***
	Male Red	.639	1.532	.052	8	.997	***	Male Grey/Male Red	*	-
90	Female Grey	.340	.780	.030	19	.988	***	Female Grey/Male Grey	***	-
	Male Grey	.331	1.149	.063	25	.967	***	Female Red/Male Red	*	-
	Female Red	.115	1.304	.217	9	.916	***	Female Grey/Female Red	*	-
	Male Red	-.133	1.847	.087	8	.993	***	Male Grey/Male Red	**	-
91	Female Grey	-.794	.479	.127	16	.709	**	Female Grey/Male Grey	**	-
	Male Grey	-.952	1.017	.122	21	.886	***	Male Grey/Male Red	NS	NS
	Female Red	-.822	.805	.449	9	.562	NS			
	Male Red	-1.016	1.210	.105	8	.978	***			
94	Female Grey	.058	.609	.036	19	.971	***	Female Grey/Male Grey	***	-
	Male Grey	.077	1.129	.100	25	.920	***	Female Red/Male Red	NS	***
	Female Red	-.283	1.311	.227	9	.909	***	Female Grey/Female Red	*	-
	Male Red	-.293	1.619	.073	8	.994	***	Male Grey/Male Red	NS	NS

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
95	Female Grey	-.356	.698	.034	19	.981	***	Female Grey/Male Grey	***	–
	Male Grey	-.286	1.252	.092	25	.943	***	Female Red/Male Red	***	–
	Female Red	-.582	1.188	.116	9	.968	***	Female Grey/Female Red	NS	***
	Male Red	-.625	1.681	.036	8	.999	***	Male Grey/Male Red	NS	NS
96	Female Grey	-.566	.784	.058	19	.957	***	Female Grey/Male Grey	***	–
	Male Grey	-.534	1.250	.074	25	.962	***	Female Red/Male Red	NS	***
	Female Red	-.807	1.512	.335	9	.862	**	Female Grey/Female Red	NS	***
	Male Red	-.550	1.498	.101	8	.987	***	Male Grey/Male Red	NS	***
97	Female Grey	-.137	.675	.045	18	.966	***	Female Grey/Male Grey	***	–
	Male Grey	-.102	1.139	.093	25	.931	***	Female Red/Male Red	NS	***
	Female Red	-.546	1.263	.230	9	.901	***	Female Grey/Female Red	NS	NS
	Male Red	-.462	1.542	.146	8	.974	***	Male Grey/Male Red	NS	NS
98	Female Grey	-.246	.674	.058	16	.952	***	Female Grey/Male Grey	***	–
	Male Grey	-.146	1.244	.100	24	.935	***	Female Red/Male Red	*	–
	Female Red	-.599	1.572	.188	9	.953	***	Female Grey/Female Red	*	–
	Male Red	-.562	1.988	.051	8	.998	***	Male Grey/Male Red	*	–

Muscle Code Number	Allometric Relationships							Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
102	Female Grey	-.750	.488	.062	18	.890	***	Female Grey/Male Grey	***	-
	Male Grey	-.722	.957	.090	25	.912	***	Female Red/Male Red	NS	NS
	Female Red	-.793	.835	.259	9	.773	*	Female Grey/Female Red	NS	***
	Male Red	-1.057	1.441	.394	8	.831	*	Male Grey/Male Red	NS	NS
103	Female Grey	.059	.694	.038	19	.975	***	Female Grey/Male Grey	***	-
	Male Grey	-.002	1.170	.076	25	.954	***	Female Red/Male Red	**	-
	Female Red	-.183	1.197	.181	9	.929	***	Female Grey/Female Red	NS	**
	Male Red	-.482	1.811	.077	8	.995	***	Male Grey/Male Red	*	-
104	Female Grey	.641	.675	.042	19	.969	***	Female Grey/Male Grey	***	-
	Male Grey	.640	1.229	.100	25	.932	***	Female Red/Male Red	*	-
	Female Red	.206	1.421	.108	9	.981	***	Female Grey/Female Red	*	-
	Male Red	.090	1.898	.073	8	.996	***	Male Grey/Male Red	*	-
105	Female Grey	1.432	.986	.021	19	.996	***	Female Grey/Male Grey	*	-
	Male Grey	1.410	1.063	.022	25	.995	***	Female Red/Male Red	NS	NS
	Female Red	1.353	1.240	.160	9	.947	***	Female Grey/Female Red	NS	***
	Male Red	1.503	1.049	.084	8	.981	***	Male Grey/Male Red	NS	***

Muscle Code Number		Allometric Relationships						Comparison between the two sexes and species	k	log a
		log a	k	SE k	n	r	P			
106	Female Grey	1.627	.981	.018	19	.997	***	Female Grey/Male Grey	***	-
	Male Grey	1.602	1.134	.029	25	.992	***	Female Red/Male Red	NS	NS
	Female Red	1.549	1.224	.163	9	.943	***	Female Grey/Female Red	NS	***
	Male Red	1.644	1.156	.055	8	.993	***	Male Grey/Male Red	NS	**
107	Female Grey	1.431	1.011	.020	19	.997	***	Female Grey/Male Grey	*	-
	Male Grey	1.408	1.080	.019	25	.996	***	Female Red/Male Red	NS	NS
	Female Red	1.342	1.269	.136	9	.962	***	Female Grey/Female Red	NS	***
	Male Red	1.507	1.051	.066	8	.988	***	Male Grey/Male Red	NS	***
108	Female Grey	1.635	.982	.020	19	.997	***	Female Grey/Male Grey	***	-
	Male Grey	1.605	1.143	.028	25	.993	***	Female Red/Male Red	NS	NS
	Female Red	1.543	1.240	.155	9	.949	***	Female Grey/Female Red	NS	***
	Male Red	1.631	1.181	.067	8	.990	***	Male Grey/Male Red	NS	**
109	Female Grey	1.258	.915	.066	19	.959	***	Female Grey/Male Grey	NS	NS
	Male Grey	1.258	.975	.096	25	.904	***	Male Grey/Male Red	*	-
	Female Red	.540	1.719	1.919	9	.321	NS			
	Male Red	.431	1.811	.370	8	.894	**			

TABLE 9

Predicted muscle group weights for grey and red kangaroos. Values predicted from the allometric functions given with Figures 55 to 66.

	HALF CARCASS MUSCLE WEIGHT (kg)					
	3.5	5.0	6.5	9	12	15
PREDICTED FOREQUARTER MUSCLE WEIGHT (kg)						
Female Grey	0.84	1.18	1.51			
Male Grey	0.97	1.40	1.85	2.59	3.51	4.43
Female Red	1.00	1.43	1.86			
Male Red	0.97	1.50	2.06	3.07	4.38	5.76
PREDICTED HINDQUARTER MUSCLE WEIGHT (kg)						
Female Grey	2.61	3.80	5.02			
Male Grey	2.43	3.47	4.50	6.22	8.27	10.32
Female Red	2.49	3.54	4.58			
Male Red	2.57	3.50	4.38	5.80	7.43	9.01
PREDICTED PROXIMAL HINDLIMB MUSCLE WEIGHT (kg)						
Female Grey	1.61	2.34	3.08			
Male Grey	1.49	2.13	2.77	3.82	5.09	6.36
Female Red	1.52	2.15	2.77			
Male Red	1.54	2.10	2.63	3.49	4.47	5.43
PREDICTED DISTAL HINDLIMB MUSCLE WEIGHT (kg)						
Female Grey	0.43	0.61	0.78			
Male Grey	0.43	0.60	0.77	1.04	1.36	1.67
Female Red	0.33	0.45	0.57			
Male Red	0.36	0.48	0.60	0.79	1.00	1.21

	HALF CARCASS MUSCLE WEIGHT (kg)					
	3.5	5.0	6.5	9	12	15
PREDICTED SPINAL MUSCLE WEIGHT (kg)						
Female Grey	0.78	1.13	1.48			
Male Grey	0.72	1.02	1.32	1.82	2.41	2.99
Female Red	0.90	1.26	1.62			
Male Red	0.93	1.27	1.59	2.09	2.68	3.24
PREDICTED ABDOMINAL MUSCLE WEIGHT (kg)						
Female Grey	0.26	0.45	0.65			
Male Grey	0.23	0.36	0.50	0.75	1.08	1.43
Female Red	0.33	0.49	0.66			
Male Red	0.31	0.44	0.56	0.76	1.01	1.25
PREDICTED PROXIMAL FORELIMB MUSCLE WEIGHT (kg)						
Female Grey	0.08	0.11	0.13			
Male Grey	0.13	0.20	0.27	0.39	0.55	0.71
Female Red	0.09	0.14	0.20			
Male Red	0.10	0.18	0.29	0.51	0.86	1.27
PREDICTED DISTAL FORELIMB MUSCLE WEIGHT (kg)						
Female Grey	0.01	0.01	0.02			
Male Grey	0.03	0.04	0.06	0.09	0.14	0.19
Female Red	0.02	0.03	0.05			
Male Red	0.03	0.06	0.09	0.17	0.28	0.42
PREDICTED THORAX-FORELEG MUSCLE WEIGHT (kg)						
Female Grey	0.06	0.08	0.09			
Male Grey	0.09	0.14	0.20	0.29	0.41	0.53
Female Red	0.07	0.10	0.14			
Male Red	0.07	0.13	0.21	0.36	0.59	0.87

	HALF CARCASS MUSCLE WEIGHT (kg)					
	3.5	5.0	6.5	9	12	15
PREDICTED NECK-FORELEG MUSCLE WEIGHT (kg)						
Female Grey	0.01	0.02	0.02			
Male Grey	0.02	0.03	0.03	0.05	0.06	0.08
Female Red	0.02	0.02	0.03			
Male Red	0.02	0.03	0.04	0.06	0.08	0.12
PREDICTED INTRINSIC NECK AND THORAX MUSCLE WEIGHT (kg)						
Female Grey	0.18	0.25	0.32			
Male Grey	0.21	0.30	0.38	0.52	0.68	0.84
Female Red	0.22	0.31	0.40			
Male Red	0.21	0.31	0.41	0.58	0.79	1.01
PREDICTED TOTAL TAIL MUSCLE WEIGHT (kg)						
Female Grey	0.49	0.69	0.90			
Male Grey	0.53	0.80	1.07	1.53	2.12	2.71
Female Red	0.55	0.85	1.17			
Male Red	0.62	0.92	1.24	1.79	2.46	3.16

TABLE 10

Comparisons between the relative proportions of muscle in grey kangaroo (*Macropus giganteus*), red kangaroos (*Megaleia rufa*), wallaroos (*Macropus robustus*), red neck wallabies (*Macropus rufogriseus*) and swamp wallabies (*Wallabia bicolour*). Comparisons relative to the grey kangaroo = 100 and based on mature animals.

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Carcass Muscle % Empty Body Weight	Female	100	89	92	101	92
	Male	100	105	103		
Forequarter Muscle Weight % Half Carcass Muscle Weight	Female	100	116	99	100	107
	Male	100	109	94		
Hindquarter Muscle Weight % Half Carcass Muscle Weight	Female	100	95	99	99	97
	Male	100	94	103		
Proximal Hindlimb Muscle Weight % Half Carcass Muscle Weight	Female	100	95	98	101	100
	Male	100	96	106		
Distal Hindlimb Muscle Weight % Half Carcass Muscle Weight	Female	100	79	94	88	83
	Male	100	73	91		

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Spinal muscle Weight % Half Carcass Muscle Weight	Female	100	112	99	106	98
	Male	100	111	105		
Abdominal Muscle Weight % Half Carcass Muscle Weight	Female	100	101	101	95	104
	Male	100	98	109		
Proximal Forelimb Muscle Weight % Half Carcass Muscle Weight	Female	100	121	106	85	109
	Male	100	115	79		
Distal Forelimb Muscle Weight % Half Carcass Muscle Weight	Female	100	195	167	41	203
	Male	100	148	120		
Thorax-Leg Muscle Weight % Half Carcass Muscle Weight	Female	100	113	127	94	106
	Male	100	105	79		
Neck-Leg Muscle Weight % Half Carcass Muscle Weight	Female	100	144	125	136	128
	Male	100	87	87		
Intrinsic Neck and Thorax Muscle Weight % Half Carcass Muscle Weight	Female	100	122	94	105	118
	Male	100	97	96		
Tail Muscle Weight % Half Carcass Muscle Weight	Female	100	134	99	92	92
	Male	100	105	64		

TABLE 11

Two phase linear functions for individual muscles which show curvilinear growth relative to half-carcass muscle. Male grey kangaroos.

* Muscle Code Number	X_e (kg)	SE X_e	Y_e (g)	SE Y_e	b1	SE b1	b2	SE b2
2	8.9	0.8	552.0	44.3	60.95	2.91	32.60	5.64
3	13.0	0.5	318.0	12.0	23.80	0.90	-18.50	16.60
4	10.3	1.2	358.0	20.0	34.30	1.30	10.20	3.60
6	5.0	1.0	257.0	40.0	52.50	4.20	32.80	1.90
8	8.9	1.0	379.5	38.1	43.18	1.43	31.03	2.77
18	9.6	1.4	119.9	15.0	12.53	0.87	6.79	2.08
20	7.8	0.02	165.3	5.4	21.27	1.41	12.24	1.61
24	10.4	0.8	513.6	34.7	49.02	1.78	19.97	6.76
25	9.9	1.1	336.1	31.6	33.54	1.53	21.07	3.68
26	9.7	0.6	386.3	22.2	39.47	1.32	21.21	3.17
28	8.5	0.1	24.7	0.7	2.84	0.16	1.93	0.22
29	10.3	0.01	210.0	4.1	19.72	0.85	10.98	1.97

* A key to the muscle code numbers together with a description of the individual muscles, is given in Appendix I.

TABLE 11 (CONT.)

Muscle Code Number	X_e (kg)	SE X_e	Y_e (g)	SE Y_e	b1	SE b1	b2	SE b2
31	10.4	1.1	71.2	6.4	6.53	0.28	3.25	1.05
39	13.5	0.001	32.2	1.2	2.29	0.16	11.53	2.28
43	10.9	1.5	294.0	30.0	26.80	0.90	18.00	2.60
48	6.4	1.2	431.7	58.3	67.25	6.78	42.92	3.26
51	8.2	1.1	192.1	24.2	24.16	1.26	16.87	1.73
52	7.9	0.7	58.6	10.4	8.00	1.60	24.33	2.19
53	6.4	0.7	43.7	23.0	6.84	4.97	36.50	2.39
57	7.5	1.4	11.5	3.8	1.60	0.47	3.44	0.48
58	9.6	0.6	33.6	3.6	3.65	0.42	10.58	1.02
59	8.2	1.0	10.0	2.3	1.31	0.29	3.16	0.39
60	7.7	0.5	49.2	8.5	6.81	1.31	20.28	1.32
64	8.4	0.8	14.3	2.4	1.79	0.25	3.72	0.34
79	8.0	0.7	258.9	30.8	32.10	2.59	55.75	3.54
80	9.2	0.4	24.3	2.9	2.99	0.45	13.46	1.07
81	8.3	0.9	0.8	0.2	0.11	0.04	0.38	0.05
82	7.8	0.5	35.7	8.1	4.98	1.43	20.49	1.44
83	7.6	0.4	23.6	4.5	3.37	0.83	13.79	0.83

TABLE 11 (CONT.)

Muscle Code Number	X_e (kg)	SE X_e	Y_e (g)	SE Y_e	b1	SE b1	b2	SE b2
84	9.9	0.7	1.7	0.2	0.18	0.03	0.51	0.07
85	6.4	0.7	17.8	6.8	2.66	1.35	10.78	0.65
86	8.2	0.8	26.1	5.5	3.47	0.79	9.99	1.09
88	8.1	0.6	32.5	8.1	4.48	1.45	19.78	1.98
89	8.0	0.6	83.2	11.8	11.02	1.69	30.63	2.31
90	8.3	0.6	21.0	3.2	2.75	0.45	8.08	0.62
91	4.4	1.8	0.3	0.3	0.05	0.08	0.18	0.02
94	6.6	0.7	5.7	2.9	0.82	0.62	4.71	0.30
95	6.5	0.5	3.0	1.3	0.46	0.28	2.68	0.14
96	8.2	0.4	3.4	0.4	0.47	0.06	1.56	0.08
97	7.5	0.6	6.1	1.4	0.90	0.24	3.14	0.24
100	6.5	1.5	3.4	1.8	0.54	0.28	1.36	0.14
103	6.6	0.7	6.0	2.3	0.92	0.45	3.67	0.22
104	7.6	0.4	38.4	7.8	5.60	1.47	24.92	1.48

TABLE 12

Muscle growth impetus patterns for the male grey kangaroo. Estimated empty body weights at which growth impetus changes occur and direction of the change (Increase in impetus = +, Decrease in impetus = -).

Muscle Group	Half Carcass Muscle Weight (kg)	SE	Empty Body Weight (kg)	Direction of Change
Forequarter Muscle Weight	8.0	0.8	31.8	+
Hindquarter Muscle Weight	9.3	0.6	36.7	-
Tail Muscle Weight	4.5	2.5	18.3	+
Distal Forelimb Muscle Weight	7.1	0.7	28.3	+
Thorax-Foreleg Muscle Weight	7.6	0.5	30.2	+
Proximal Forelimb Muscle Weight	8.0	0.7	31.8	+
Intrinsic Neck and Thorax Muscle Weight	10.2	0.3	40.2	+
Neck-Foreleg Muscle Weight	13.2	0.5	51.7	+
Spinal Muscle Weight	5.8	3.0	23.3	-
Distal Hindlimb Muscle Weight	9.8	1.1	38.6	-
Proximal Hindlimb Muscle Weight	13.1	0.2	51.3	-

Individual Muscle Code Number *	Muscle Group	Half Carcass Muscle Weight(kg)	SE	Empty Body Weight (kg)	Direction of Change
91	Distal Forelimb	4.4	1.8	18.0	+
53	Thorax-Foreleg	6.4	0.7	25.7	+
85	Proximal Forelimb	6.4	0.7	25.8	+
95	Distal Forelimb	6.5	0.5	26.0	+
100	Distal Forelimb	6.5	1.5	26.2	+
94	Distal Forelimb	6.6	0.7	26.2	+
103	Distal Forelimb	6.6	0.7	26.3	+

* A key to the muscle code numbers together with a description of the individual muscles, is given in Appendix I.

TABLE 12 (CONT.)

Individual Muscle Code Number	Muscle Group	Half Carcass Muscle Weight (kg)	SE	Empty Body Weight (kg)	Direction of Change
57	Thorax-Foreleg	7.5	1.4	29.7	+
97	Distal Forelimb	7.5	0.6	29.8	+
104	Distal Forelimb	7.6	0.4	30.1	+
83	Proximal Forelimb	7.6	0.4	30.2	+
60	Thorax-Foreleg	7.7	0.5	30.6	+
82	Proximal Forelimb	7.8	0.5	30.8	+
52	Thorax-Foreleg	7.9	0.7	31.4	+
79	Intrinsic Neck and Thorax	8.0	0.7	31.6	+
89	Proximal Forelimb	8.0	0.6	31.8	+
88	Proximal Forelimb	8.1	0.6	32.2	+
86	Proximal Forelimb	8.2	0.8	32.3	+
59	Neck-Foreleg	8.2	1.0	32.4	+
96	Distal Forelimb	8.2	0.4	32.6	+
81	Proximal Forelimb	8.3	0.9	32.7	+
90	Proximal Forelimb	8.3	0.6	32.9	+
64	Intrinsic Neck and Thorax	8.4	0.8	33.5	+
80	Proximal Forelimb	9.2	0.4	36.3	+
58	Neck-Foreleg	9.6	0.6	37.7	+
84	Proximal Forelimb	9.9	0.7	39.2	+
39	Spinal	13.5	0.001	52.8	+
6	Proximal Hindlimb	5.0	1.0	20.3	-
48	Spinal	6.4	1.2	25.7	-
20	Proximal Hindlimb	7.8	0.02	31.1	-
51	Abdominal	8.2	1.1	32.6	-
28	Distal Hindlimb	8.5	0.1	33.6	-
8	Proximal Hindlimb	8.9	1.0	35.0	-
2	Proximal Hindlimb	8.9	0.8	35.4	-
18	Proximal Hindlimb	9.6	1.4	37.9	-

TABLE 12 (CONT.)

Individual Muscle Code Number	Muscle Group	Half Carcass Muscle Weight (kg)	SE	Empty Body Weight(kg)	Direction of Change
26	Distal Hindlimb	9.7	0.6	38.3	-
25	Distal Hindlimb	9.9	1.1	39.0	-
4	Proximal Hindlimb	10.3	1.2	40.4	-
29	Distal Hindlimb	10.3	0.01	40.4	-
24	Proximal Hindlimb	10.4	0.8	40.8	-
31	Distal Hindlimb	10.4	1.1	40.8	-
43	Spinal	10.9	1.5	42.9	-
3	Proximal Hindlimb	13.0	0.5	50.9	-

Empty body weight calculated from $$\text{EBW} = \frac{\text{Half Carcass Muscle Weight} + 0.287}{.261}$$

and 40.2 kg empty body weight respectively.

The tail muscle was the only other muscle group to exhibit an increase in growth rate in the second growth phase. Growth impetus increase in tail muscle occurred at 18.3 kg empty body weight.

In the hindquarter, the second growth phase was characterized by a decrease in growth rate. Hindquarter muscle as a whole, exhibited decreased growth rate at 36.7 kg empty body weight. Within the hindquarter, growth impetus decrease occurred in spinal muscle, distal hindlimb muscle and proximal hindlimb muscle at 23.3, 38.6 and 51.3 kg empty body weight respectively.

Abdominal wall muscle, as evident in Figure 60, markedly increases its growth rate at a low empty body weight. However, on statistical analysis, the growth pattern of the abdominal wall muscle could not be demonstrated to be different, at the 5% significance level, to a monophasic growth pattern.

Forty-three individual muscles exhibited a biphasic growth pattern. The remaining muscles were monophasic, excepting a few small muscles which had no demonstrable growth pattern. Of the forty-three muscles with a biphasic growth pattern, twenty-seven were late maturing with an increase in growth rate during their second growth phase and sixteen were early maturing with a decrease in growth rate during their second growth phase.

Species Differences

The species differences discussed are based on female animals and are extracted from Table 10.

Forequarter muscle as a percentage of carcass muscle, is greatest in the red kangaroo and wallaroo. The values for grey kangaroos, red neck wallabies and swamp wallabies, were approximately the same on a proportionate basis. Conversely, hindquarter muscle is least developed in the red kangaroo, followed by the wallaroo.

The red kangaroo, wallaroo and swamp wallaby were heavier muscled in both proximal and distal forelimb muscle groups than the grey kangaroo. The red neck wallaby was the least developed in both the proximal and distal forelimb muscle groups.

The extrinsic musculature of the pectoral limb was similarly well developed in the red kangaroo, wallaroo, red neck wallaby and swamp wallaby, relative to the grey kangaroo, in which it was least developed.

The musculature of the tail was most developed in the red kangaroo.

The musculature of the swamp wallaby differed in proportion from both the grey and red kangaroo. In many characteristics, the musculature of the red neck wallaby resembled the grey kangaroo and the musculature of the wallaroo, that of the red kangaroo.

DISCUSSION.

Female Grey Kangaroo

Female muscle growth patterns tend to reflect the muscle growth pattern of the immature male. The characteristic biphasic muscle growth pattern of the male can be divided into a prepubertal and sexually mature growth phase. However, in the female, sexual maturity does not establish a similar clear change in muscle growth pattern. Thus, in females the growth rate of individual muscles tends to remain constant. The resultant monophasic growth pattern in the female musculature resembles the immature, rather than the mature growth pattern of the male.

Stated simply, the musculature of the female is similar to that of the immature male.

An interesting triphasic growth pattern occurred in the abdominal wall muscle. At low body weights, this muscle group is relatively slow growing. At body weights consistent with weaning, a marked increase in growth rate occurs, presumably to accommodate the increasing bulk of the digestive tract contents. A further increase in growth rate occurs with the onset of sexual maturity. The establishment of a pouch young results in the hypertrophy of the m. marsupialis, which adds to the overall weight of the abdominal wall muscle group.

Male Grey Kangaroo

Male muscle growth patterns are basically biphasic. Two biphasic growth patterns occur. Many individual forequarter muscles and the forequarter muscle as a whole, exhibit a growth rate increase in their second growth phase. In the hindquarter, the converse holds true. However, although individual muscles exhibit biphasic growth patterns, the musculature as a whole, relative to empty body weight, exhibits a monophasic growth pattern. Thus there is no effect on the growth rate of total muscle by the changes occurring in the growth rates of the individual carcass muscles.

Berg and Butterfield (1976) summarized existing knowledge on muscle growth in cattle as follows:-

"The study of growth of muscles indicates that the muscular system is a complex of many units, the growth of each of which is conditioned by genetic and environmental influences. These influences may act in the evolutionary background of the species in determining a pattern for serial development of the musculature, or they may act in response to the day-to-day activities of the individual".

"The stimuli and mechanisms which produce different rates of growth in different muscles are largely unknown, but it is suggested that the weight of evidence favours a strong influence of an evolutionarily acquired genetic pattern in ante-natal growth which is modified by function in the immediate post-natal period. Then follows a prepubertal and adolescent phase, when the relative weights of muscles alter little, and from which phase the steers and heifers do not emerge. The young adult male enters a maturing phase which adapts the musculature to the dual role of survival and reproduction with its attendant battles. This phase is undoubtedly stimulated by androgens, but the mechanism of selective action on muscles is unknown."

The situation in the kangaroo is similar to that described by Berg and Butterfield (1976) in cattle. Figure 67A is a histogram showing the distribution of the half-carcass muscle weights at which individual muscles with a biphasic growth pattern change their rate of growth. In relation to empty body weight, the maximum number of muscles

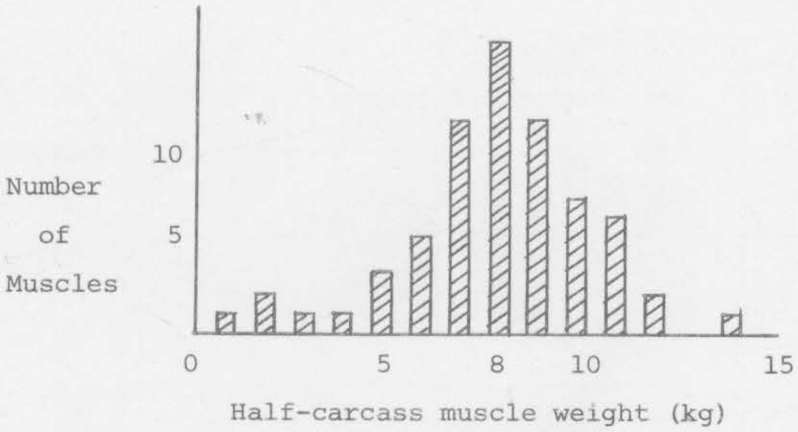

Figure 67A. Histogram of the half-carcass muscle weights at which individual muscles change their growth rates. Male grey kangaroo.

are changing their growth rates at 33.3 ($\pm$1.1) kg; or in relation to the animal's life, the maximum number of muscles change their growth rate at puberty. As this change does not occur in females, and as it is associated with puberty in the male, it is most likely brought about by androgenic hormone.

The mechanism of the selective action of the "muscle growth stimulus factor" is unknown. Approximately half of the individual carcass muscles grow at a constant rate, exhibiting a monophasic growth pattern. The remaining muscles exhibit a biphasic growth pattern, but this biphasic growth pattern may be either an early or late maturing growth pattern. Figure 67A is that of a normal distribution or normal variation in response of biological tissue to a growth stimulus. The biphasic muscle growth patterns presented in this figure can be represented in two histograms, grouping early and late maturing muscles separately.

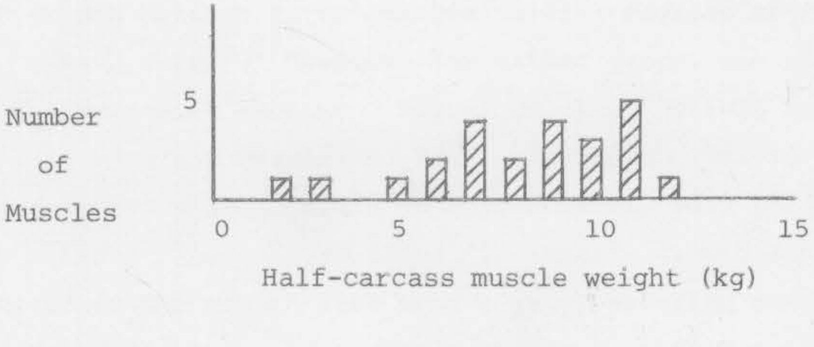

Figure 67B. Histogram of the half-carcass muscle weights at which individual early maturing muscles change their growth rates. Male grey kangaroo.

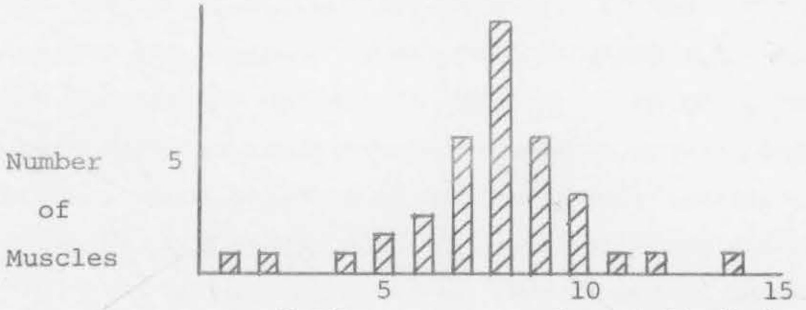

Figure 67C. Histogram of the half-carcass muscle weights at which individual late maturing muscles change their growth rates. Male grey kangaroo.

Irrespective of whether the biphasic growth pattern is early maturing (Figure 67B) or late maturing (Figure 67C), the muscles in each growth pattern group exhibit varying degrees of responsiveness to the "growth force". However, for either group, the period of maximum responsiveness is puberty. The stimulatory "growth force" triggering the late maturing muscles to begin the growth rate increase of their second growth phase, occurs at approximately 31.3 (±1.2) kg empty body weight. The corresponding "inhibitory growth factor" which decelerates the growth rate of the early maturing muscles into their second growth phase, occurs at approximately 36.6 (±1.8) kg empty body weight.

One may postulate that the factor increasing the rate of growth of one muscle is the same factor decreasing the growth rate of another. Alternatively, a second factor may be postulated as the decreasing growth factor. Possibly a second growth inhibitory factor could be a metabolic by-product of the muscles undergoing growth rate increase. As yet, the mechanism controlling relative muscle growth is unknown.

The constancy of the growth forces acting within the musculature of the kangaroo is remarkable. Firstly, in the weight range within this study, carcass muscle increases as a constant percentage of empty body weight, despite the intricate pattern of growth rate changes within the individual carcass muscles. If the contribution of the monophasic and biphasic growth pattern muscles to each kilogram of muscle increase is calculated, then at 20 kg empty body weight, 396g and 604g from the monophasic and biphasic muscles respectively, constitutes each kilogram of carcass muscle increase. At 50 kg empty body weight, monophasic muscles contribute 380g and the biphasic muscles 620g to each kilogram of carcass muscle increase. Within the biphasic muscle group, at 20 kg empty body weight, early maturing muscles accounted for 494g and late maturing muscles 110g of the muscle weight increase. At 50 kg empty body weight, early maturing muscles accounted for 282g, and late maturing muscles 338g of the muscle weight increase for each kilogram increase in carcass muscle.

Development of the musculature of the male grey kangaroo may be summarized by the generalization that growth of the musculature as a whole, is constant relative to empty body weight. Within this constant growth rate, development of form is brought about by re-allocation of the proportion of muscle present in the various body regions. Changes in proportion are mediated by differential growth rates.

Two further muscle growth theories are tested against the grey kangaroo muscle growth data. Berg and Butterfield (1976) postulated that "in general, large muscles grow proportionately faster than small muscles" and "in general, muscles most closely related to the skeleton grow slowest and those most removed, grow fastest". The 'k' values for the allometric functions fitted to the female grey kangaroo muscle growth data, were analysed to seek evidence to test either theory.

In the grey kangaroo, larger muscles were found to grow at a significantly greater rate than smaller muscles. No correlation was found between close association with the skeleton and rate of muscle growth. Though no correlation was found between growth rate and closeness of association of muscle with bone in the grey kangaroo, the arbitrary and subjective way in which muscles were grouped as to their areas of bone attachment, requires that a more critical assessment of this theory be made before it is rejected for the kangaroo.

Centripetal and Cranio-Caudal Growth Theories

Male Grey Kangaroo

In the forequarter, a wave of muscle growth rate increase begins in the distal limb at 28.3 kg empty body weight and reaches the thorax by 40.2 kg empty body weight. In the hindlimb, a wave of muscle growth rate decrease begins distally in the crus at 38.6 kg empty body weight and passes into the proximal hindlimb muscle group at 51.3 kg empty body weight. Two centripetal patterns of growth impetus are therefore present in the musculature of the male grey kangaroo. A wave of increasing growth impetus commencing in the distal pectoral limb, and a wave of decreasing growth impetus commencing in the distal pectoral limb and a wave of decreasing growth impetus commencing in the distal pelvic limb.

Growth impetus patterns were not evident in the musculature along the body axis. The most significant finding in the growth impetus of spinal muscle was the divergence in the growth pattern of the musculature of the tail. While the growth rate of the spinal muscle group decreased at 23.3 kg empty body weight, growth rate increased in the tail muscle at 18.3 kg empty body weight. Clearly, a cranio-caudal wave of decreasing growth impetus does not pass through the spinal musculature to end in the tail.

The centripetal growth impetus patterns of the male grey kangaroo will alter the muscle-weight distribution of animals at differing empty body weights. In cattle, Butterfield (1963) demonstrated little difference in the muscle-weight distribution of steers over 240 days of age and concluded that in steers there was no optimum time to slaughter on the basis of muscle-weight distribution. In female grey kangaroos, as in steers, the muscle-weight distribution alters little from vacation of the pouch to late adult life. However, in male grey kangaroos, muscle-weight distribution changes markedly through life and an optimum time to slaughter, based on muscle-weight distribution, may be determined.

With the assumption that the greater the percentage of hindquarter muscle, the more valuable the carcass, the empty body weight at which the proportion of forequarter muscle commences to increase and hindquarter muscle to decrease, would be the weight to advocate slaughter. Thus on a muscle-weight distribution basis, male grey kangaroos should be slaughtered between 31 and 37 kg empty body weight. This optimum weight range for slaughter should be qualified by the knowledge that tail muscle increases its proportion of total muscle at 18 kg; spinal muscle decreases its proportion at 23 kg; and proximal hindlimb muscle decreases its proportion of total muscle at 51 kg empty body weight.

Factors other than muscle-weight distribution affect the optimum slaughter weight. Growth rate and absolute size will influence when animals should be harvested. However, carcass fat content, which is the predominant characteristic in the determination of slaughter weight in domestic animals, is not a factor in the kangaroo. Fat will be shown to comprise a very low percentage of the kangaroo body.

The technical problems associated with the harvesting of wild animals will probably determine the body weights at which kangaroos are slaughtered.

MUSCLE WEIGHT DISTRIBUTION

Domestic animals have been bred for superiority in one or more characters regarded as desireable. Butterfield (1963a) made a critical evaluation of the superiority in muscle-weight distribution of the recognized improved British breeds of cattle over unimproved Shorthorn cattle. Despite the intensive selection on the improved type of cattle, he found that "all breeds of cattle have a basically similar muscle-weight distribution." He postulated two basic reasons for this rather startling result. Selection of cattle for beef production has been unduly influenced by conformation and body fat distribution without critical assessment of factors truely correlated to muscle-weight distribution. The attachments of individual muscles were similar between breeds and as all cattle have the same basic functional requirements, a similar muscle-weight distribution could be expected.

An interesting model exists in the kangaroo. As in cattle, attachments of individual muscles were similar between grey and red kangaroos. Unlike cattle, functional requirements of the locomotor systems varied as a result of differences in locomotion between the two species.

The author was collecting specimens of the red kangaroo with Mr. Ron McMillan, a commercial kangaroo shooter based at Coonamble, N.S.W. The red kangaroos were grazing crops also grazed by grey kangaroos. At night, under spot-light shooting conditions, it was difficult to identify coat colours for the kangaroos, yet Mr. McMillan was able to consistently differentiate between the red and grey species. When questioned on this, he pointed out that the two species hop in characteristically different ways. The grey kangaroos hop with the body axis more vertical, the red kangaroos with the body axis more horizontal.

Windsor and Dagg (1971) analysed the bipedal hop patterns of grey and red kangaroos. They concluded that ".... bipedal hop patterns ... were found to vary considerably with the habitat of the species. Species which live in open country, generally have a shorter period of suspension than those which live in dense forests or on rocky hills."

This difference in locomotion would be most likely to affect the distal hindlimb, proximal hindlimb and spinal muscle groups. The distal and proximal hindlimb muscles must supply the vertical propulsive force. The spinal musculature supports the spinal column against gravitational stress.

Both distal and proximal hindlimb muscle weights were significantly greater for both sexes of the grey kangaroo, when compared with the same sex of the red kangaroo. Conversely, spinal muscle weights were significantly greater for the red kangaroo. On a proportionate basis, distal hindlimb muscle weight was 21% less for female red kangaroos and 27% less for male red kangaroos, when compared with the same sex of the grey kangaroo. Proximal hindlimb muscle weight was 5% less for female red kangaroos and 4% less for male red kangaroos, when compared with the same sex of grey kangaroo. Spinal muscle weight was 12% greater for female red kangaroos and 11% greater for male red kangaroos, when compared with the same sex of the grey kangaroo.

A hypothesis that the hindlimb musculature of the grey kangaroo is bulkier to enable greater vertical lift, and that the spinal muscle of the red kangaroo is bulkier to support the greater strain of a vertebral column held nearer the horizontal, would provide a functional basis for the observed differences in muscle weight distribution.

The relationships may be fortuitous only. However, a functional basis for the differences observed is most likely.

The interesting feature is the large percentage differences which can be achieved in muscle-weight distribution within animals with basically similar attachments for individual muscles. Selection on the grey kangaroo has adapted it to a forest habitat, the red kangaroo to an open plains habitat. The functional requirements for locomotion in the two habitats are the most likely reason for the different muscle-weight distribution in the muscle groups discussed. Selection for genetic improvement in muscle-weight distribution in domestic animals may best be achieved if indices estimating the functional muscular capabilities of individual animals were defined and used as a basis for selection. Closer scrutiny of the draught breeds of cattle may find breeds which do have a muscle-weight distribution significantly different to that found in the breeds studied by Butterfield (1963a).

CHAPTER 6

BONE GROWTH PATTERNS

"We have an English proverb, that bones bring meat to town."

Thomas Fuller

"The vertebrate skeleton serves for support and protection while providing levers for muscular action. It functions as a storehouse for minerals, and as a site for fat storage and blood cell formation.

Miller et al (1964)

".... bone cannot expand from within.... bone cannot grow by the interstitial mechanism, but only by the appositional - by having new layers added to one or more of its surfaces."

Ham and Leeson (1961)

INTRODUCTION.

The skeleton may be classified into axial, appendicular and heterotopic skeleton. The bones of the skeleton themselves are classified according to shape and comprise long bones, short bones, sesamoid bones, flat bones and irregular bones. The biochemistry of bone was discussed by White et al (1959). Ham and Leeson (1961) presented a detailed description of the microscopic structure of bone and the gross morphology of bone is well documented in the texts of Sisson and Grossman (1953) and Cunningham (1931).

The growth and development of bone has been intensively studied in relation to the effects of nutrition on bone growth. Dickerson and McCance (1961) studied the effect of severe undernutrition in growing and adult animals on the dimensions and chemistry of long bones. McCance et al (1961, 1962) studied the effect of severe undernutrition on the development of the skulls, jaws and teeth of pigs and also the effect of undernutrition and realimentation on the mechanical properties of bone. Adams (1971) studied the effect of intrauterine growth retardation on the development of the skeleton of the pig. Tulloh and Romberg (1963) studied the effect of gravity on bone development in lambs. Glucksmann (1942) examined the effect of mechanical stresses on bone formation. Simpson et al (1950) examined some of the endocrine influences on skeletal growth and differentiation.

Quantitative studies on the skeleton include the work of Lowrance and Latimer (1957), Cuthbertson and Pomeroy (1962), as well as the major growth studies cited in the introduction to regional growth.

This section of the study investigates patterns of bone growth in the kangaroo. Species are compared.

METHODS AND MATERIALS.

The general methods and materials used are described in Chapters 2 and 3.

RESULTS

The results are presented in the following format. A figure of the data plot for each bone relationship investigated is presented together with the functions fitted to the data. The functions are compared to establish differences, if any, between the two sexes and species of the grey and red kangaroo. In the grey kangaroo, where a change in growth impetus occurs, the estimated point (X_e Y_e) of the change and its magnitude (b1 b2) are given, based on the two phase linear function described by Griffiths and Miller (1973).

In conjunction with the mathematical presentation of the results, a brief written summary of the differences found between the grey and red kangaroo is presented. Bone weights are predicted from the functions fitted to the data and presented in Table 13. For the grey kangaroo, the empty body weights at which growth impetus changes occur in bone are presented in Table 15.

Finally, the relative proportions of bone for the five species of macropod studied are presented in Table 14.

Symbols used in the text are:-

Y	dependent variable
X	independent variable
X_e Y_e	estimated point of change in the growth impetus
log	logarithm of
a	allometric function: is the fractional coefficient
k	ratio of the relative growth of Y to X
b, bl, b2	rates of growth of Y to X
n	number of observations
r	correlation coefficient
SE	standard error
NS	not significant at the 5% level
*	significant at the 5% level
**	significant at the 1% level
***	significant at the 0.1% level

(I) Female Grey Kangaroo

Monophasic growth patterns were evident in the hindlimb bone weights.

Forelimb bone weight on half carcass bone weight exhibited biphasic growth. The second growth phase exhibited a growth impetus increase at 13.4 kg empty body weight. Within the forelimb, radius weight and clavicle weight on half carcass bone weight were biphasic with an increase in growth impetus occurring at 13.4 and 18.4 kg empty body weight respectively.

Forelimb bone weights (Figure 68) were significantly greater for female red kangaroos but not significantly different between males when the same sex of grey and red kangaroo were compared. Between sexes within species, forelimb bone weights were significantly greater for males.

FORELIMB BONE

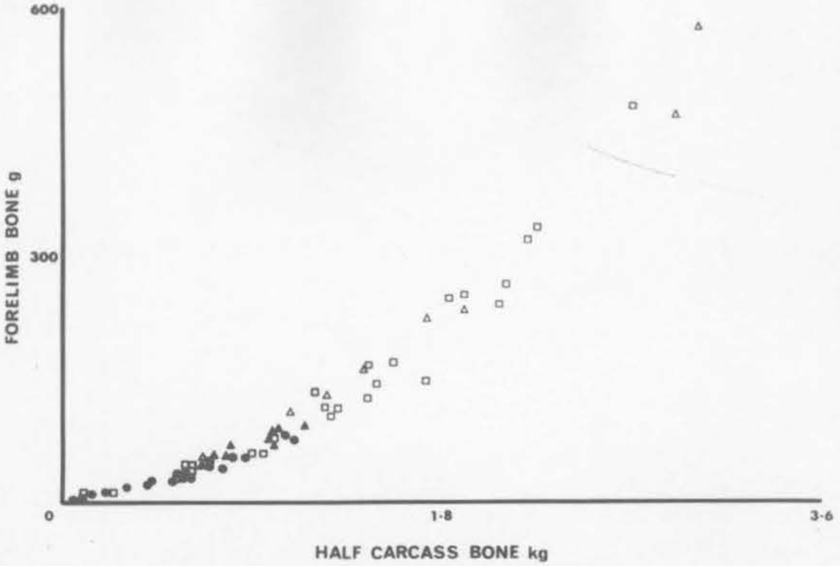

Figure 68 Relationship of forelimb bone weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.765 + .936 \log X$ P ***
$n = 19$ $r = .986$ SE $k = .039$

☐ Male Grey Kangaroo $\log Y = 1.954 + 1.322 \log X$ P ***
$n = 25$ $r = .974$ SE $k = .064$

▲ Female Red Kangaroo $\log Y = 1.896 + 1.187 \log X$ P ***
$n = 9$ $r = .955$ SE $k = .139$

△ Male Red Kangaroo $\log Y = 1.971 + 1.546 \log X$ P ***
$n = 8$ $r = .997$ SE $k = .052$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	–
Female Red/Male Red	*	–
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (.6kg, 32.6g)

SE X_e = .1 SE Y_e = 5.2

Estimated slopes $b1 = 50.67$ $b2 = 89.85$

SE $b1 = 5.96$ SE $b2 = 7.93$

B. Male

Estimated point of change (X_e, Y_e) (1.1kg, 76.0g)

SE X_e= .1 SE Y_e = 25.5

Estimated slopes $b1 = 66.95$ $b2 = 228.14$

SE $b1 = 29.38$ SE $b2 = 15.13$

Hindlimb bone weights (Figure 69) were significantly greater for both sexes of the grey kangaroo when compared between the same sex of the red kangaroo. Between sexes within species, hindlimb bone weights were significantly greater for female grey kangaroos but not significantly different between red kangaroos.

HINDLIMB BONE

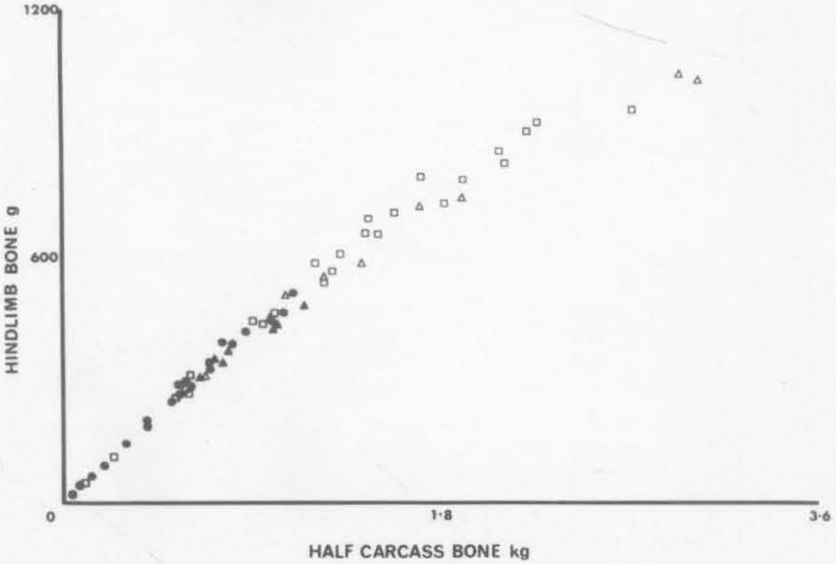

Figure 69 Relationship of hindlimb bone weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 2.674 + 1.016 \log X$ P ***
$n = 19$ $r = .999$ SE $k = .012$

□ Male Grey Kangaroo $\log Y = 2.646 + .937 \log X$ P ***
$n = 25$ $r = .995$ SE $k = .019$

▲ Female Red Kangaroo $\log Y = 2.633 + .839 \log X$ P ***
$n = 9$ $r = .984$ SE $k = .058$

△ Male Red Kangaroo $\log Y = 2.646 + .793 \log X$ P ***
$n = 8$ $r = .993$ SE $k = .038$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	**	–
Female Red/Male Red	NS	NS
Female Grey/Female Red	*	–
Male Grey/Male Red	**	–

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (1.6kg, 738.2g)
SE $X_e = .1$ SE $Y_e = 38.9$

Estimated slopes $b1 = 443.83$ $b2 = 227.84$
SE $b1 = 14.73$ SE $b2 = 33.09$

Vertebrae weights (Figure 70) were not significantly different between sexes or species in the grey and red kangaroo.

TOTAL VERTEBRAE

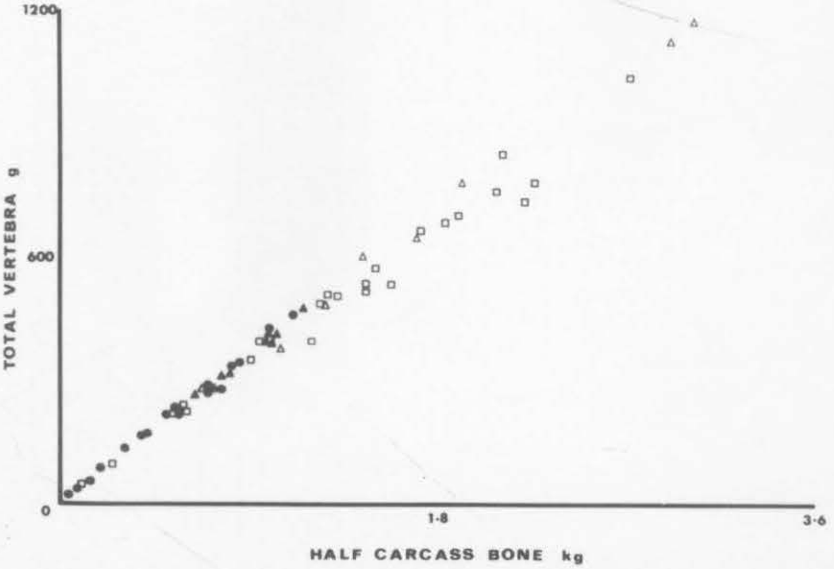

Figure 70 Relationship of half carcass vertebral weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 2.599 + .988 \log X$ P ***
$n = 19$ $r = .999$ SE $k = .011$

□ Male Grey Kangaroo $\log Y = 2.580 + .956 \log X$ P ***
$n = 25$ $r = .996$ SE $k = .017$

▲ Female Red Kangaroo $\log Y = 2.609 + 1.068 \log X$ P ***
$n = 9$ $r = .989$ SE $k = .060$

△ Male Red Kangaroo $\log Y = 2.590 + .998 \log X$ P ***
$n = 8$ $r = .994$ SE $k = .043$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = 2.589 + .969 \log X$ P ***
Two Sexes and Species $n = 61$ $r = .998$ SE $k = .009$

Rib weights (Figure 71) were significantly greater for female red kangaroos but not significantly different for males when the same sex of grey and red kangaroo were compared. Between sexes within species, rib weights were significantly greater for male grey kangaroos but not significantly different between the red kangaroos.

RIBS

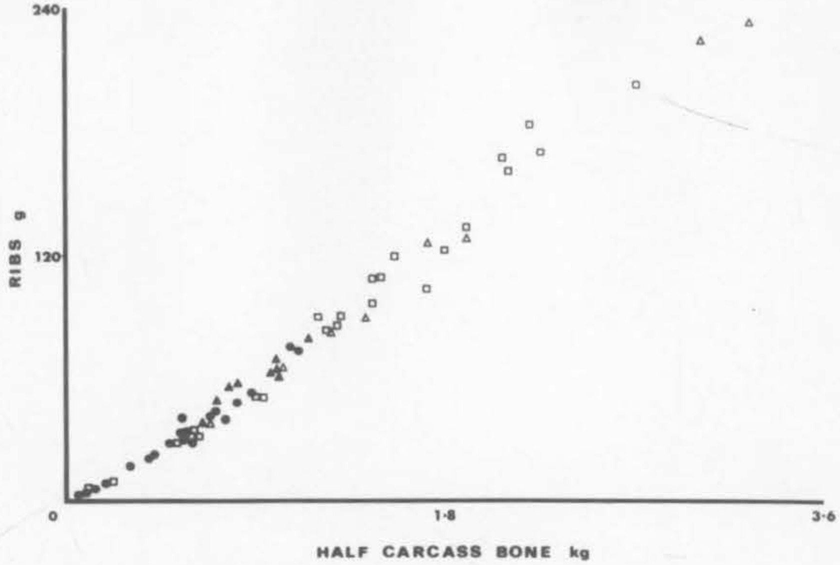

Figure 71 Relationship of rib weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.780 + 1.088 \log X$ P ***
$n = 19$ $r = .992$ SE $k = .033$

□ Male Grey Kangaroo $\log Y = 1.804 + 1.176 \log X$ P ***
$n = 25$ $r = .994$ SE $k = .027$

▲ Female Red Kangaroo $\log Y = 1.819 + 1.032 \log X$ P ***
$n = 9$ $r = .949$ SE $k = .130$

△ Male Red Kangaroo $\log Y = 1.786 + 1.200 \log X$ P ***
$n = 8$ $r = .998$ SE $k = .034$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	*	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = 1.805 + 1.141 \log X$ P ***
Two Sexes and Species $n = 61$ $r = .994$ SE $k = .016$

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (0.8kg, 43.8g)

SE $X_e = 0.2$ SE $Y_e = 19.2$

Estimated slopes $b1 = 56.09$ $b2 = 87.92$

SE $b1 = 16.16$ SE $b2 = 3.80$

Clavicle weights (Figure 72) were significantly greater for female red kangaroos but not significantly different between males when the same sex of grey and red kangaroo were compared. Between sexes within species, clavicle weights were significantly greater for male grey kangaroos but not significantly different between the red kangaroos.

CLAVICLE

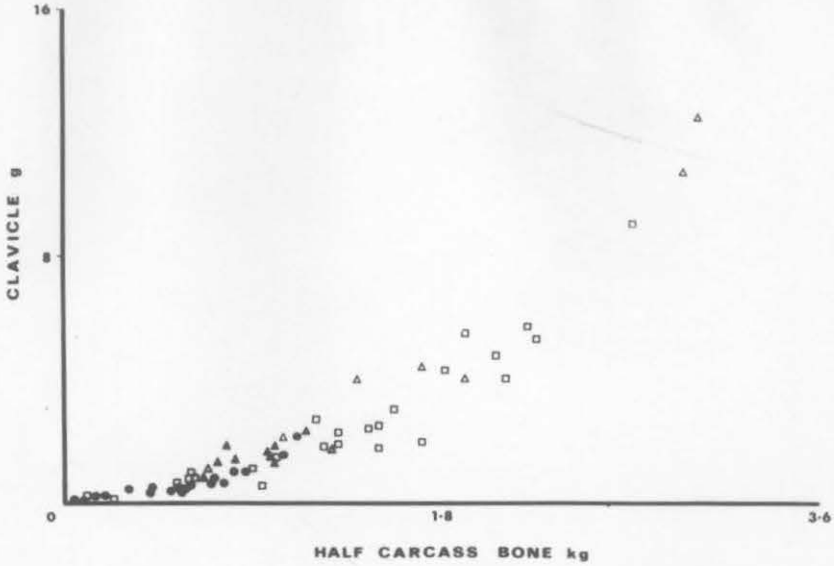

Figure 72 Relationship of clavicle weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = .016 + .905 \log X$ $n = 19 \quad r = .936 \quad SE\ k = .082$	P ***
■ Male Grey Kangaroo	$\log Y = .183 + 1.337 \log X$ $n = 25 \quad r = .934 \quad SE\ k = .107$	P ***
▲ Female Red Kangaroo	$\log Y = .231 + 1.146 \log X$ $n = 9 \quad r = .743 \quad SE\ k = .390$	P *
△ Male Red Kangaroo	$\log Y = .249 + 1.627 \log X$ $n = 8 \quad r = .967 \quad SE\ k = .174$	P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	**	–
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (0.8kg, 0.7g)
$SE\ X_e = 0.0 \quad SE\ Y_e = 0.1$

Estimated slopes $b1 = 0.79 \quad b2 = 3.56$
$SE\ b1 = 0.15 \quad SE\ b2 = 0.39$

B. Male

Estimated point of change (X_e, Y_e) (1.7kg, 2.8g)
$SE\ X_e = 0.1 \quad SE\ Y_e = 0.5$

Estimated slopes $b1 = 1.82 \quad b2 = 5.76$
$SE\ b1 = 0.35 \quad SE\ b2 = 0.79$

Scapula weights (Figure 73) were significantly greater for female red kangaroos but not significantly different between males when the same sex of grey and red kangaroos were compared. Between sexes within species, scapula weights were significantly greater for males.

SCAPULA

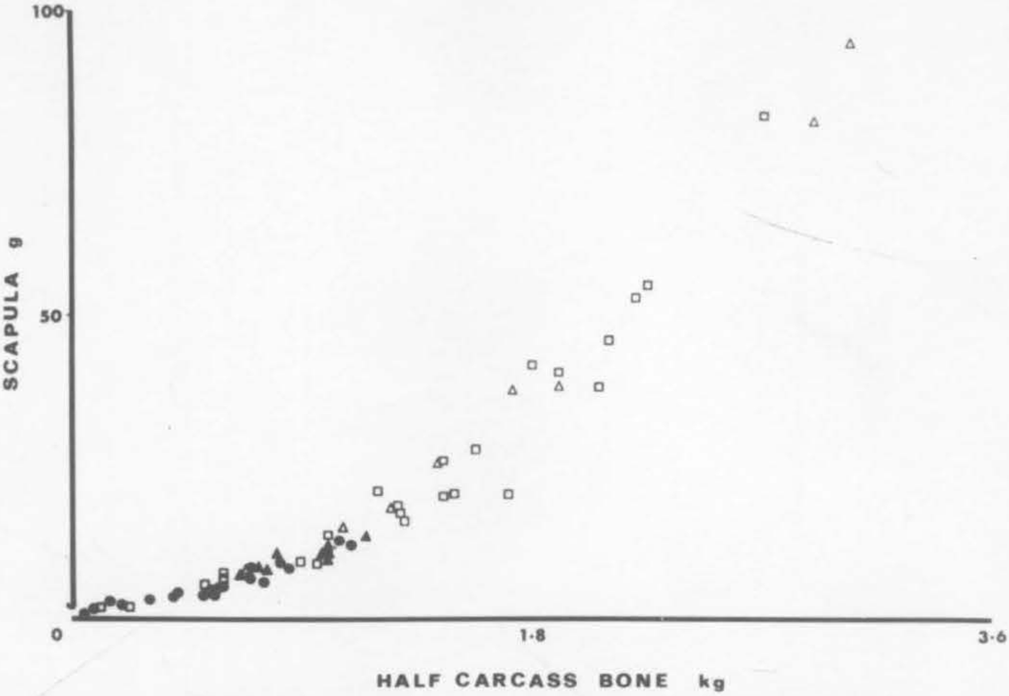

Figure 73 Relationship of scapula weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .962 + .898 \log X$ P ***
$n = 19$ $r = .981$ SE $k = .043$

□ Male Grey Kangaroo $\log Y = 1.158 + 1.325 \log X$ P ***
$n = 25$ $r = .967$ SE $k = .073$

▲ Female Red Kangaroo $\log Y = 1.048 + .944 \log X$ P ***
$n = 9$ $r = .903$ SE $k = .169$

△ Male Red Kangaroo $\log Y = 1.163 + 1.618 \log X$ P ***
$n = 8$ $r = .995$ SE $k = .066$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	**	-
Female Grey/Female Red	NS	**
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (1.7kg, 26.4g)
SE $X_e = 0.1$ SE $Y_e = 3.0$

Estimated slopes $b1 = 17.42$ $b2 = 55.48$
SE $b1 = 2.19$ SE $b2 = 4.91$

Humerus weights (Figure 74) were significantly greater for female red kangaroos but not significantly different between males, when the same sex of grey and red kangaroo were compared. Between sexes within species, humerus weights were significantly greater for males.

HUMERUS

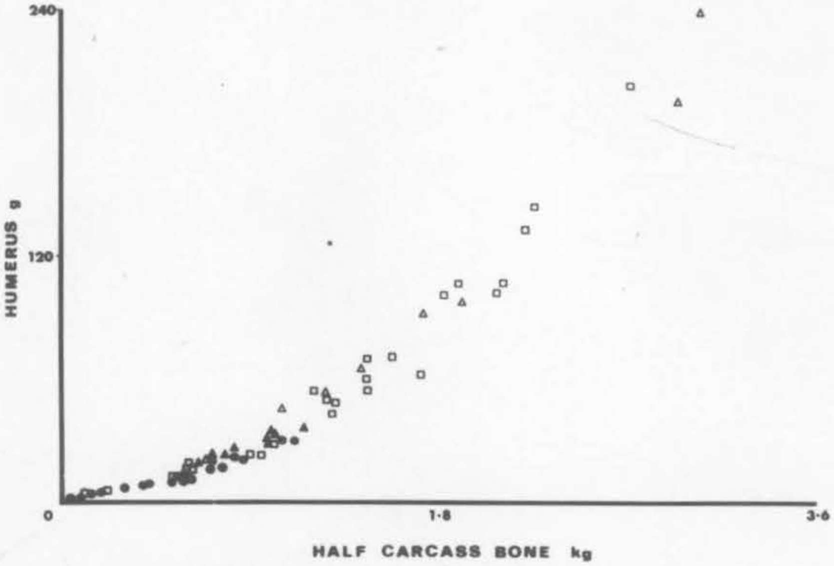

Figure 74 Relationship of humerus weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.350 + .970 \log X$ P ***
$n = 19$ $r = .987$ SE $k = .038$

□ Male Grey Kangaroo $\log Y = 1.555 + 1.373 \log X$ P ***
$n = 25$ $r = .973$ SE $k = .068$

▲ Female Red Kangaroo $\log Y = 1.492 + 1.151 \log X$ P ***
$n = 9$ $r = .968$ SE $k = .113$

△ Male Red Kangaroo $\log Y = 1.578 + 1.573 \log X$ P ***
$n = 8$ $r = .997$ SE $k = .050$

<u>Comparison of differences between the two sexes and species</u>

Comparison	k	log a
Female Grey/Male Grey	***	–
Female Red/Male Red	**	–
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	NS

<u>Change in the Growth Impetus in the Grey Kangaroo</u>

A. Female

Estimated point of change (X_e, Y_e) (0.6kg, 12.5g)
SE $X_e = 0.0$ SE $Y_e = 0.8$

Estimated slopes $b1 = 19.63$ $b2 = 34.95$
SE $b1 = 1.68$ SE $b2 = 2.49$

B. Male

Estimated point of change (X_e, Y_e) (1.1kg, 29.0g)
SE $X_e = 0.1$ SE $Y_e = 9.8$

Estimated slopes $b1 = 26.24$ $b2 = 97.24$
SE $b1 = 11.96$ SE $b2 = 6.15$

Radius weights (Figure 75) were significantly greater for female red kangaroos but not significantly different between males, when the same sex of grey and red kangaroo were compared. Between sexes within species, radius weights were significantly greater for male grey kangaroos, but not significantly different between the red kangaroo.

RADIUS

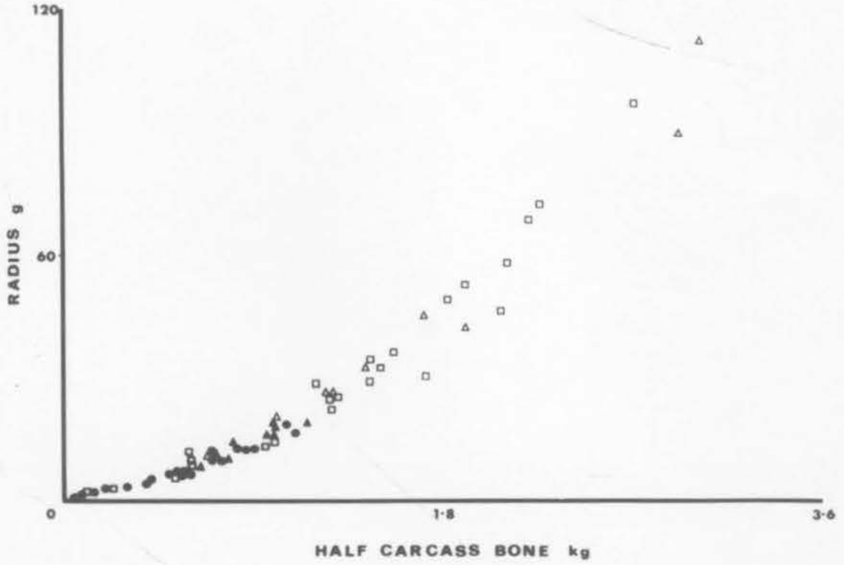

Figure 75 Relationship of radius weight to half carcass bone weight in grey and red kangaroos.

●	Female Grey Kangaroo	$\log Y = 1.122 + .949 \log X$ $n = 19$ $r = .980$ SE $k = .047$	P ***
□	Male Grey Kangaroo	$\log Y = 1.285 + 1.292 \log X$ $n = 25$ $r = .973$ SE $k = .064$	P ***
▲	Female Red Kangaroo	$\log Y = 1.230 + 1.522 \log X$ $n = 9$ $r = .935$ SE $k = .219$	P ***
△	Male Red Kangaroo	$\log Y = 1.268 + 1.512 \log X$ $n = 8$ $r = .993$ SE $k = .071$	P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change	(X_e, Y_e) (1.4kg, 26.2g) SE $X_e = 0.1$ SE $Y_e = 4.7$
Estimated slopes	$b1 = 20.26$ $b2 = 51.18$ SE $b1 = 3.70$ SE $b2 = 3.99$

Ulna weights (Figure 76) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, ulna weights were significantly greater for males.

ULNA

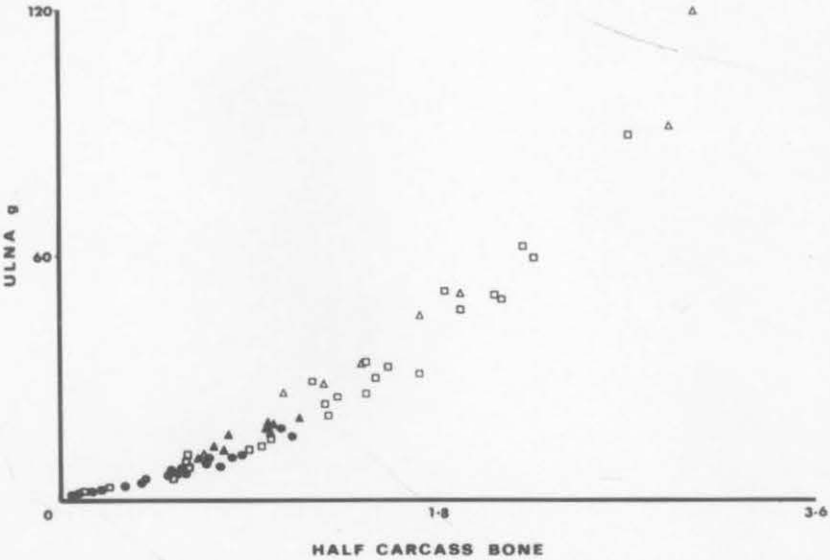

Figure 76 Relationship of ulna weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.089 + .896 \log X$ P ***
$n = 19$ $r = .984$ SE $k = .039$

☐ Male Grey Kangaroo $\log Y = 1.268 + 1.257 \log X$ P ***
$n = 25$ $r = .975$ SE $k = .060$

▲ Female Red Kangaroo $\log Y = 1.247 + 1.112 \log X$ P ***
$n = 9$ $r = .942$ SE $k = .150$

△ Male Red Kangaroo $\log Y = 1.315 + 1.465 \log X$ P ***
$n = 8$ $r = .994$ SE $k = .067$

<u>Comparison of differences between the two sexes and species</u>

Comparison	k	log a
Female Grey/Male Grey	***	-
Female Red/Male Red	NS	*
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	*

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (1.1kg, 16.1g)
SE $X_e = 0.1$ SE $Y_e = 4.8$

Estimated slopes $b1 = 14.46$ $b2 = 40.40$
SE $b1 = 5.20$ SE $b2 = 2.68$

Femur weights (Figure 77) were significantly greater for both sexes of the grey kangaroo, when compared between the same sex of the red kangaroo. Between sexes within species, femur weights were significantly greater for female grey kangaroos, but significantly greater for male red kangaroos.

FEMUR

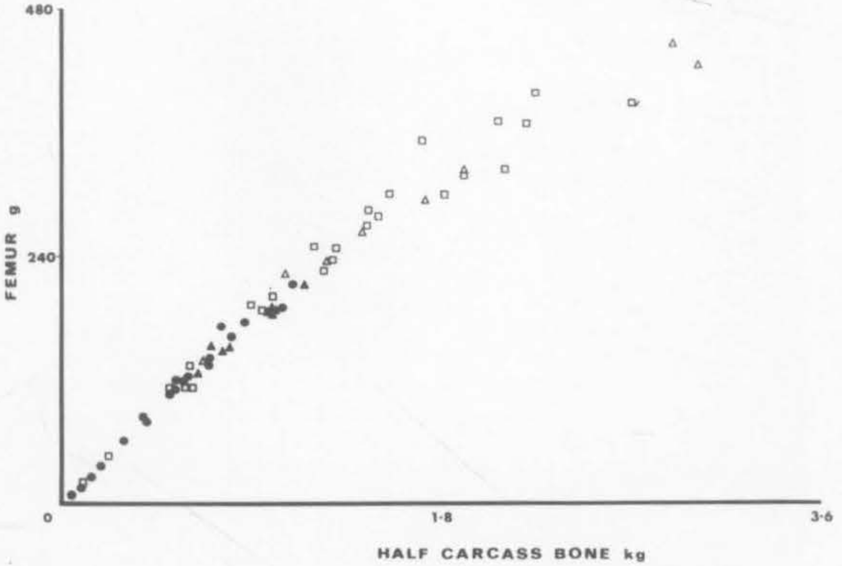

Figure 77 Relationship of femur weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 2.312 + 1.071 \log X$ P ***
$n = 19$ $r = .998$ SE $k = .018$

◻ Male Grey Kangaroo $\log Y = 2.272 + .942 \log X$ P ***
$n = 25$ $r = .992$ SE $k = .025$

▲ Female Red Kangaroo $\log Y = 2.271 + .858 \log X$ P ***
$n = 9$ $r = .982$ SE $k = .062$

△ Male Red Kangaroo $\log Y = 2.294 + .741 \log X$ P ***
$n = 8$ $r = .993$ SE $k = .036$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	***	–
Female Red/Male Red	NS	*
Female Grey/Female Red	*	–
Male Grey/Male Red	**	–

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (1.7kg, 317.2g)
SE $X_e = 0.1$ SE $Y_e = 19.9$

Estimated slopes $b1 = 186.84$ $b2 = 80.86$
SE $b1 = 9.19$ SE $b2 = 20.66$

Tibia weights (Figure 78) were significantly greater for both sexes of the grey kangaroo, when compared between the same sex of the red kangaroo. Between sexes within species, tibia weights were significantly greater for female grey kangaroos but not significantly different between red kangaroos.

TIBIA

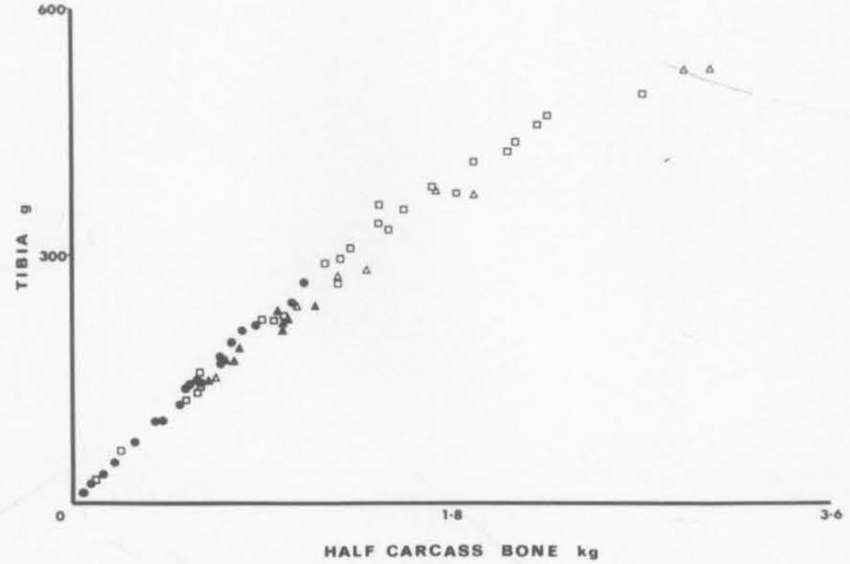

Figure 78 Relationship of tibia weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 2.380 + .989 \log X$ P ***
$n = 19$ $r = .999$ SE $k = .012$

□ Male Grey Kangaroo $\log Y = 2.355 + .929 \log X$ P ***
$n = 25$ $r = .996$ SE $k = .017$

▲ Female Red Kangaroo $\log Y = 2.339 + .833 \log X$ P ***
$n = 9$ $r = .969$ SE $k = .081$

△ Male Red Kangaroo $\log Y = 2.338 + .827 \log X$ P ***
$n = 8$ $r = .993$ SE $k = .041$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	**	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	**
Male Grey/Male Red	*	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (1.6kg, 358.3g)
SE $X_e = 0.1$ SE $Y_e = 18.9$

Estimated slopes $b1 = 228.19$ $b2 = 133.02$
SE $b1 = 6.97$ SE $b2 = 12.56$

Fibula weights (Figure 79) were significantly greater for both sexes of the grey kangaroo, when compared between the same sex of the red kangaroo. Between sexes within species, fibula weights were significantly greater for female grey kangaroos, but not significantly different between the red kangaroo.

FIBULA

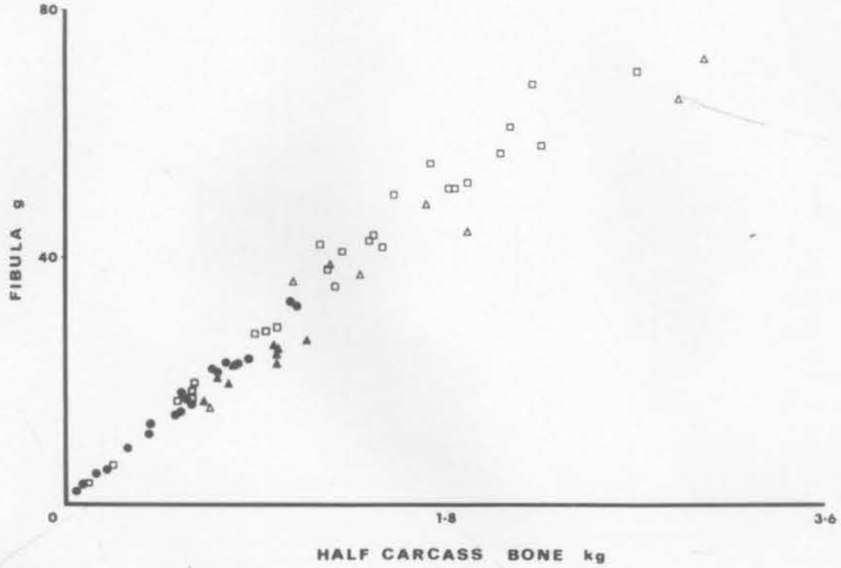

Figure 79 Relationship of fibula weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.448 + .915 \log X$ P ***
$n = 19$ $r = .996$ SE $k = .020$

□ Male Grey Kangaroo $\log Y = 1.469 + .974 \log X$ P ***
$n = 25$ $r = .995$ SE $k = .021$

▲ Female Red Kangaroo $\log Y = 1.386 + .739 \log X$ P ***
$n = 9$ $r = .933$ SE $k = .108$

△ Male Red Kangaroo $\log Y = 1.436 + .890 \log X$ P ***
$n = 8$ $r = .951$ SE $k = .118$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	*	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	*

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (1.7kg, 51.8g)
SE $X_e = 0.0$ SE $Y_e = 1.1$

Estimated slopes $b1 = 30.19$ $b2 = 19.18$
SE $b1 = 1.34$ SE $b2 = 2.77$

Marsupial bone weights (Figure 80) were not significantly different between female grey and red kangaroos. Marsupial bone weights were significantly greater for female than male grey kangaroos.

MARSUPIAL BONE

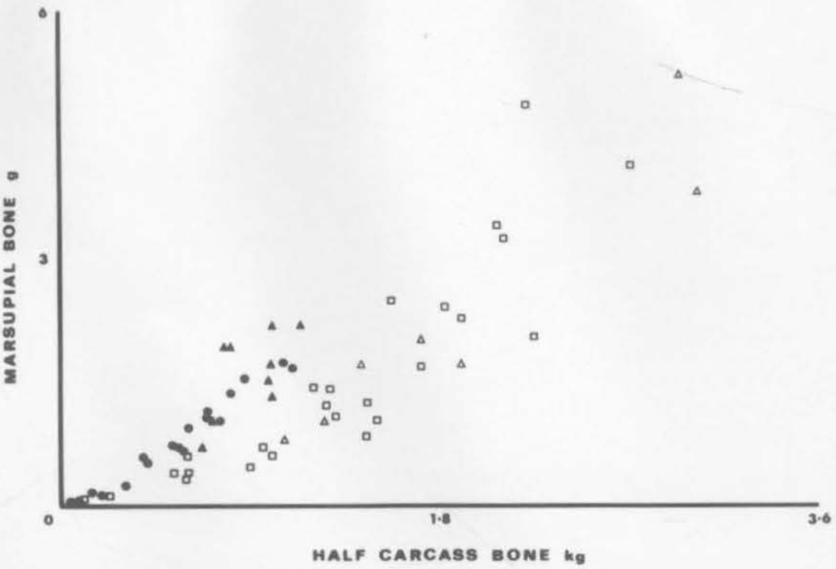

Figure 80 Relationship of marsupial bone weight to half carcass bone weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .164 + 1.113 \log X$ P ***
$n = 19$ $r = .954$ SE $k = .085$

◻ Male Grey Kangaroo $\log Y = -.047 + 1.317 \log X$ P ***
$n = 25$ $r = .941$ SE $k = .099$

▲ Female Red Kangaroo $\log Y = .255 + 1.430 \log X$ P *
$n = 9$ $r = .709$ SE $k = .538$

△ Male Red Kangaroo $\log Y = .128 + .807 \log X$ P NS
$n = 8$ $r = .655$ SE $k = .380$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	***
Female Grey/Female Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Female

Estimated point of change (X_e, Y_e) (0.2kg, 0.1g)
SE $X_e = 0.1$ SE $Y_e = 0.1$

Estimated slopes $b1 = 0.17$ $b2 = 1.82$
SE $b1 = 1.32$ SE $b2 = 0.12$

Marsupial bone lengths (Figure 81) were not significantly different between females but were significantly greater for male red kangaroos when the same sex of grey and red kangaroo were compared. Between sexes within species, marsupial bone lengths were significantly greater for females.

MARSUPIAL BONE

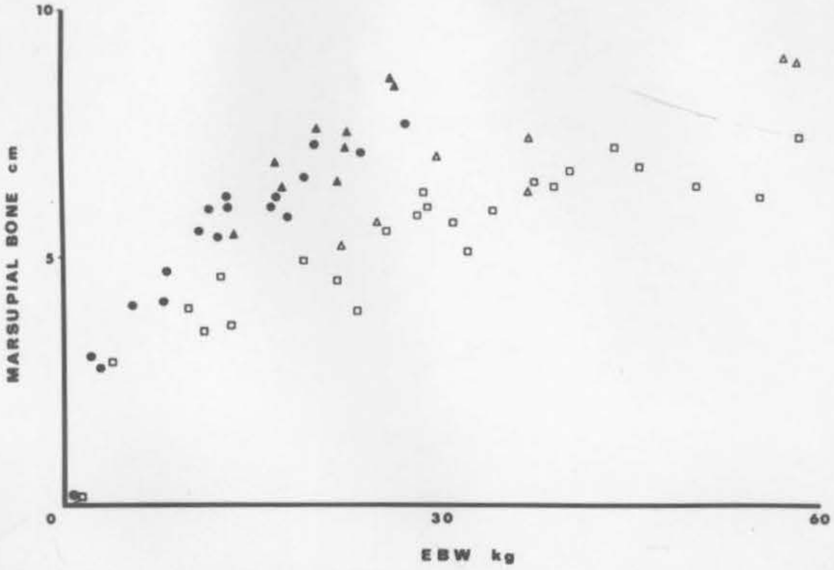

Figure 81 Relationship of marsupial bone length to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .302 + .405 \log X$ P ***
$n = 18$ $r = .982$ SE $k = .020$

◻ Male Grey Kangaroo $\log Y = .172 + .392 \log X$ P ***
$n = 24$ $r = .957$ SE $k = .025$

▲ Female Red Kangaroo $\log Y = .072 + .596 \log X$ P **
$n = 9$ $r = .893$ SE $k = .113$

△ Male Red Kangaroo $\log Y = .043 + .514 \log X$ P ***
$n = 7$ $r = .944$ SE $k = .081$

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	***
Female Red/Male Red	NS	***
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	**

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (7.0kg, 4.7cm)
SE $X_e = 1.9$ SE $Y_e = 0.4$

Estimated slopes $b1 = 0.45$ $b2 = 0.16$
SE $b1 = 0.11$ SE $b2 = 0.02$

B. Male

Estimated point of change (X_e, Y_e) (41.6kg, 6.8cm)
SE $X_e = 4.7$ SE $Y_e = .5$

Estimated slopes $b1 = 0.11$ $b2 = -0.01$
SE $b1 = .01$ SE $b2 = .05$

TABLE 13

Predicted bone weights for grey and red kangaroos. Values are predicted from the allometric functions given with Figures 68 to 81.

	HALF CARCASS BONE WEIGHTS (kg)					
	0.6	0.9	1.2	1.5	2.0	2.5
PREDICTED FORELIMB BONE WEIGHT (g)						
Female Grey	36	53	69			
Male Grey	46	78	114	154	225	302
Female Red	43	69	98			
Male Red	42	79	124	175	273	386
PREDICTED HINDLIMB BONE WEIGHT (g)						
Female Grey	281	424	568			
Male Grey	274	401	525	647	847	1044
Female Red	280	393	501			
Male Red	295	407	511	610	767	915
PREDICTED HALF CARCASS VERTEBRAE WEIGHT (g)						
Female Grey	240	358	476			
Male Grey	233	344	453	560	737	913
Female Red	236	363	494			
Male Red	234	350	467	583	777	971
PREDICTED HALF-CARCASS RIB WEIGHT (g)						
Female Grey	35	54	73			
Male Grey	35	56	79	103	144	187
Female Red	39	59	80			
Male Red	33	54	76	99	140	183

TABLE 13 (CONT.)

	HALF CARCASS BONE WEIGHT (kg)					
	0.6	0.9	1.2	1.5	2.0	2.5
PREDICTED CLAVICLE WEIGHT (g)						
Female Grey	0.7	0.9	1.2			
Male Grey	0.8	1.3	1.9	2.6	3.9	5.2
Female Red	1.0	1.5	2.1			
Male Red	0.8	1.5	2.4	3.4	5.5	7.9
PREDICTED SCAPULA WEIGHT (g)						
Female Grey	6	8	11			
Male Grey	7	13	18	25	36	48
Female Red	7	10	13			
Male Red	6	12	20	28	45	64
PREDICTED HUMERUS WEIGHT (g)						
Female Grey	14	20	27			
Male Grey	18	31	46	63	93	126
Female Red	17	28	38			
Male Red	17	32	50	72	113	160
PREDICTED RADIUS WEIGHT (g)						
Female Grey	8	12	16			
Male Grey	10	17	24	33	47	63
Female Red	8	14	22			
Male Red	9	16	24	34	53	74
PREDICTED ULNA WEIGHT (g)						
Female Grey	8	11	14			
Male Grey	10	16	23	31	44	59
Female Red	10	16	22			
Male Red	10	18	27	37	57	79

TABLE 13 (CONT.)

	HALF CARCASS BONE WEIGHT (kg)					
	0.6	0.9	1.2	1.5	2.0	2.5
PREDICTED FEMUR WEIGHT (g)						
Female Grey	119	183	249			
Male Grey	116	169	222	274	359	443
Female Red	120	170	218			
Male Red	135	182	225	266	329	388
PREDICTED TIBIA WEIGHT (g)						
Female Grey	145	216	287			
Male Grey	141	205	268	330	431	530
Female Red	143	200	254			
Male Red	143	200	253	305	386	465
PREDICTED FIBULA WEIGHT (g)						
Female Grey	18	25	33			
Male Grey	18	27	35	44	58	72
Female Red	17	23	28			
Male Red	17	25	32	39	51	62
PREDICTED MARSUPIAL BONE WEIGHT (g)						
Female Grey	0.8	1.3	1.8			
Male Grey	0.5	0.8	1.1	1.5	2.2	3.0
Female Red	0.9	1.6	2.3			
Male Red	0.9	1.2	1.6	1.9	2.4	2.8

	EMPTY BODY WEIGHT (kg)					
	15	20	30	40	50	55
PREDICTED MARSUPIAL BONE LENGTH (cm)						
Female Grey	6.0	6.7	7.9			
Male Grey	4.3	4.8	5.6	6.3	6.9	7.1
Female Red	5.9	7.0	9.0			
Male Red	4.4	5.1	6.3	7.4	8.2	8.7

TABLE 14

Comparisons between the relative proportions of bone in grey kangaroos (*Macropus giganteus*), red kangaroos (*Megaleia rufa*), wallaroos (*Macropus robustus*), red neck wallabies (*Macropus rufogriseus*) and swamp wallabies (*Wallabia bicolour*). Comparisons relative to the grey kangaroo = 100 and based on mature animals.

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Forelimb bone weight % Half Carcass Bone Weight	Female	100	115	93	82	100
	Male	100	107	70		
Hindlimb bone weight % Half Carcass Bone Weight	Female	100	94	101	98	107
	Male	100	91	94		
Vertebrae weight % Half Carcass Bone Weight	Female	100	102		106	89
	Male	100	108	117		
Rib weight % Half Carcass Bone Weight	Female	100	97	101	93	107
	Male	100	96	116		
Clavicle weight % Half Carcass Bone Weight	Female	100	112	72	70	63
	Male	100	129	70		
Scapula weight % Half Carcass Bone Weight	Female	100	105	111	89	112
	Male	100	107	83		

TABLE 14 (CONT.)

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Humerus weight % Half Carcass Bone Weight	Female	100	118	99	94	108
	Male	100	106	71		
Radius weight % Half Carcass Bone Weight	Female	100	115	73	69	87
	Male	100	101	64		
Ulna weight % Half Carcass Bone Weight	Female	100	118	91	74	98
	Male	100	115	66		
Femur weight % Half Carcass Bone Weight	Female	100	100	113	108	118
	Male	100	94	109		
Tibia weight % Half Carcass Bone Weight	Female	100	91	92	91	102
	Male	100	90	83		
Fibula weight % Half Carcass Bone Weight	Female	100	80	93	87	73
	Male	100	82	86		
Marsupial bone weight % Half Carcass Bone Weight	Female	100	131	296	202	172
	Male	100	82	152		
Marsupial bone length on Empty Body Weight	Female	100	112	238	221	158
	Male	100	129	387		

TABLE 15

Bone growth impetus patterns for the grey kangaroo. Estimated empty body weights at which growth impetus changes occur and the direction of the change. (Increase in impetus = +, decrease in impetus = -).

Bone Measurement	Empty Body Weight X_e kg	SE X_e	Half Carcass Bone Weight X_e	SE X_e	Direction
FEMALES					
Marsupial bone length	7.0	1.9			-
Marsupial bone weight	3.4		0.2	0.1	+
Humerus weight	13.4		0.6	0.0	+
Clavicle weight	18.4		0.8	0.0	+
Forelimb bone weight	13.4		0.6	0.1	+
MALES					
Total hindlimb bone weight	34.8		1.6	0.1	-
Tibia weight	3.48		1.6	0.1	-
Fibula weight	37.1		1.7	0.0	-
Femur weight	37.1		1.7	0.1	-
Marsupial bone length	41.6	4.7			-
Total forelimb bone weight	23.5		1.1	0.1	+
Rib weight	16.6		0.8	0.2	+
Ulna weight	23.5		1.1	0.1	+
Humerus weight	23.5		1.1	0.1	+
Radius weight	30.3		1.4	0.1	+
Scapula weight	37.1		1.7	0.1	+
Clavicle weight	37.1		1.7	0.1	+

The vertebral column exhibited monophasic growth.

In female grey kangaroos, forelimb bone had a greater tendency to follow the biphasic male growth pattern than did forelimb muscle. Where growth impetus increased in forelimb bone, the increase in growth impetus occurred at a lower empty body weight than for the corresponding relationship in males.

(II) Male Grey Kangaroos

A monophasic growth pattern was found for total vertebrae weight on half carcass bone weight. The remaining bone weight relationships investigated exhibited biphasic growth patterns.

In the hindlimb, growth impetus decrease occurred in tibia, fibula and femur at 34.8, 37.1 and 37.1 kg empty body weight respectively. Decrease in growth impetus of total hindlimb bone weight occurred at 34.8 kg empty body weight.

In the forelimb, ulna, radius, humerus, scapula and clavicle exhibited growth impetus increase at 23.5, 30.3, 23.5, 37.1 and 37.1 kg empty body weight, respectively. Increase in growth impetus of total forelimb bone weight occurred at 23.5 kg empty body weight.

Centripetal growth impetus decrease was not demonstrable from bone weight relationships in the hindlimb. With the overlap in standard errors, no clear gradient of impetus decrease could be shown passing from tibia to femur.

Centripetal growth impetus increase was demonstrable in the forelimb. The wave of impetus increase commenced in the distal forelimb at 23.5 kg empty body weight and reached the scapula by 37.1 kg empty body weight.

Species Differences

The species differences discussed are based on female animals and are extracted from Table 14.

The relative magnitude of the marsupial bone weight and length are greater in the smaller species of macropod and decrease with increasing species size. The relationships are greater for red kangaroos than greys which possibly reflects the more horizontal bipedal hop pattern of the red kangaroo.

Forelimb bone weight is relatively greatest in the red kangaroo and least in the red neck wallaby. Hindlimb bone weight is relatively greatest in the wallaroo and least in the red kangaroo.

It was not possible to establish similarities between species based on the relative proportions of the different skeletal units. The various conformation and functional differences between species produced intermingled patterns of bone weight distribution.

DISCUSSION.

Centripetal and Cranio-caudal Growth Patterns

Bone weight growth patterns in females did not demonstrate any clear waves of growth intensity. Biphasic growth patterns did occur, but could not be demonstrated to support the theories of centripetal or cranio-caudal growth.

In males, a wave of centripetal growth impetus increase was evident in the forelimb. In the hindlimb, if the weight of the pes were to be considered as chiefly comprising bone, then a wave of centripetal growth impetus decrease begins at the pes at 9.2 kg empty body weight and passes to the bones of the crus and thigh at approximately 35 kg empty body weight.

The marsupial or epipubic bones.

The two epipubic bones lie on either side of the ventral mid-line and articulate with the pubis. The bones are embedded in the abdominal musculature in both female and male kangaroos. In females, they lie deep to both the pouch and the m. marsupialis. Growth in weight and length of the epipubic bones is illustrated in Figures 80 and 81.

It may be postulated that as the abdominal musculature inserts into the epipubic bones, their chief function is to support the abdominal contents and not the marsupium or pouch. If this were the case, the name marsupial bone could be misleading and should be dropped in favour of the name epipubic bone.

To examine the functional importance of the epipubic bones, the bones from males and females were compared. Both the weight and length of the epipubic bones were greater in females, when compared between males of the same size. The most likely explanation of the relatively greater size of the epipubic bones in the female, is that they do contribute significantly to the support of the pouch.

Although the epipubic bones undoubtedly give support to the abdomen, their anatomical proximity to, and support of the pouch, justifies the terminology of marsupial bone.

CHAPTER 7

FAT GROWTH PATTERNS

INTRODUCTION.

"These kanguroos had much resemblance to the large species found in the forest lands of New South Wales; except that their colour was darker, and they were not wholly destitute of fat....."

Matthew Flinders (1802)

"Fat is the most variable carcass tissue."

Berg and Butterfield (1976).

Fat is conspicuous in the kangaroo by virtue of its relative absence. Ledger (1968) discussed the relatively low levels of carcass fat found in various species of African game animals and stated that "in game animals the higher levels of carcass yields were attainable with less than 5% carcass fat. These high yields of lean carcasses appear to result from the higher lean constants (carcass muscular tissue as a percentage of liveweight) rather than from any differences in digesta contents (fill), also there was no evidence that these animals compensated the low carcass fat by increased deposits of internal fat (pericardial, omental and mesenteric)." Differences in level of fatness are undoubtedly the single greatest carcass difference between the domestic animals selected for productivity and wild animals selected by survival in the wild.

Hetzer and Davey (1971) discussed the influence of diet and genotype on fat deposition; Johnson _et al_ (1973a) discussed the partition of fatty tissues between depots in the bovine carcass and Carpenter _et al_ (1961), Cook _et al_ (1964) and Johnson _et al_ (1973b) discussed intramuscular fat distribution in pigs and cattle.

Two recent works on quantitative fat studies are those of Warren (1974) and Berg and Butterfield (1976). Warren in his study on the growth, partition and distribution of fat in merino sheep presented an extensive literature review on fat studies encompassing historical studies, methods of studying fat distribution and the results of more contemporary research. Berg and Butterfield (1976) discussed the principles emerging from past quantitative studies of fat growth and deposition in cattle.

This section of the study investigates fat growth patterns in the kangaroo. Species are compared.

METHODS AND MATERIALS.

The general methods and materials used are described in Chapters 2 and 3.

RESULTS.

The results are presented in the following format.

A figure of the data plot for each fat relationship investigated is presented together with the functions fitted to the data. The functions are compared to establish differences, if any, between the two sexes and species of the grey and red kangaroo.

Symbols used in the text are:-

Y	dependent variable
X	independent variable
log	logarithm of
a	allometric function: is the fractional coefficient
k	ratio of the relative growth of Y to X

n	number of observations
r	correlation coefficient
SE	standard error
NS	not significant at the 5% level
*	significant at the 5% level
**	significant at the 1% level
***	significant at the 0.1% level

Fat levels are very low in the kangaroo. It is unlikely that greater than 1 kg of fat will be yielded as dissectible fat from the carcasses of grey or red kangaroos of either sex or weighing up to 60 kg empty body weight. In fact, the total dissectible body fat approached 1 kg in only one of the animals studied.

Female kangaroos were fatter than males and red kangaroos were fatter than grey kangaroos.

DISCUSSION.

Body fat levels would appear to be unsuitable as indices of body condition in the kangaroo. It is evident from the data plots that fat deposition is variable between individual animals. Thus to obtain acceptable mean values for a population, a relatively large number of animals would need to be sampled. It is also evident from the data plots that fat levels in the kangaroo are so low that fat does not constitute a significant percentage of the body weight.

If fat were to be used as an index of body condition, then to avoid the laborious and time-consuming dissection or chemical analyses techniques required to estimate total body fat, individual depot fats may be used as an index of total fat. Caughley (1962) used kidney fat as an index of body condition. From an examination of Figures 89 and 92, it is apparent that the correlation of thigh fat pad weight to

TOTAL DISSECTED FAT

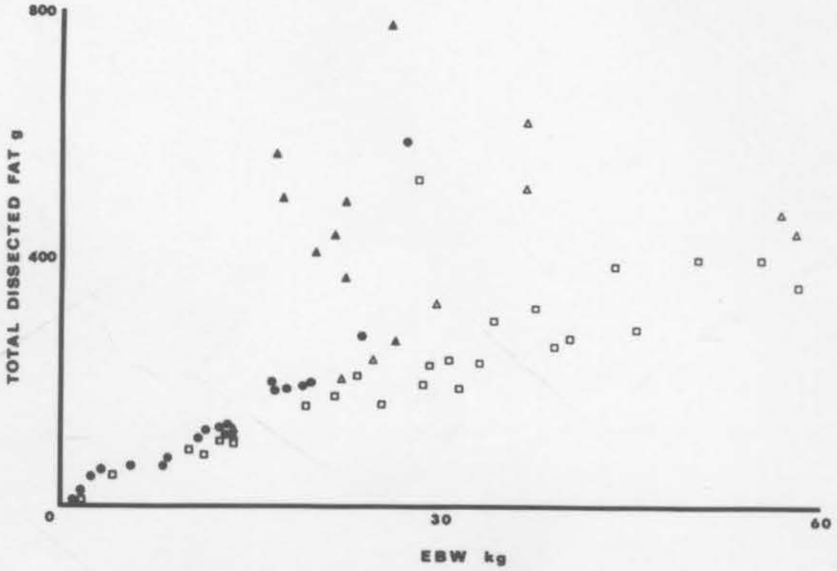

Figure 82 Relationship of total dissected fat weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo log Y = .813 + 1.170 log X
n = 19 r = .955 SE k = .088 P ***

◘ Male Grey Kangaroo log Y = .771 + 1.070 log X
n = 24 r = .951 SE k = .074 P ***

▲ Female Red Kangaroo log Y = .685 + 1.435 log X
n = 9 r = .525 SE k = .880 P NS

△ Male Red Kangaroo log Y = .946 + 1.036 log X
n = 8 r = .870 SE k = .240 P **

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	***
Male Grey/Male Red	NS	***

Note Data transformation (x + 1, y + 1)

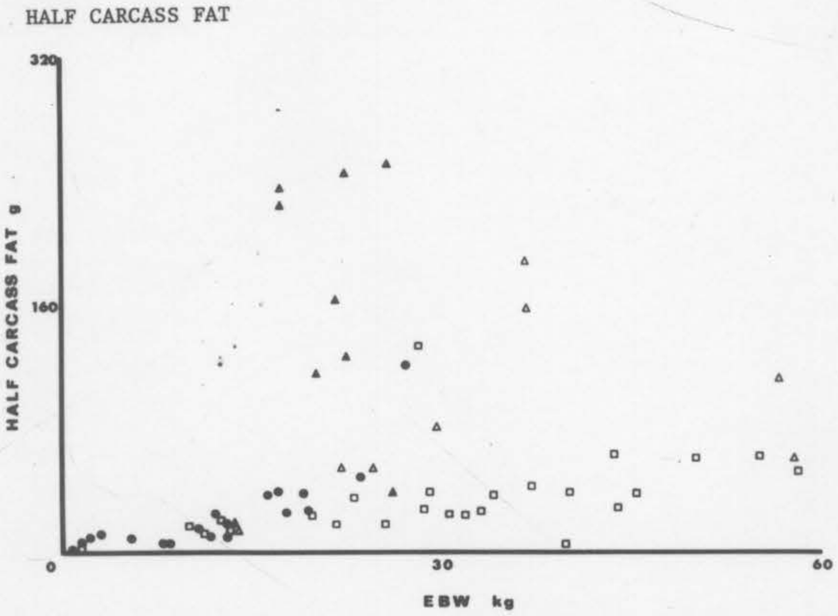

Figure 83 Relationship of half carcass fat weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .235 + .978 \log X$
$n = 19$ $r = .838$ SE $k = .154$ P ***

▣ Male Grey Kangaroo $\log Y = .215 + .885 \log X$
$n = 25$ $r = .869$ SE $k = .105$ P ***

▲ Female Red Kangaroo $\log Y = .278 + 1.364 \log X$
$n = 9$ $r = .313$ SE $k = 1.563$ P NS

△ Male Red Kangaroo $\log Y = .203 + 1.101 \log X$
$n = 8$ $r = .689$ SE $k = .472$ P NS

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS

Note. Data transformation (x + 1, y + 1)

STIFLE FAT PAD

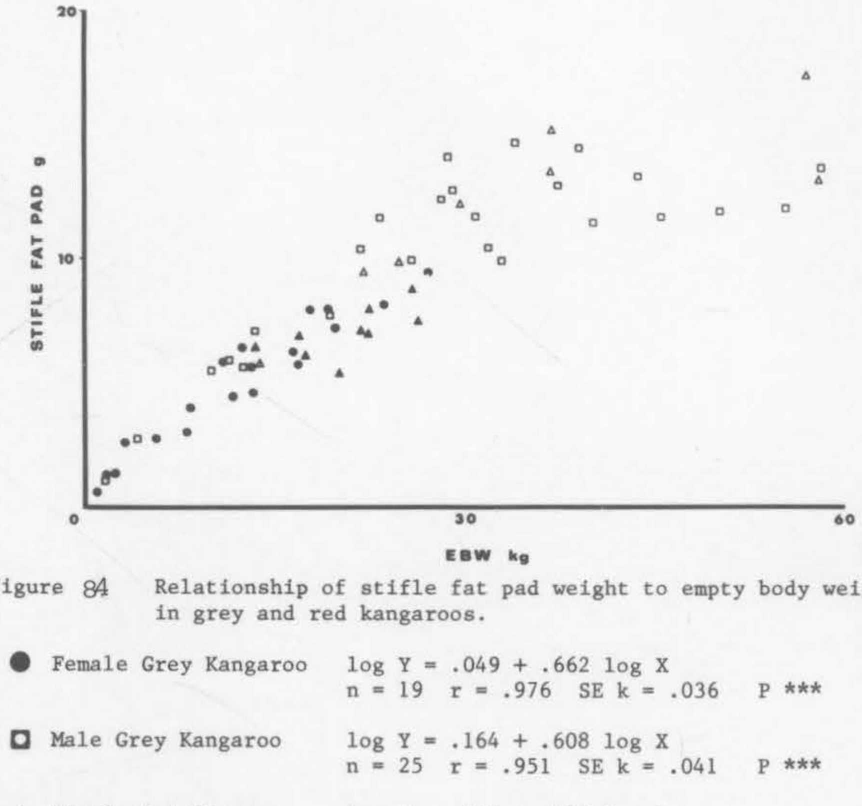

Figure 84 Relationship of stifle fat pad weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .049 + .662 \log X$
$n = 19 \quad r = .976 \quad SE\ k = .036 \quad P$ ***

□ Male Grey Kangaroo $\log Y = .164 + .608 \log X$
$n = 25 \quad r = .951 \quad SE\ k = .041 \quad P$ ***

▲ Female Red Kangaroo $\log Y = .393 + .379 \log X$
$n = 9 \quad r = .605 \quad SE\ k = .188 \quad P$ NS

△ Male Red Kangaroo $\log Y = .172 + .612 \log X$
$n = 8 \quad r = .913 \quad SE\ k = .112 \quad P$ **

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	*
Male Grey/Male Red	NS	NS

Note. Data transformation (x + 1, y + 1)

TAIL FAT

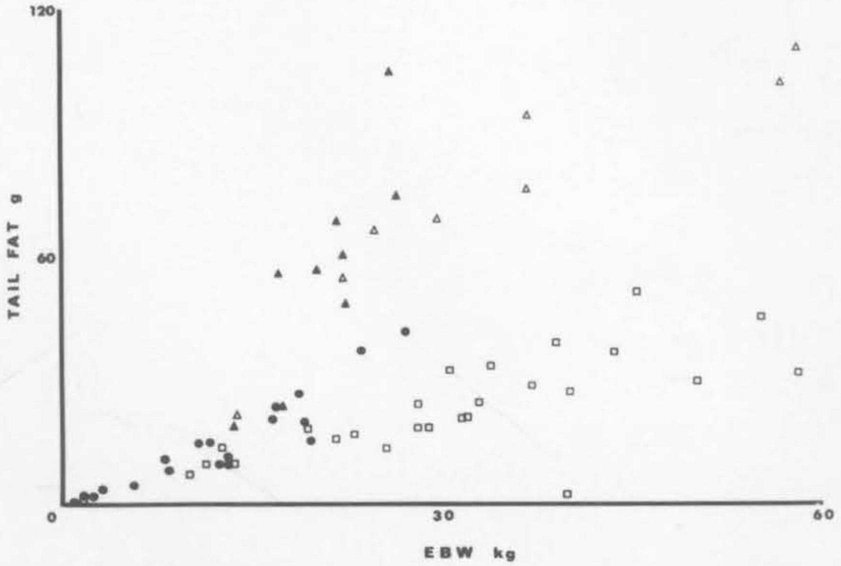

Figure 85 Relationship of tail fat weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = -.216 + 1.222 \log X$ $n = 19$ $r = .972$ SE $k = .072$	P ***
□ Male Grey Kangaroo	$\log Y = -.284 + 1.116 \log X$ $n = 25$ $r = .965$ SE $k = .064$	P ***
▲ Female Red Kangaroo	$\log Y = -1.214 + 2.204 \log X$ $n = 9$ $r = .855$ SE $k = .506$	P **
△ Male Red Kangaroo	$\log Y = .307 + 1.011 \log X$ $n = 8$ $r = .931$ SE $k = .162$	P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	***
Female Red/Male Red	*	-
Female Grey/Female Red	*	-
Male Grey/Male Red	NS	***

Note. Data transformation (x + 1, y + 1)

HALF CARCASS FAT

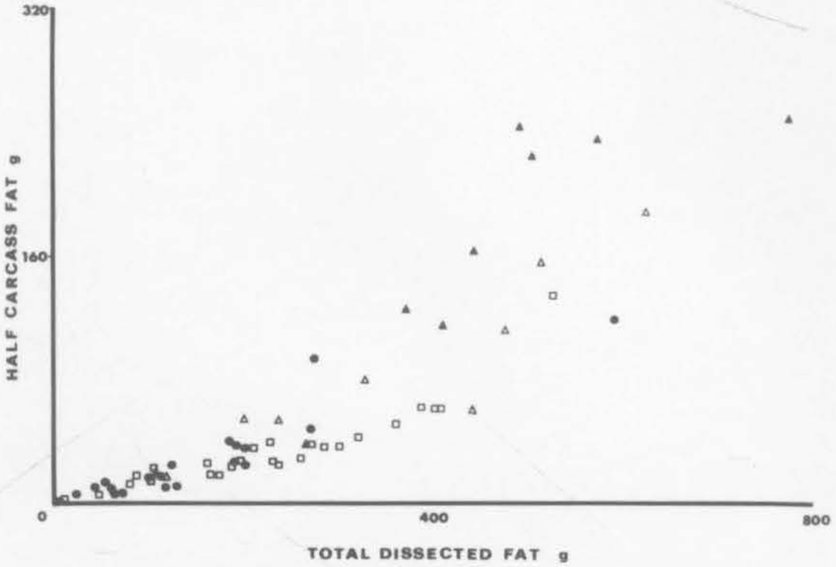

Figure 86 Relationship of half carcass fat weight to total dissected fat weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = -.547 + .887 \log X$ $n = 19$ $r = .931$ SE $k = .084$	P ***
◘ Male Grey Kangaroo	$\log Y = -.519 + .867 \log X$ $n = 24$ $r = .945$ SE $k = .064$	P ***
▲ Female Red Kangaroo	$\log Y = -1.807 + 1.504 \log X$ $n = 9$ $r = .945$ SE $k = .197$	P ***
△ Male Red Kangaroo	$\log Y = -1.275 + 1.251 \log X$ $n = 8$ $r = .933$ SE $k = .197$	P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	*	–
Male Grey/Male Red	NS	***

Note. Data transformation $(x + 1, y + 1)$

HALF CARCASS SUBCUTANEOUS FAT

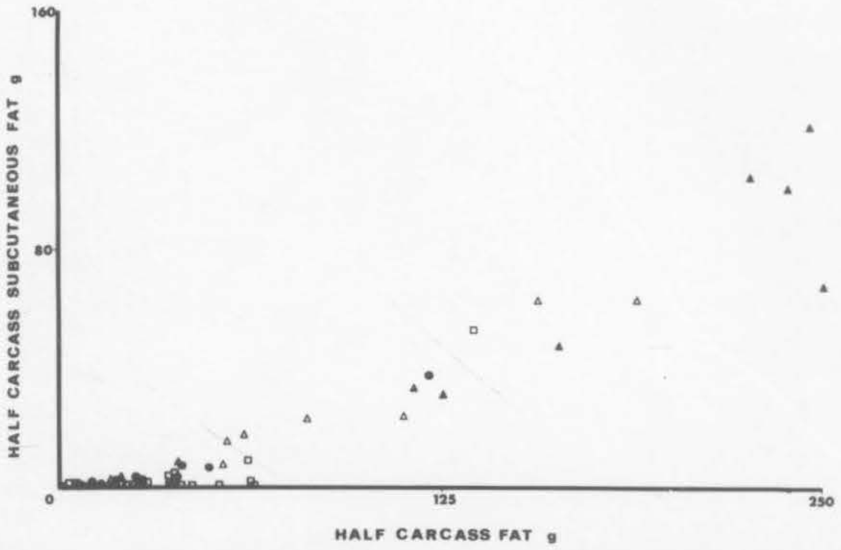

Figure 87 Relationship of half carcass subcutaneous fat weight to half carcass fat weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.099 + 1.282 \log X$
$n = 9$ $r = .984$ SE $k = .087$ P ***

□ Male Grey Kangaroo $\log Y = -1.305 + 1.378 \log X$
$n = 8$ $r = .974$ SE $k = .130$ P ***

⬟ Female Red Kangaroo $\log Y = -.628 + .781 \log X$
$n = 19$ $r = .732$ SE $k = .176$ P ***

▲ Male Red Kangaroo $\log Y = -.837 + .714 \log X$
$n = 25$ $r = .564$ SE $k = .218$ P **

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	**
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	**
Male Grey/Male Red	NS	***

Note. Data transformation $(x + 1, y + 1)$

HALF CARCASS INTERMUSCULAR FAT

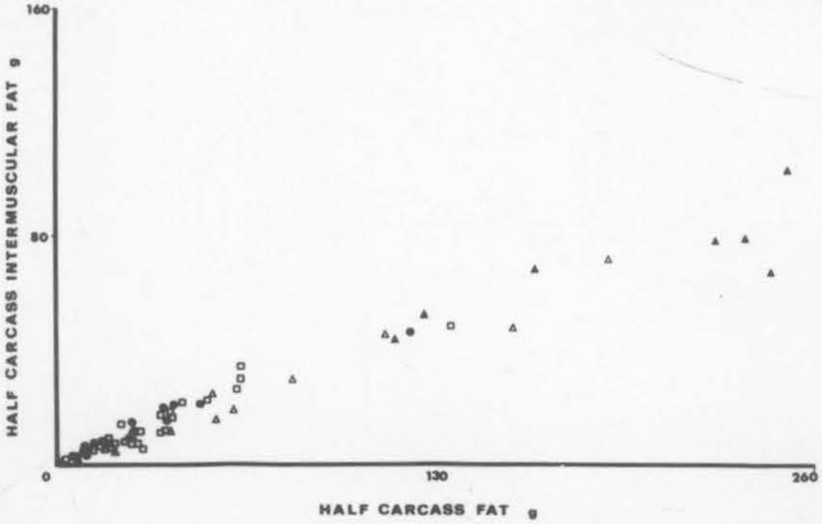

Figure 88 Relationship of half carcass intermuscular fat weight to half carcass fat weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = -.233 + .933 \log X$ $n = 19$ $r = .982$ SE $k = .044$	P ***
◘ Male Grey Kangaroo	$\log Y = -.407 + 1.012 \log X$ $n = 25$ $r = .949$ SE $k = .070$	P ***
▲ Female Red Kangaroo	$\log Y = -.681 + 1.107 \log X$ $n = 9$ $r = .987$ SE $k = .067$	P ***
△ Male Red Kangaroo	$\log Y = -.400 + .979 \log X$ $n = 8$ $r = .980$ SE $k = .081$	P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	*
Female Red/Male Red	NS	NS
Female Grey/Female Red	*	-
Male Grey/Male Red	NS	NS

Overall Equation Two Sexes and Species $\log Y = -.272 + .927 \log X$
$n = 61$ $r = .975$ SE $k = .027$ P ***

Note. Data transformation $(x + 1, y + 1)$

THIGH FAT PAD

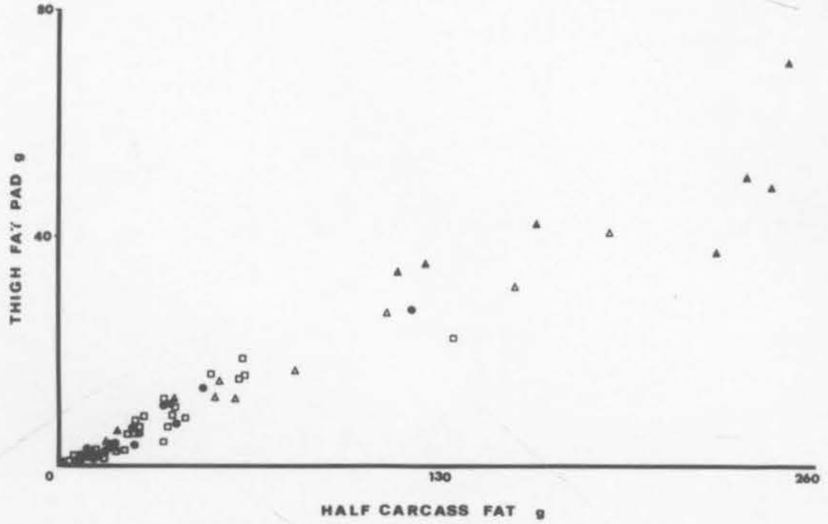

Figure 89 Relationship of thigh fat pad weight to half carcass fat weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = -.412 + .858 \log X$		
	$n = 19$ $r = .955$ SE $k = .064$	P ***	
□ Male Grey Kangaroo	$\log Y = -.444 + .882 \log X$		
	$n = 25$ $r = .908$ SE $k = .085$	P ***	
▲ Female Red Kangaroo	$\log Y = -.204 + .815 \log X$		
	$n = 9$ $r = .976$ SE $k = .068$	P ***	
△ Male Red Kangaroo	$\log Y = -.461 + .906 \log X$		
	$n = 8$ $r = .989$ SE $k = .056$	P ***	

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	*
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Note. Data transformation (x + 1, y + 1)

STIFLE FAT PAD

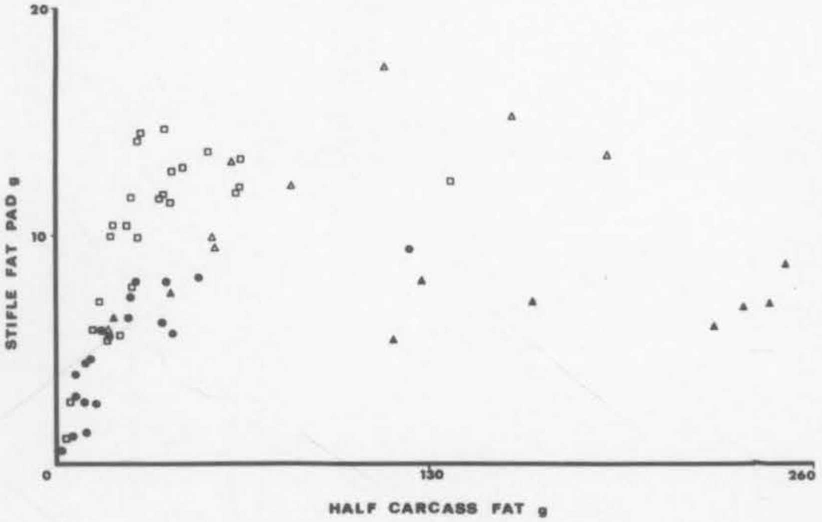

Figure 90 Relationship of stifle fat pad weight to half carcass fat weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .102 + .504 \log X$
$n = 19$ $r = .868$ SE $k = .070$ P ***

◘ Male Grey Kangaroo $\log Y = .234 + .537 \log X$
$n = 25$ $r = .854$ SE $k = .068$ P ***

▲ Female Red Kangaroo $\log Y = .845 + .024 \log X$
$n = 9$ $r = .168$ SE $k = .054$ P NS

△ Male Red Kangaroo $\log Y = .401 + .373 \log X$
$n = 8$ $r = .888$ SE $k = .079$ P **

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	***
Male Grey/Male Red	NS	*

TAIL FAT

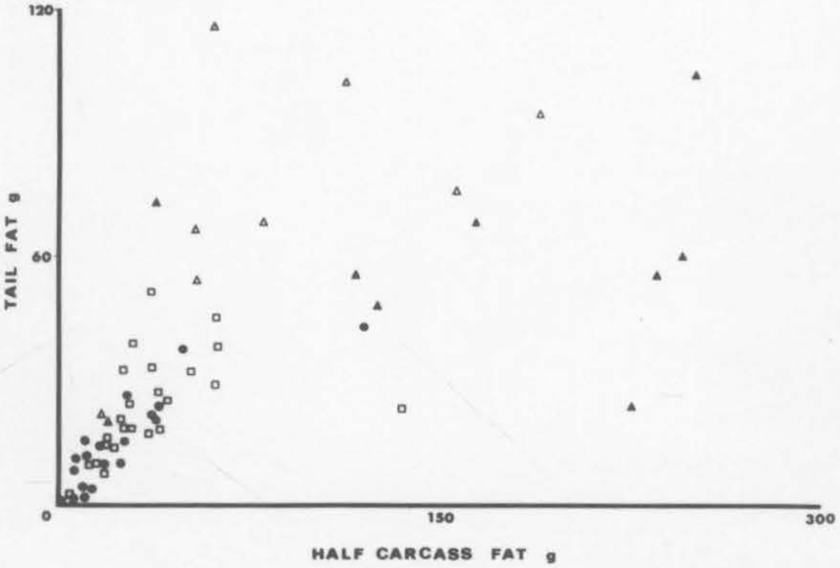

Figure 91 Relationship of tail fat weight to half carcass fat weight in grey and red kangaroos.

● Female Grey Kangaroo	log Y = -.097 + .914 log X n = 19 r = .848 SE k = .138	P ***
□ Male Grey Kangaroo	log Y = -.133 + .970 log X n = 25 r = .854 SE k = .123	P ***
▲ Female Red Kangaroo	log Y = 1.196 + .247 log X n = 9 r = .418 SE k = .203	P NS
△ Male Red Kangaroo	log Y = .816 + .546 log X n = 8 r = .803 SE k = .165	P *

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Male Grey/Male Red	NS	*

TOTAL KIDNEY FAT

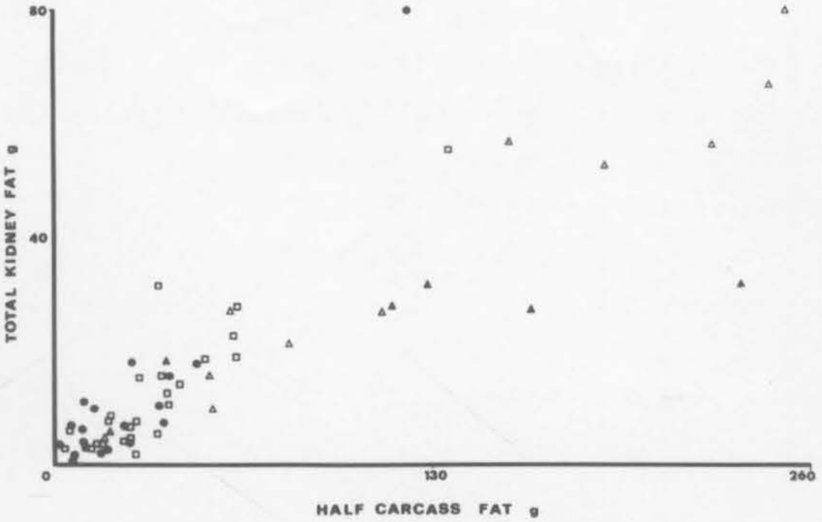

Figure 92 Relationship of total kidney fat weight to half carcass fat weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = .055 + .664 \log X$ $n = 19 \quad r = .682 \quad SE\ k = .172$	P **
□ Male Grey Kangaroo	$\log Y = -.078 + .745 \log X$ $n = 24 \quad r = .742 \quad SE\ k = .144$	P ***
▲ Female Red Kangaroo	$\log Y = -.133 + .781 \log X$ $n = 9 \quad r = .915 \quad SE\ k = .131$	P ***
△ Male Red Kangaroo	$\log Y = -.588 + 1.027 \log X$ $n = 8 \quad r = .947 \quad SE\ k = .142$	P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Overall Equation Two Sexes and Species	$\log Y = -.059 + .743 \log X$ $n = 60 \quad r = .840 \quad SE\ k = .063$	P ***

Note. Data transformation $(x + 1, y + 1)$

half-carcass fat is superior to that of kidney fat. Thus if one fat depot were to be selected as an index of body condition, probably the thigh fat pad should be used. The thigh fat pad is located on the lateral aspect of the proximal thigh. It is bounded by the mm. sartorius, gluteus medius and vastus lateralis. The deposit lies in the subcutaneous tissue and is readily dissected free from the carcass. Other fat deposits occur in the stifle and tail. Examination of Figures 84, 85, 90 and 91 illustrates the fact that these fat deposits are more closely related to body weight rather than body fat. This is expected as these fat deposits have a functional rather than energy storage role.

It is very difficult to prove a negative case. While the kangaroos used in this study, contained very low levels of fat, this does not necessarily prove that kangaroos do not deposit fat in quantities approaching those found in the domestic animals. It is, however, the author's opinion that the wild kangaroo does not fatten to any appreciable degree.

Warren (1974) demonstrated a fattening phase in ewes and wethers. This fattening phase was correlated to the final mature muscle weights of the animals. He found that ewes began rapid fat deposition at 58% of their mature muscle weight or at 16 kg pelt free empty body weight. Wethers began rapid fat deposition at 55% of their mature muscle weight or at 19 kg pelt free empty body weight. He postulated that at ".... this proportion of the final mature muscle weight .... muscle no longer has a significantly greater preference for available nutrient than fat."

Clearly, if fattening occurs in the kangaroo, it is not related to the mature muscle weight. Female kangaroos used in this study ranged to over an estimated 6,000 days in age and no muscle weight correlated fat growth was evident. Although male kangaroos of greater weight than those used in this study have been recorded, the animals used ranged to over an estimated 3,000 days in age and could reasonably be classed as mature animals. Again, no muscle weight correlated fat growth was evident.

Although a principle for fat deposition holding for the sheep need not necessarily apply to the kangaroo, it adds to the circumstantial evidence against fat deposition in significant amounts in kangaroos.

The kangaroo would be an interesting animal for inclusion in a comparative biochemical study on fat deposition.

CHAPTER 8

VISCERAL GROWTH PATTERNS

INTRODUCTION.

Whereas descriptions of the viscera of the kangaroo are relatively abundant, little has been published on the quantitative visceral anatomy. Altman and Dittmer (1962) cited organ weights for one hundred and twenty two mammal species. Despite their extensive literature review, only two marsupial species were cited, neither of which were macropods.

The only systematic quantitative study of the visceral anatomy of the kangaroo known to the author is that of Tribe and Peel (1963). Tribe and Peel (1963) investigated the body composition of nine red kangaroos and four grey kangaroos and presented data for full and empty stomach, small intestine, caecum and large intestine weight; and skin, salivary gland, oesophagus, liver, heart, lung, kidney, spleen, pancreas, bladder, testes and ovaries plus uterus weights.

Isolated references to individual organs are presented with the discussion of the results from this study.

This section of the study investigates the growth and development of the viscera of the kangaroo. Species are compared.

METHODS AND MATERIALS.

The general methods and materials used are described in Chapters 2 and 3.

RESULTS.

The results are presented in the following format. A figure of the data plot for each visceral relationships investigated is presented together with the functions fitted to the data. The functions are compared to establish differences, if any, between the two sexes and species of the grey and red kangaroo. In the grey kangaroo, where a change in growth impetus occurs, the estimated point (X_e Y_e) of the change and its magnitude (bl b2) are given, based on the two phase linear function described by Griffiths and Miller (1973).

In conjunction with the mathematical presentation of the results, a brief written summary of the differences found between the grey and red kangaroo is presented. Visceral weights are predicted from the functions fitted to the data and presented in Table 16. For the grey kangaroo, the empty body weights at which growth impetus changes occur in the viscera are presented in Table 18. Finally, the relative proportions of viscera for the five species of macropod studied are presented in Table 17.

Symbols used in the text are:-

Y	dependent variable
X	independent variable
log	logarithm of
a	allometric function: is the fractional coefficient
k	ratio of the relative growth of Y to X
b, bl, b2	rates of growth of Y to X
n	number of observations
r	correlation coefficient
SE	standard error
NS	not significant at the 5% level
*	significant at the 5% level
**	significant at the 1% level
***	significant at the 0.1% level
X_e, Y_e	estimated point of change in the growth impetus

Hide weights (Figure 93) were not significantly different between females but were significantly greater for male grey kangaroos, when the same sex of the grey and red kangaroo were compared. Between sexes within species, hide weights were significantly greater for male grey kangaroos but not significantly different between red kangaroos.

HIDE

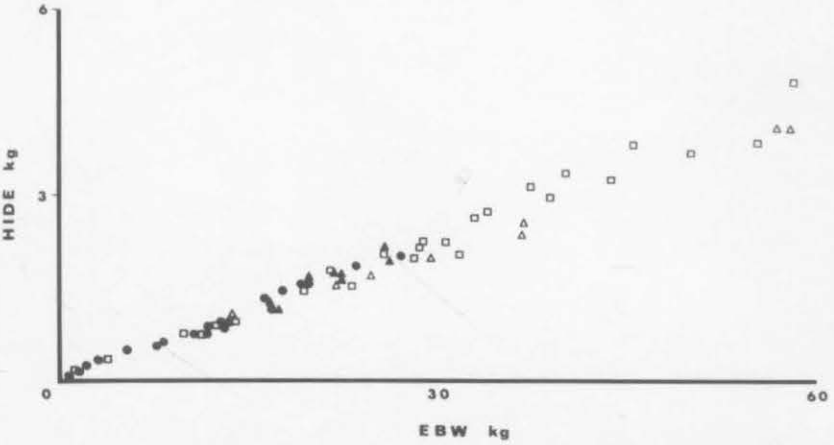

Figure 93 Relationship of hide weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.007 + 0.902 \log X$
$n = 19$ $r = .994$ SE $k = .024$ P ***

□ Male Grey Kangaroo $\log Y = -1.087 + .978 \log X$
$n = 25$ $r = .995$ SE $k = .021$ P ***

▲ Female Red Kangaroo $\log Y = -1.405 + 1.215 \log X$
$n = 9$ $r = .966$ SE $k = .123$ P ***

△ Male Red Kangaroo $\log Y = -1.108 + .967 \log X$
$n = 8$ $r = .994$ SE $k = .044$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	*	–
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	*

Overall Equation $\log Y = -1.042 + .939 \log X$
Two Sexes and Species $n = 61$ $r = .994$ SE $k = .013$ P ***

Salivary gland weights (Figure 94) were not significantly different between sexes or species in the grey and red kangaroo.

SALIVARY GLAND

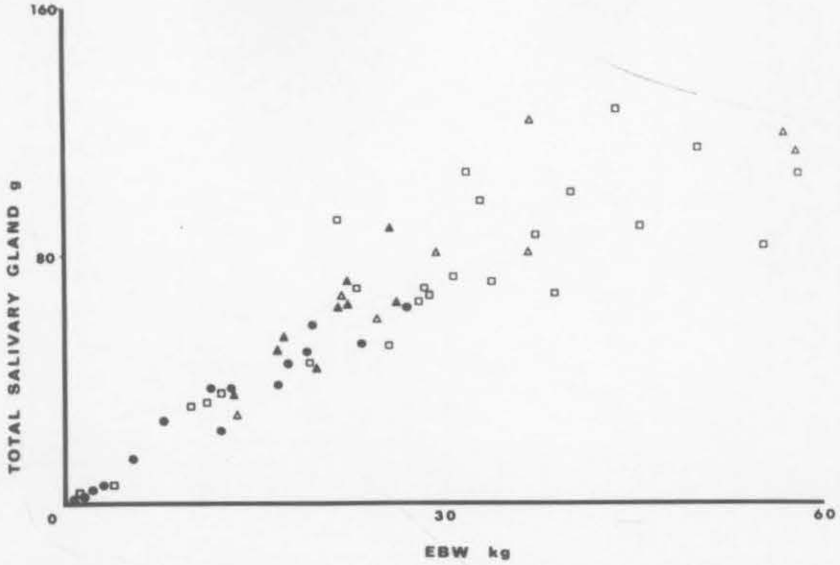

Figure 94 Relationship of total salivary gland weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .319 + 1.069 \log X$
$n = 15$ $r = .988$ SE $k = .047$ P ***

□ Male Grey Kangaroo $\log Y = .387 + .993 \log X$
$n = 24$ $r = .960$ SE $k = .062$ P ***

▲ Female Red Kangaroo $\log Y = .264 + 1.141 \log X$
$n = 9$ $r = .866$ SE $k = .249$ P **

△ Male Red Kangaroo $\log Y = .501 + .923 \log X$
$n = 8$ $r = .919$ SE $k = .162$ P **

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = .363 + 1.023 \log X$
Two Sexes and Species $n = 56$ $r = .976$ SE $k = .031$ P ***

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (32.1kg, 85.5g)
SE $X_e = 5.8$ SE $Y_e = 12.2$

Estimated slopes $b1 = 2.62$ $b2 = 0.75$
SE $b1 = 0.42$ SE $b2 = 0.60$

Lung weights (Figure 95) were significantly greater for female red kangaroos, but not significantly different for males when the same sex of the grey and red kangaroo were compared. Between sexes within species, lung weights were significantly greater for male grey kangaroos but not significantly different between red kangaroos.

LUNGS

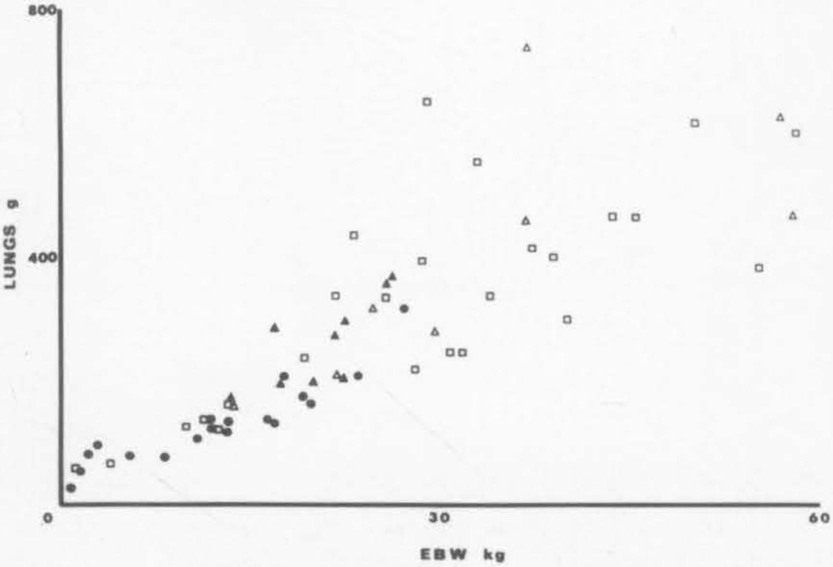

Figure 95 Relationship of lung weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = 1.546 + .499 \log X$
$n = 19$ $r = .701$ SE $k = .123$ P ***

□ Male Grey Kangaroo $\log Y = 1.489 + .702 \log X$
$n = 25$ $r = .896$ SE $k = .073$ P ***

▲ Female Red Kangaroo $\log Y = 1.111 + .985 \log X$
$n = 9$ $r = .753$ SE $k = .325$ P *

△ Male Red Kangaroo $\log Y = 1.133 + .950 \log X$
$n = 8$ $r = .860$ SE $k = .230$ P **

<u>Comparison of differences between the two sexes and species</u>

Comparison	k	log a
Female Grey/Male Grey	NS	**
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = 1.420 + .724 \log X$
Two Sexes and Species $n = 61$ $r = .858$ SE $k = .056$ P ***

Heart weights (Figure 96) were not significantly different between the same sex of the grey and red kangaroo. Between sexes within species, heart weights were significantly greater for female grey kangaroos and significantly different in red kangaroos.

HEART

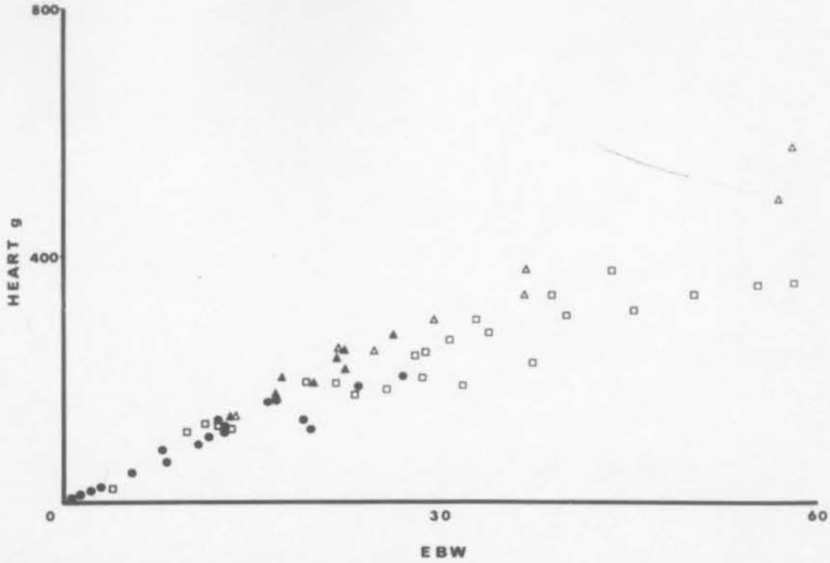

Figure 96 Relationship of heart weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .949 + .980 \log X$
$n = 19$ $r = .989$ SE $k = .036$ P ***

□ Male Grey Kangaroo $\log Y = .424 + 1.319 \log X$
$n = 25$ $r = .932$ SE $k = .107$ P ***

▲ Female Red Kangaroo $\log Y = 1.053 + .971 \log X$
$n = 8$ $r = .954$ SE $k = .124$ P ***

△ Male Red Kangaroo $\log Y = 1.139 + .905 \log X$
$n = 8$ $r = .989$ SE $k = .055$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	**	-
Female Red/Male Red	NS	**
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (43.5kg, 337.1g)
SE $X_e = 0.002$ SE $Y_e = 11.7$

Estimated slopes $b1 = 7.29$ $b2 = 1.06$
SE $b1 = 0.54$ SE $b2 = 1.89$

Liver weights (Figure 97) were significantly greater for both sexes of the red kangaroo when compared between the same sex of the grey kangaroo. Between sexes within species, the liver weights were not significantly different between grey kangaroos, but were significantly greater for male red kangaroos.

LIVER

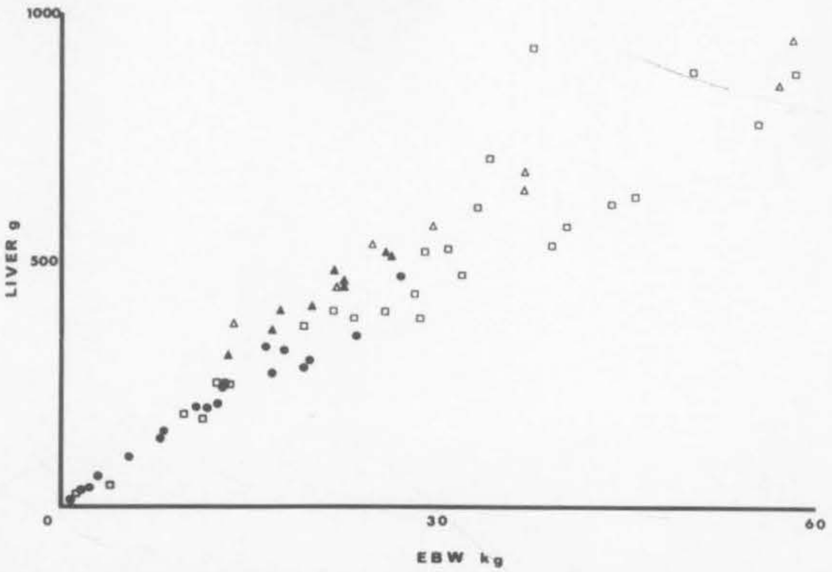

Figure 97 Relationship of liver weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo log Y = 1.317 + .938 log X
n = 19 r = .995 SE k = .022 P ***

□ Male Grey Kangaroo log Y = 1.245 + .981 log X
n = 25 r = .979 SE k = .042 P ***

▲ Female Red Kangaroo log Y = 1.610 + .779 log X
n = 9 r = .977 SE k = .064 P ***

△ Male Red Kangaroo log Y = 1.823 + .639 log X
n = 8 r = .988 SE k = .040 P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	*
Female Grey/Female Red	NS	***
Male Grey/Male Red	*	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (19.3kg, 363.4g)
SE X_e = 0.04 SE Y_e = 39.6

Estimated slopes b1 = 19.63 b2 = 13.48
SE b1 = 4.62 SE b2 = 2.05

Kidney weights (Figure 98) were significantly greater for female red kangaroos, but not significantly different between males, when the same sex of grey and red kangaroo were compared. Between sexes within species, the kidney weights were not significantly different.

KIDNEY

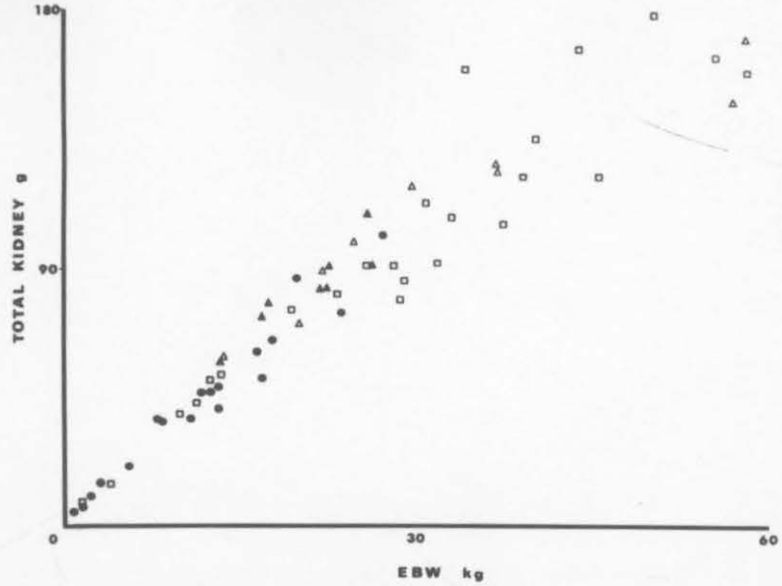

Figure 98 Relationship of total kidney weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo	$\log Y = .762 + .836 \log X$ $n = 18$ $r = .989$ SE $k = .031$	P ***
◘ Male Grey Kangaroo	$\log Y = .725 + .867 \log X$ $n = 25$ $r = .985$ SE $k = .032$	P ***
▲ Female Red Kangaroo	$\log Y = .922 + .753 \log X$ $n = 9$ $r = .904$ SE $k = .135$	P ***
△ Male Red Kangaroo	$\log Y = 1.050 + .664 \log X$ $n = 8$ $r = .978$ SE $k = .058$	P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Overall Equation Two Sexes and Species	$\log Y = .756 + .852 \log X$ $n = 60$ $r = .988$ SE $k = .018$	P ***

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change	(X_e, Y_e) (16.2kg, 63.0g) SE $X_e = 14.7$ SE $Y_e = 45.6$
Estimated slopes	$b1 = 3.84$ $b2 = 2.81$ SE $b1 = 1.49$ SE $b2 = 0.35$

Spleen weights (Figure 99) were not significantly different between sexes or species in the grey and red kangaroo.

SPLEEN

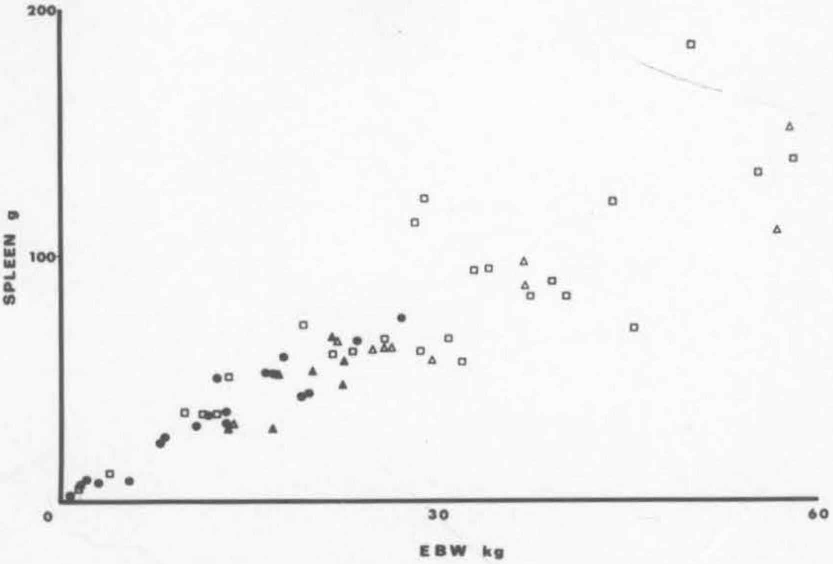

Figure 99 Relationship of spleen weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .529 + .929 \log X$
$n = 19$ $r = .972$ SE $k = .055$ P ***

◘ Male Grey Kangaroo $\log Y = .600 + .881 \log X$
$n = 25$ $r = .952$ SE $k = .059$ P ***

▲ Female Red Kangaroo $\log Y = .147 + 1.179 \log X$
$n = 9$ $r = .836$ SE $k = .292$ P **

△ Male Red Kangaroo $\log Y = .445 + .954 \log X$
$n = 8$ $r = .953$ SE $k = .123$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = .549 + .903 \log X$
Two Sexes and Species $n = 61$ $r = .967$ SE $k = .031$ P ***

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (14.2kg, 47.5g)
SE $X_e = 15.2$ SE $Y_e = 41.0$

Estimated slopes $b1 = 3.41$ $b2 = 2.15$
SE $b1 = 2.14$ SE $b2 = 0.50$

Bladder weights (Figure 100) were not significantly different between the same sex of the grey and red kangaroo. Between sexes within species, bladder weights were significantly greater for males.

BLADDER

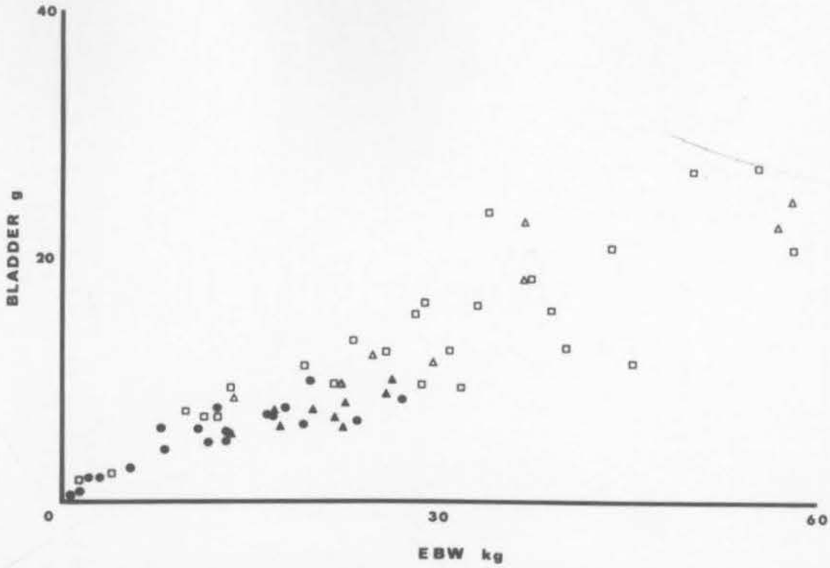

Figure 100 Relationship of bladder weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.047 + .733 \log X$
$n = 19$ $r = .966$ SE $k = .047$ P ***

□ Male Grey Kangaroo $\log Y = .095 + .710 \log X$
$n = 25$ $r = .930$ SE $k = .058$ P ***

▲ Female Red Kangaroo $\log Y = -.047 + .693 \log X$
$n = 9$ $r = .786$ SE $k = .206$ P *

▲ Male Red Kangaroo $\log Y = -.037 + .809 \log X$
$n = 8$ $r = .923$ SE $k = .138$ P **

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	**
Female Red/Male Red	NS	***
Female Grey/Female Red	NS	NS
Male Grey/Male Red	NS	NS

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (15.2kg, 7.4g)
SE $X_e = 2.5$ SE $Y_e = 0.8$

Estimated slopes $b1 = 0.43$ $b2 = 0.06$
SE $b1 = 0.07$ SE $b2 = 0.12$

B. Male

Estimated point of change (X_e, Y_e) (13.4kg, 8.3g)
SE $X_e = 0.2$ SE $Y_e = 1.5$

Estimated slopes $b1 = 0.56$ $b2 = 0.35$
SE $b1 = 0.30$ SE $b2 = 0.07$

Empty gut weights (Figure 101) were not significantly different between females, but significantly different for males when the same sex of grey and red kangaroo were compared. Between sexes within species, empty gut weights were significantly greater for female grey kangaroos, but not significantly different between red kangaroos.

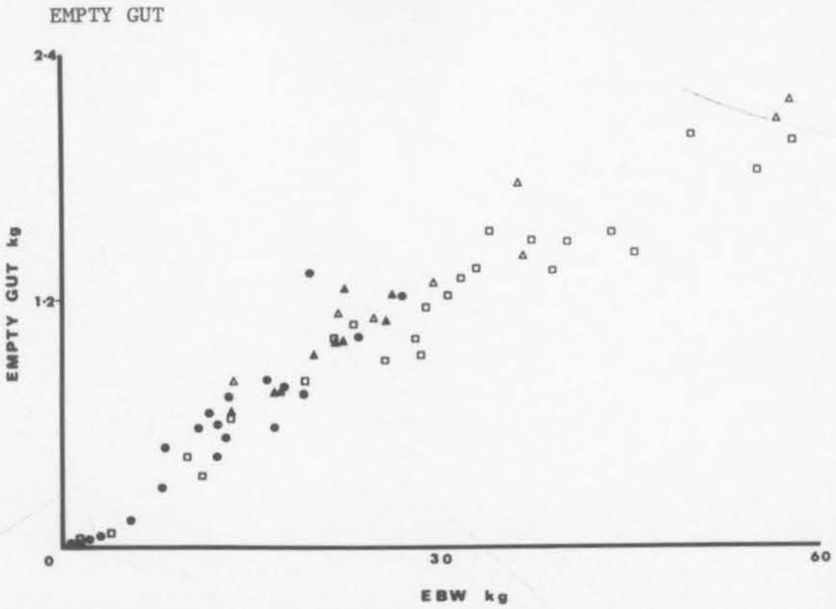

Figure 101 Relationship of empty gut weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.721 + 1.320 \log X$
$n = 19$ $r = .980$ SE $k = .065$ P ***

□ Male Grey Kangaroo $\log Y = -1.637 + 1.144 \log X$
$n = 25$ $r = .980$ SE $k = .048$ P ***

▲ Female Red Kangaroo $\log Y = -1.331 + .996 \log X$
$n = 9$ $r = .936$ SE $k = .141$ P ***

△ Male Red Kangaroo $\log Y = -.895 + .693 \log X$
$n = 8$ $r = .979$ SE $k = .058$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	*	-
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	**	-

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (2.8kg, 0.2kg)
SE $X_e = 5.1$ SE $Y_e = 0.2$

Estimated slopes $b1 = 0.04$ $b2 = 0.03$
SE $b1 = 0.03$ SE $b2 = 0.002$

Gut fill weights (Figure 102) were not significantly different between females, but significantly different for males when the same sex of the grey and red kangaroo were compared. Between sexes within species, gut fill weights were significantly greater for female grey kangaroos, but not significantly different between red kangaroos.

GUT FILL

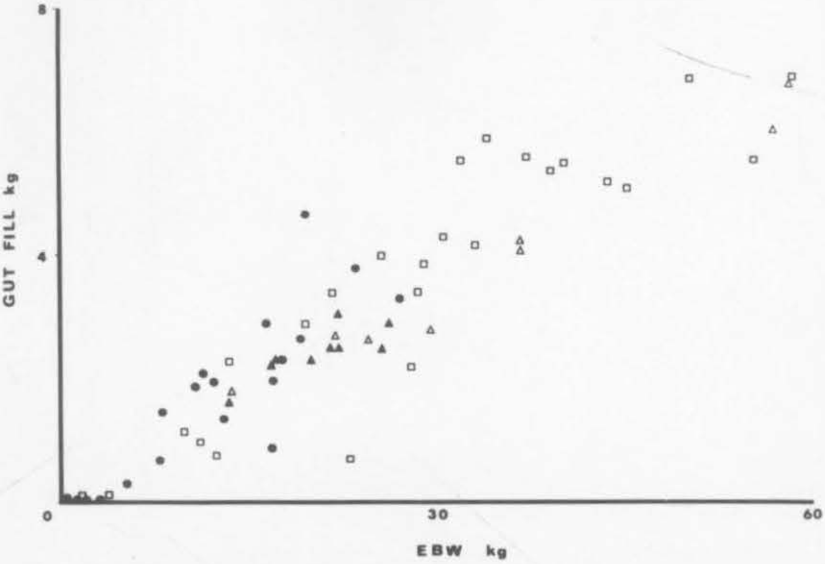

Figure 102 Relationship of gut fill weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -1.908 + 1.860 \log X$
$n = 19$ $r = .960$ SE $k = .132$ P ***

□ Male Grey Kangaroo $\log Y = -1.824 + 1.604 \log X$
$n = 25$ $r = .949$ SE $k = .111$ P ***

▲ Female Red Kangaroo $\log Y = -.567 + .718 \log X$
$n = 9$ $r = .848$ SE $k = .169$ P **

△ Male Red Kangaroo $\log Y = -.821 + .913 \log X$
$n = 8$ $r = .978$ SE $k = .080$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	**
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	NS
Male Grey/Male Red	*	-

Overall Equation $\log Y = -1.721 + 1.569 \log X$
Two Sexes and Species $n = 61$ $r = .947$ SE $k = .069$ P ***

Change in the Growth Impetus in the Grey Kangaroo

Male

Estimated point of change (X_e, Y_e) (1.5kg, .1kg)
SE $X_e = 59.5$ SE $Y_e = .4$

Estimated slopes $b1 = .03$ $b2 = .13$
SE $b1 = .08$ SE $b2 = .02$

Empty stomach weights (Figure 103) were significantly greater for both sexes of the grey kangaroo, when compared between the same sex of the red kangaroo. Between sexes within species, empty stomach weights were not significantly different.

STOMACH

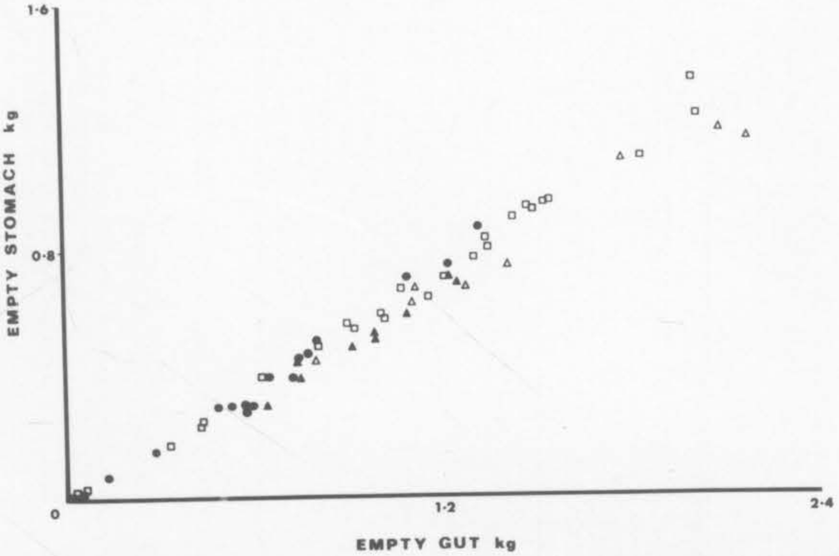

Figure 103 Relationship of empty stomach weight to empty gut weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.208 + 1.191 \log X$
$n = 19$ $r = .998$ SE $k = .020$ P ***

□ Male Grey Kangaroo $\log Y = -.230 + 1.150 \log X$
$n = 25$ $r = .998$ SE $k = .014$ P ***

▲ Female Red Kangaroo $\log Y = -.269 + 1.171 \log X$
$n = 9$ $r = .974$ SE $k = .103$ P ***

△ Male Red Kangaroo $\log Y = -.252 + 1.006 \log X$
$n = 8$ $r = .986$ SE $k = .070$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	**
Male Grey/Male Red	NS	**

Empty small intestine weights (Figure 104) were significantly greater for female red kangaroos, but not significantly different between males, when the same sex of grey and red kangaroo were compared. Between sexes within species, empty small intestine weights were not significantly different.

SMALL INTESTINE

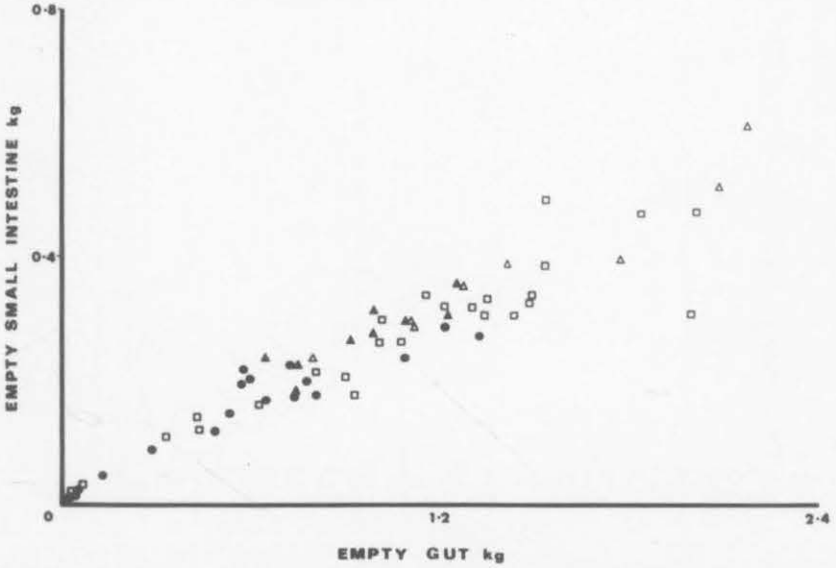

Figure 104 Relationship of empty small intestine weight to empty gut weight in grey and red kangaroos.

● Female Grey Kangaroo log Y = −.602 + .822 log X
n = 19 r = .992 SE k = .025 P ***

□ Male Grey Kangaroo log Y = −.595 + .801 log X
n = 25 r = .985 SE k = .029 P ***

▲ Female Red Kangaroo log Y = −.550 + .753 log X
n = 9 r = .847 SE k = .178 P **

△ Male Red Kangaroo log Y = −.564 + .893 log X
n = 8 r = .970 SE k = .092 P ***

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	*
Male Grey/Male Red	NS	NS

Overall Equation log Y = −.583 + .831 log X
Two Sexes and Species n = 61 r = .989 SE k = .016 P ***

Empty large intestine weights (Figure 105) were significantly greater for both sexes of the red kangaroo, when compared between the same sex of the grey kangaroo. Between sexes within species, empty large intestine weights were not significantly different.

LARGE INTESTINE

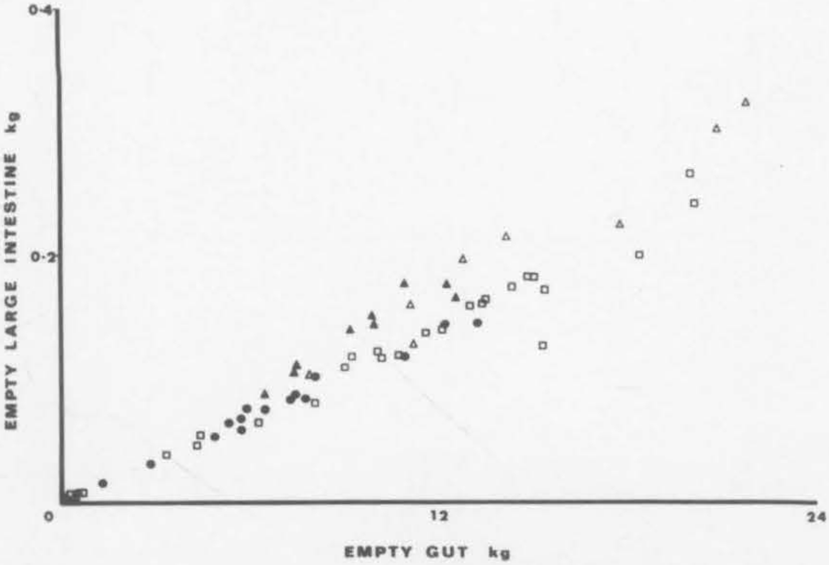

Figure 105 Relationship of empty large intestine weight to empty gut weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.946 + .969 \log X$
$n = 19$ $r = .994$ SE $k = .026$ P ***

□ Male Grey Kangaroo $\log Y = -.934 + .956 \log X$
$n = 25$ $r = .994$ SE $k = .022$ P ***

▲ Female Red Kangaroo $\log Y = -.832 + 1.021 \log X$
$n = 9$ $r = .955$ SE $k = .119$ P ***

△ Male Red Kangaroo $\log Y = -.874 + 1.123 \log X$
$n = 8$ $r = .970$ SE $k = .114$ P ***

Comparison of differences between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	***

Adrenal weights (Figure 106) were significantly greater for female grey kangaroos, but not significantly different between males, when the same sex of the grey and red kangaroo were compared. Between sexes within species, adrenal weights were significantly greater for female grey kangaroos, but not significantly different in the red kangaroo.

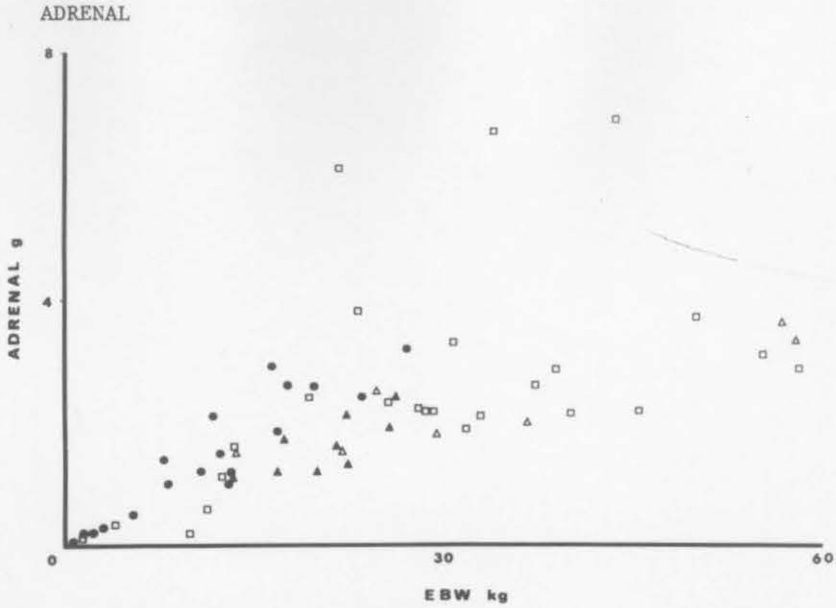

Figure 106 Relationship of adrenal weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = -.946 + 1.023 \log X$
$n = 18$ $r = .972$ SE $k = .062$ P ***

☐ Male Grey Kangaroo $\log Y = -1.141 + .996 \log X$
$n = 22$ $r = .902$ SE $k = .107$ P ***

▲ Female Red Kangaroo $\log Y = -1.034 + .939 \log X$
$n = 9$ $r = .734$ SE $k = .328$ P *

△ Male Red Kangaroo $\log Y = -.539 + .591 \log X$
$n = 7$ $r = .861$ SE $k = .156$ P *

Comparison of differences
between the two sexes and species

Comparison	k	log a
Female Grey/Male Grey	NS	***
Female Red/Male Red	NS	NS
Female Grey/Female Red	NS	***
Male Grey/Male Red	NS	NS

Overall Equation $\log Y = -.925 + .898 \log X$
Two Sexes and Species $n = 59$ $r = .891$ SE $k = .061$ P ***

Change in the Growth Impetus in the Grey Kangaroo

A. Female

Estimated point of change (X_e, Y_e) (8.0kg, 1.1g)
SE $X_e = 0.8$ SE $Y_e = 0.2$

Estimated slopes $b1 = 0.15$ $b2 = 0.11$
SE $b1 = 0.05$ SE $b2 = 0.02$

B. Male

Estimated point of change (X_e, Y_e) (22.1kg, 2.4g)
SE $X_e = 4.7$ SE $Y_e = .3$

Estimated slopes $b1 = .13$ $b2 = .02$
SE $b1 = .04$ SE $b2 = .01$

NB The three male grey kangaroo data values greater than 5.0g were deleted from the data.

Testes weights (Figure 107) were not significantly different between male grey and red kangaroos. Predicted testes weights were non-significantly greater in red kangaroos.

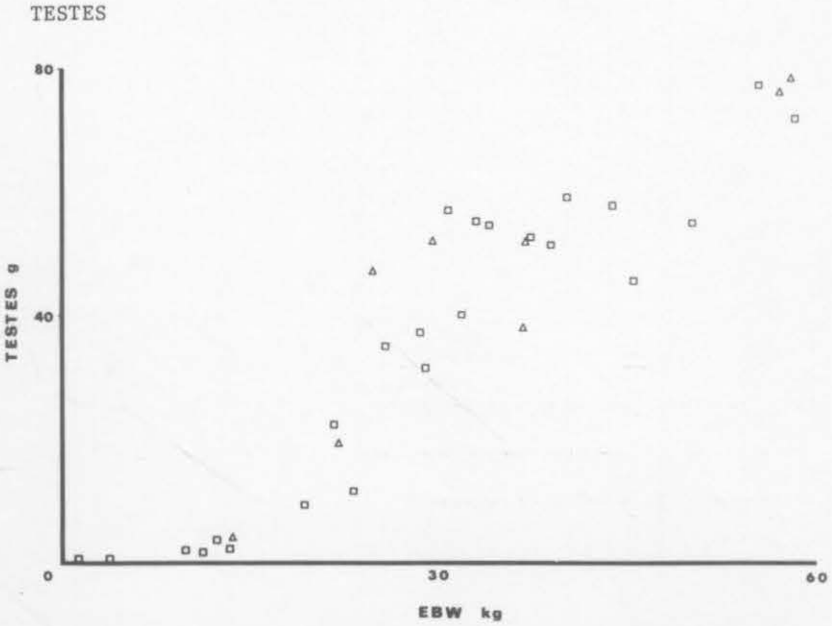

Figure 107 Relationship of testicular weight to empty body weight in grey and red kangaroos.

■ Male Grey Kangaroo $\log Y = -1.180 + 1.783 \log X$
$n = 24$ $r = .949$ SE $k = 0.127$ P ***

▲ Male Red Kangaroo $\log Y = -1.134 + 1.788 \log X$
$n = 8$ $r = .885$ SE $k = .384$ P **

Comparison of differences between the two species

Comparison	k	log a
Male Grey/Male Red	NS	NS

Predicted ovary plus uterus weights (Figure 108) were non-significantly greater for female grey kangaroos.

OVARY AND UTERUS

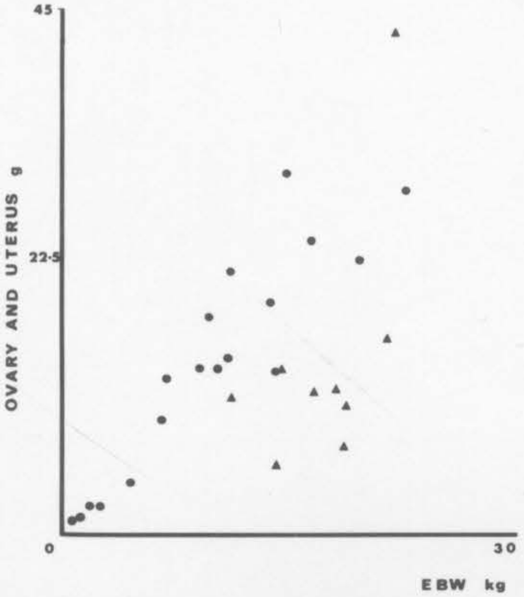

Figure 108 Relationship of ovary plus uterus weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $\log Y = .049 + 1.009 \log X$
$n = 19$ $r = .972$ SE $k = .059$ P ***

▲ Female Red Kangaroo $\log Y = -.568 + 1.262 \log X$
$n = 9$ $r = .493$ SE $k = .843$ P NS

<u>Change in the Growth Impetus in the Grey Kangaroo</u>

Female

Estimated point of change (X_e, Y_e) (13.4kg, 17.8g)
SE $X_e = 4.7$ SE $Y_e = 5.9$

Estimated slopes $b1 = 1.40$ $b2 = .70$
SE $b1 = .24$ SE $b2 = .38$

THYMUS

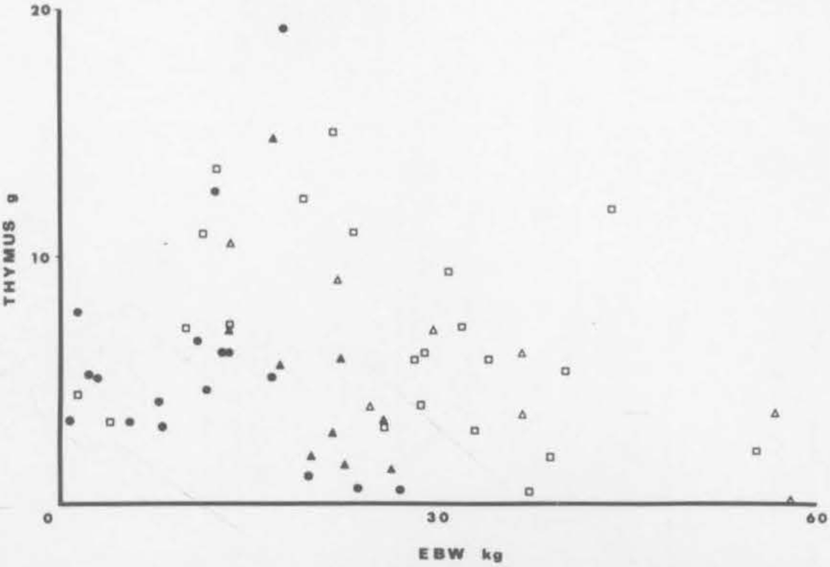

Figure 109 Relationship of thymus weight to empty body weight in grey and red kangaroos.

□ Combined Grey and Red ▲ Male 0-20kg E.B.W.	log Y = .441 + .486 log X n = 8 r = .811 SE k = .143	 P *
□ Combined Grey and Red ▲ Male 20-60kg E.B.W.	log Y = 5.870 - 3.533 log X n = 25 r = -.674 SE k = .807	 P ***

NB. Overall linear allometric and quadratic functions were non-significant at the 5% level for both sexes and species. Functions fitted to the female data for the weight ranges 0-10kg, 10-20kg and 15-30kg were non-significant. The point 20kg E.B.W. around which the two allometric functions were applied to the male data was chosen after visual inspection of the graph.

TABLE 16

Predicted viscera weights for grey and red kangaroos. Values are predicted from the allometric functions given with Figures 93 to 109.

	EMPTY BODY WEIGHT (kg)					
	15	20	30	40	50	55
PREDICTED HIDE WEIGHT (kg)						
Female Grey	1.13	1.47	2.12			
Male Grey	1.16	1.53	2.28	3.02	3.76	4.12
Female Red	1.06	1.50	2.45			
Male Red	1.07	1.41	2.09	2.76	3.43	3.76
PREDICTED SALIVARY GLAND WEIGHT (g)						
Female Grey	38	51	79			
Male Grey	36	48	71	95	119	130
Female Red	40	56	89			
Male Red	39	50	73	95	117	128
PREDICTED LUNG WEIGHT (g)						
Female Grey	136	157	192			
Male Grey	206	253	336	411	481	514
Female Red	186	247	368			
Male Red	178	234	344	452	559	611
PREDICTED HEART WEIGHT (g)						
Female Grey	126	167	249			
Male Grey	94	138	236	344	462	524
Female Red	156	207	307			
Male Red	160	207	299	388	475	518

TABLE 16 (CONT.)

	EMPTY BODY WEIGHT (kg)					
	15	20	30	40	50	55
PREDICTED LIVER WEIGHT (g)						
Female Grey	263	345	504			
Male Grey	250	332	494	656	816	896
Female Red	336	420	576			
Male Red	375	451	585	703	810	861
PREDICTED KIDNEY WEIGHT(g)						
Female Grey	56	71	99			
Male Grey	56	71	101	130	158	171
Female Red	64	80	108			
Male Red	68	82	107	130	151	161
PREDICTED SPLEEN WEIGHT(g)						
Female Grey	42	55	80			
Male Grey	43	56	80	103	125	136
Female Red	34	48	77			
Male Red	37	49	71	94	116	127
PREDICTED BLADDER WEIGHT (g)						
Female Grey	7	8	11			
Male Grey	9	10	14	17	20	21
Female Red	6	7	9			
Male Red	8	10	14	18	22	24
PREDICTED EMPTY GUT WEIGHT (kg)						
Female Grey	0.68	0.99	1.69			
Male Grey	0.51	0.71	1.13	1.57	2.03	2.26
Female Red	0.69	0.92	1.38			
Male Red	0.83	1.02	1.34	1.64	1.92	2.05

TABLE 16 (CONT.)

	EMPTY BODY WEIGHT (kg)					
	15	20	30	40	50	55
PREDICTED GUT FILL WEIGHT (kg)						
Female Grey	1.90	3.25	6.91			
Male Grey	1.15	1.83	3.51	5.57	7.97	9.28
Female Red	1.89	2.33	3.12			
Male Red	1.79	2.33	3.37	4.38	5.37	5.86

	EMPTY GUT WEIGHT (kg)				
	0.6	0.9	1.2	1.6	2.0
PREDICTED EMPTY STOMACH WEIGHT (kg)					
Female Grey	0.34	0.55	0.77		
Male Grey	0.33	0.52	0.73	1.01	1.31
Female Red	0.30	0.48	0.67		
Male Red	0.33	0.50	0.67	0.90	1.12
PREDICTED EMPTY SMALL INTESTINE WEIGHT (kg)					
Female Grey	0.16	0.23	0.29		
Male Grey	0.17	0.23	0.29	0.37	0.44
Female Red	0.19	0.26	0.32		
Male Red	0.17	0.25	0.32	0.42	0.51
PREDICTED EMPTY LARGE INTESTINE WEIGHT (kg)					
Female Grey	0.07	0.10	0.14		
Male Grey	0.07	0.11	0.14	0.18	0.23
Female Red	0.09	0.13	0.18		
Male Red	0.08	0.12	0.16	0.23	0.29

TABLE 16 (CONT.)

	EMPTY BODY WEIGHT (kg)					
	15	20	30	40	50	55
PREDICTED ADRENAL WEIGHT (g)						
Female Grey	2	2	4			
Male Grey	1	1	2	3	4	4
Female Red	1	2	2			
Male Red	1	2	2	3	3	3
PREDICTED TESTES WEIGHT (g)						
Male Grey	8	14	28	48	71	84
Male Red	9	16	32	54	80	95
PREDICTED OVARIES AND UTERUS WEIGHT (g)						
Female Grey	17	23	35			
Female Red	8	12	20			

TABLE 17

Comparisons between the relative proportions of viscera for grey kangaroo (*Macropus giganteus*), red kangaroos (*Megaleia rufa*), wallaroos (*Macropus robustus*); red neck wallabies (*Macropus rufogriseus*), and swamp wallabies (*Wallabia bicolour*). Comparisons relative to the grey kangaroo = 100 and based on mature animals.

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Hide weight % Empty Body Weight	Female	100	103	123	108	114
	Male	100	93	113		
Salivary Glands weight % Empty Body Weight	Female	100	130		80	129
	Male	100	121	159		
Lung weight % Empty Body Weight	Female	100	135	70	90	236
	Male	100	110	93		
Heart weight % Empty Body Weight	Female	100	86	100	117	96
	Male	100	149	133		
Liver weight % Empty Body Weight	Female	100	122	140	116	154
	Male	100	107	140		
Kidney weight % Empty Body Weight	Female	100	104	118	122	96
	Male	100	94	148		

TABLE 17 (CONT.)

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Spleen weight % Empty Body Weight	Female	100	86	69	108	84
	Male	100	96	125		
Bladder weight % Empty Body Weight	Female	100	120	291	174	171
	Male	100	97	149		
Empty Gut weight % Empty Body Weight	Female	100	97	117	94	101
	Male	100	110	123		
Gut Fill weight % Empty Body Weight	Female	100	72	137	96	118
	Male	100	102	133		
Empty Stomach weight % Empty Gut Weight	Female	100	88	90	87	95
	Male	100	85	92		
Empty Small Intestine weight % Empty Gut Weight	Female	100	114	128	123	84
	Male	100	127	136		
Empty Large Intestine weight % Empty Gut Weight	Female	100	135	107	122	142
	Male	100	120	80		
Adrenal weight % Empty Body Weight	Female	100	75	136	101	45
	Male	100	114	173		

TABLE 17 (CONT.)

Measurement	Sex	Grey Kangaroo	Red Kangaroo	Swamp Wallaby	Red Neck Wallaby	Wallaroo
Ovaries + Uterus weight % Empty Body Weight	Female	100	110	129	89	126
Testes weight % Empty Body Weight	Male	100	102	156		

TABLE 18

Viscera growth impetus patterns in the grey kangaroo. Estimated empty body weights at which growth impetus changes occur and direction of the change. (Increase in impetus = +, decrease in impetus = -).

Viscera Measurement	Empty Body Weight (kg)	Direction of change
FEMALE		
Adrenal weight	8.0	-
Ovaries + Uterus weight	13.4	-
Bladder weight	15.2	-
MALE		
Gut fill weight	1.5	+
Empty gut weight	2.8	-
Bladder weight	13.4	-
Spleen weight	14.2	-
Kidney weight	16.2	-
Liver weight	19.3	-
Adrenal weight	22.1	-
Salivary gland weight	32.1	-
Heart weight	43.5	-

DISCUSSION.

Hide

Green (1963) presented a comparative study on the histology of the cutaneous glands of marsupials. Mykytowycz and Nay (1964) examined the structure of the skin of grey and red kangaroos. They found "the hair cover was densest in the mid-dorsal region of the body, on the cheeks, and on the shoulders and the thighs. The density decreased ventrally. On the tail, the hair follicles were less dense on the ventral surface. The red kangaroo had the densest hair cover. The thickness of the hair fibres varied inversely in relation to the density of hair cover. Males were found to have consistently thicker skin on the ventral surface of the body, but in females, the skin was thicker on the back. In the tails of both sexes, the skin was thicker on the ventral base than on the dorsal side. The complete absence of a reticular layer was noted in the skin of all species of macropods examined."

The relationship for hide weight on empty body weight is presented in Figure 93. The hides were carrying winter fur. During specimen collection, contamination of the hide with dew, rain and grass seed occurred. When this experimental error is considered as a source of variance in hide weight, in view of the data, hide weight is remarkably constantly related to empty body weight.

From the wet hide weights of this study, the hides of male grey kangaroos were found to be significantly heavier than those for female grey kangaroos and for red kangaroos.

As demonstrated by Mykytowycz and Nay (1964), male kangaroos have thicker skin over the ventral body surface and this difference may account for the sex difference in hide weight found in the grey kangaroo.

Mykytowycz and Nay (1964) found that coat fibre density was greater in red kangaroos. However, they found that as fibre density increased, the fibre diameter decreased. Thus it would seem reasonable to postulate that wet hide weight will be influenced more by the thickness of the skin than by the density of the fur. This postulate is supported by the fact that, although fibre density is greater in red kangaroos, the hides from male grey kangaroos are significantly heavier than those from male red kangaroos.

The effect of differences in conformation of the two species on body surface area and hence perhaps on hide weight, is unknown.

Salivary Gland

Forbes and Tribe (1969) described the salivary glands of the grey and red kangaroo and Figure 110 is presented from their data.

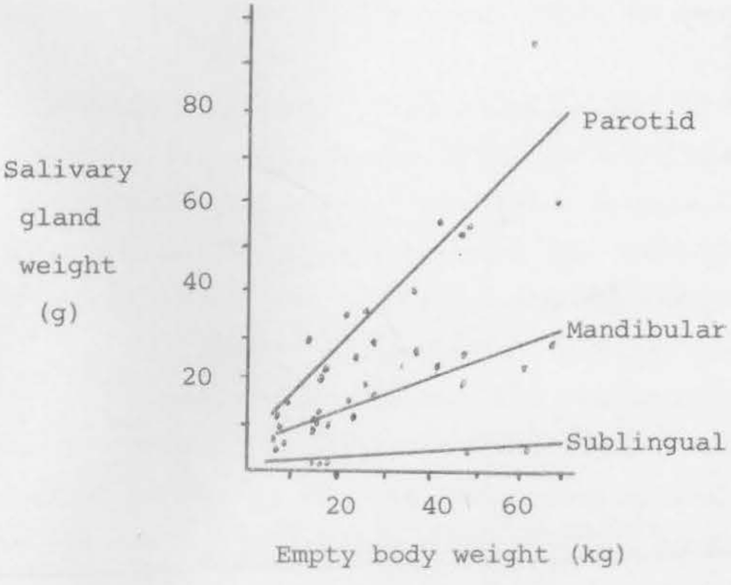

Figure 110. Relationship of parotid submaxillary and sublingual salivary gland weight to empty body weight. After Forbes and Tribe (1969).

Forbes and Tribe (1969) concluded that "The parotid of adult kangaroos, although histologically similar to that in calves and sheep, was twice as heavy in relation to body weight. The submaxillary was of similar weight, in relation to body weight, as the submaxillary of the ruminants, but had a much greater proportion of serous-type cells than the submaxillary of sheep. Weights of the three types of glands were all significantly correlated with the empty body weight .... the kangaroo parotid saliva contained amylase, which is not found in ruminant saliva."

In the present study, the relationship for salivary gland weight on empty body weight is presented in Figure 94. Two discrepancies in the data from this study and that of Forbes and Tribe (1969) occur. Forbes and Tribe (1969) described the growth of the salivary glands as monophasic, applying linear regression to the data. In this study, in the grey kangaroo, the growth of salivary glands was monophasic for females, but biphasic for males. In the male, the growth impetus for the salivary glands decreased at 32.1 (±5.8) kg empty body weight.

A large percentage of the animals used in this study were shot in the neck. Consequent damage to the salivary glands added considerably to the experimental error. The author decided to compare the predicted weights for salivary gland by using the overall equation for the red and grey kangaroos of this study, against the combined results for the equations for parotid and submaxillary gland given by Forbes and Tribe (1969). It was anticipated that the predicted values from this study would be slightly less, due to damage from shooting. In fact, the predicted values for salivary gland were greater than those obtained from the data of Forbes and Tribe (1969). No explanation is evident.

Lungs

Boardman (1941) described the lungs of the wallaroo in detail.

The relationship for lung weight to empty body weight is presented in Figure 95. The wide variation in lung weight between individual animals was, in part, attributable to experimental method. When animals were shot, they were hung by the hock at the rear of the vehicle. Consequently, fluid was able to collect in the air passages and alveoli of the lungs. It is anticipated that the lung weights after conventional slaughter and bleeding techniques would be less. In fact, the three grey kangaroos taken alive from the Brewarrina area, when slaughtered and bled, had lung weights less than the predicted lung weight for an animal of the same body weight, collected by the procedure described for this work.

Consequently, the relationship for lung weight on empty body weight in this study is valid only for comparison with other animals collected by a similar technique.

Heart

Owen (1868), Parsons (1896), Windle and Parsons (1898), Broom (1898), Craigie (1938), Pearson (1939) and Boardman (1941) described in part the cardiovascular system of the kangaroo.

The relationship for heart weight to empty body weight is presented in Figure 96. Davis (pers comm) stated that within a species, heart size is correlated to athletic ability. On the basis of this generalization, female kangaroos appear to be more athletic than males, red kangaroos appear more athletic than grey kangaroos.

From the literature, a non-critical report supporting these tentative deductions, is found in Frith and Calaby (1969) who stated "The speed travelled (by red kangaroos) is also often debated; it is clear, from pacing with motor cars, that males can achieve 35 m.p.h., for short bursts. Young mature females, 'blue flyers', have been paced for short bursts at 40 m.p.h. Normally, however, when not closely pursued, they travel at about 8 m.p.h. On hot days, bucks, particularly large ones, can be tired within a few miles by close pursuit, never exceeding 25 - 30 m.p.h. and for the last mile or so, no more than 10 - 15 m.p.h."

Red kangaroos are possibly more nomadic than grey kangaroos and Newsome (1971) recorded red kangaroos migrating up to approximately 220 kilometers. Whether this indicates a more athletic and mobile daily movement pattern than for the grey kangaroo or not, is debatable.

Bladder

Bolliger (1946) in *Trichosurus vulpecula* commented on what he described as a "persistent physiological spermatorrhoea." He stated that ".... masses of spermatozoa pile up in the wide urethra to be flushed out with the urine on micturition." Bolliger (1946) further commented on a "viscous prostatic secretion (which) frequently gives to the urine a markedly oily appearance and again it seems as if the prostatic secretion was an almost permanent one, though with some variations in quantity."

During dissection, the author noticed the presence of a viscous milky white fluid in the bladder of some animals. In view of Bolliger's (1946) comments, the bladder of marsupials may act in the capacity of an accessory sex gland with a storage function.

The relationship for bladder weight to empty body weight is presented in Figure 100. The bladder weights for males of both the grey and red kangaroo were significantly heavier than for females. This finding is consistent with the hypothesis that the bladder may act as a storage organ for seminal fluid.

Gastro-Intestinal Tract

Griffiths and Barton (1966) described the ontogeny of the stomach for pouch young of the red kangaroo. They concluded "The anterior four-fifths of the stomach of the red kangaroo consists of a sacculated region, the mucosa of which is made up of cardiac glands. This mucosa elaborates no intrinsic digestive enzymes but the stomach contents contain amylase, probably of bacterial origin. The cardia leads into a gastric pouch lined by fundic tissue composed of parietal and chief cells. The pH of this region is acid and extracts of the mucosa have peptic activity. The stomach is elongated and is coiled spirally on itself, the inside of the spiral being modified to form a groove lined by stratified cornified epithelium. The stomach of the neonatus exhibits this spiral arrangement. The whole of the stomach, however, possesses peptic activity due to the secretion, by cells of one type only, of acid and pepsin. At about the 200th day of pouch life, the epithelium of the anterior four-fifths of the stomach is transformed into cardiac glands ..... At the 236th day, the definitive structure of the adult stomach is achieved and all peptic activity is confined to the posterior gastric pouch region."

If the ages in days given by Griffiths and Barton (1966) are substituted into the age-liveweight relationship of Frith and Calaby (1969) presented in Figure 4, then the definitive structure of the adult stomach of the red kangaroo is achieved at approximately 3 - 4 kg liveweight. The expected liveweight at which the grey kangaroo stomach would achieve its adult form could reasonably be expected to be greater than in the red kangaroo, due to the longer pouch life and slower pouch growth rate of grey kangaroos.

The nutrition of pouch young has been discussed by Wilson.

Figures 101 and 102 demonstrate that in grey kangaroos, both the weight of the empty gut and the weight of the digesta increase relatively slowly during early pouch life. The standard errors associated with the point of estimated change in growth impetus for the empty gut and "digesta" are too great to allow accurate objective mathematical definition of the empty body weight at which gut weight changes growth impetus. Visual inspection of the graphs indicates that gut weight undergoes growth impetus increase between 2 - 4 kg empty body weight, and that the weight of the digesta increases mardedly between 4 - 5 kg empty body weight.

Thus the increase in weight of the digesta between 4 - 5 kg empty body weight, as found in this study, is in agreement with the histological and biochemical studies on the digestive capability of the organ. The increase in bulk of the digesta reflects the increasing fodder component of the diet. However, all but the most juvenile animal in this study, showed evidence of some grass in the stomach.

Growth of the stomach, small intestine and large intestine, when correlated to the gastro-intestinal tract as a whole, was monophasic. The stomach was relatively heavier for grey kangaroos and the large intestine relatively heavier for red kangaroos. Assuming a relationship between function and organ size, the differences in digestive emphasis in the grey and red kangaroo presumably correlate with habitat preferences. A comparative study in the digestive physiology of the two species would possibly explain the differences in gastro-intestinal tract weights found in this study.

Testes

The genitalia of male marsupials has been described by Home (1795), Owen (1868), Young (1879), MacKenzie (1919), Fordham (1928), Jones (1949), and Rodger and Hughes (1973).

Figure 107 illustrates the growth of testes on empty body weight.

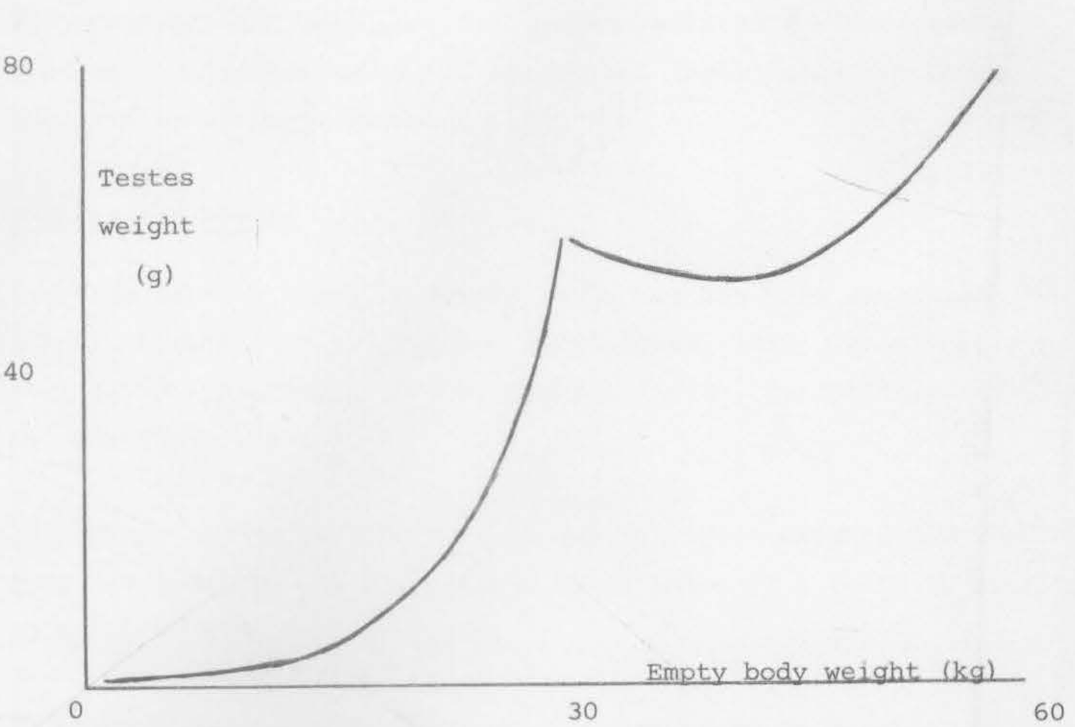

Figure 111. Projected possible relationship between testes weight and empty body weight. Grey and red kangaroos.

Interpretation of the relationship is complicated by individual variation and the relatively small number of animals (32) available. Despite the fact that the allometric functions presented with the data plot give an acceptable description of the relationship, an alternate concept of the relationship may be presented as depicted in Figure 111.

If further research confirms Figure 111 to be the correct interpretation of the data collected in this study, then it would appear that growth rate of the testes of the grey kangaroo increases around 12 kg empty body weight to peak and then plateau between 30 - 40 kg empty body weight. The testes then enter a second stage of growth rate increase.

For the kangaroo, the ecological significance, if any, of the projected pre and post-pubertal growth patterns for the testes is unknown. Ellucidation of the ecological implication relies on a detailed behavioural study.

Ovaries and Uterus

The genital tract of female kangaroos has been described by Owen (1868), Lister (1881), Fletcher (1881, 1882, 1883), Stirling (1889), Hill (1900), MacKenzie (1919), Pearson (1944), Tyndal-Biscoe (1964) and Sharman (1964).

Clark and Poole (1967) found genital tract weights for female grey kangaroos in the age classes molar index II.0 to IV to range from 26.4 (±1.5) g to 44.1 (±1.8) g.

The data from this study were insufficient to develop biologically meaningful correlations. Based on the two phase linear regression of Griffiths and Miller (1973), a growth impetus decrease in ovaries plus uterus weight occurs in the grey kangaroo at 13.4 (±4.7) kg empty body weight. Although this result is the correct mathematical interpretation of the unweighted data, it is unlikely to be biologically meaningful. Rather, it may be expected that a growth impetus increase would occur in the ovaries plus uterus with the onset of sexual maturity. The growth pattern of ovaries plus uterus may be defined only with the collection of further data.

Thymus

Studies on the marsupial thymus include the works of Johnstone (1898, 1901), Yadav and Papadimitriou (1969) and Yadav (1973). Yadav (1973) demonstrated that both cervical and thoracic lobes of the thymus occur in at least thirty-two species of macropod. Figure 112 is after Yadav (1973) and demonstrates the growth pattern of the thymus of the brush-tail possum (Trichosurus vulpecula).

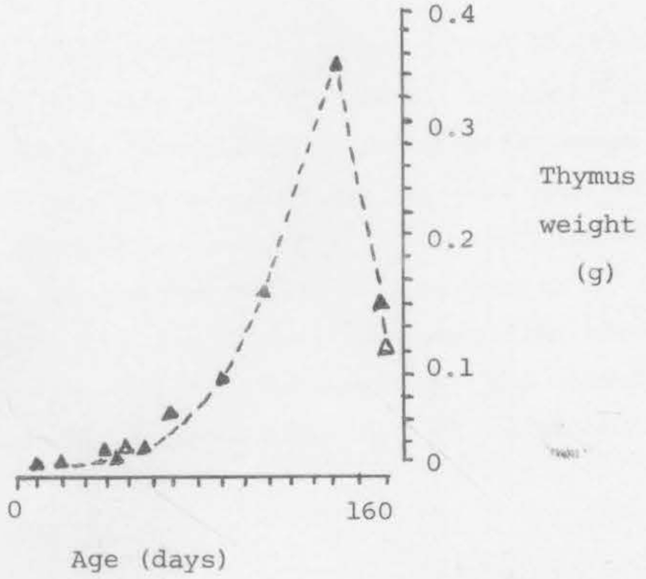

Figure 112. Relationship of thymus weight to age in <u>Trichosurus vulpecula</u>. After Yadav (1973).

The relationship for thymus weight to empty body weight for this study is given in Figure 109. The same growth pattern holds for grey and red kangaroos as that demonstrated by Yadav (1973) for <u>Trichosurus vulpecula</u>.

CHAPTER 9

THE KANGAROO AS A MEAT ANIMAL.

INTRODUCTION.

A critical assessment of the potential of the kangaroo as a meat animal is beyond the scope of this study. Reviews include Roff and Kirkpatrick (1962) on "the kangaroo industry in Queensland", Newsome and Frith (1966) on "the kangaroo and the game meat trade," Ratcliffe (1970) on "the commercial hunting of kangaroos" and Frith, Macfarlane, Doohan, Livanes and Sharman (1971) in a symposium on "kangaroos and men". This chapter of the study will investigate carcass yield and composition for the grey and red kangaroo. The carcass composition of the kangaroo will be compared with that of the sheep.

MATERIALS AND METHODS.

The general materials and methods used are described in Chapters 2 and 3.

RESULTS AND DISCUSSION.

Kangaroos may be harvested opportunistically from natural populations or produced on commercial kangaroo farms.

Commercial husbandry, to be successful, must compete both economically and ecologically with the husbandry of domestic animals. Present knowledge on kangaroo management, fecundity, growth rate, feed conversion, meat quality and market potential for the meat is scant. Until pilot harvesting schemes are completed and critical data is forthcoming, predictions of the success or failure of commercial kangaroo farming enterprises must be conjectural.

The profitability of opportunistic harvesting depends solely on selling the product at a greater price than the cost of collecting and processing. Currently, commercial kangaroo shooters receive, depending on market fluctuations, approximately 15 cents/kg for dressed kangaroo carcasses. The dressed carcass includes hide, which is not removed by the shooter. The processors sell the hides for leather, fur toys and decorative skins and the meat for pet food.

The present return to the commercial shooter gives him a marginal livelihood and precludes any payment to the grazier from whose property the animals are taken. Under the current N.S.W. licensing system, graziers find it difficult to sell kangaroos they shoot themselves. It is economically desireable for the grazier to allow a commercial shooter onto his property in so far as it saves him the cost of destroying the kangaroos himself. To the grazier, the kangaroo at present provides little or no cash return and is often classed as a pest.

The basic justification for a primitive kangaroo processing industry is that it is an economically viable way of reducing the numbers of kangaroos in natural populations. Irrespective of the source of a kangaroo, that is, opportunistically harvested or commercially produced, the maximum retail value should be realised from the carcass. To achieve this, processing methods need to be upgraded to enable sale of the meat for human consumption.

An increase in retail value of the kangaroo would mean increased profitability at all levels of the industry. Under these conditions, shooters would be able to pay graziers for animals taken from their properties and so give an incentive to the grazier to tolerate larger kangaroo populations. Alternatively, an increased return from the kangaroo may encourage serious exploitation of natural populations. Precedents may be quoted to illustrate conservation or depletion of wild animal populations under commercial harvesting.

The relationships of carcass weight to empty body weight and carcass muscle, carcass bone and carcass fat to empty body weight for grey and red kangaroos investigated in this study, are presented in Figures 113 and 114.

Carcass weight and half-carcass tissue weights for grey and red kangaroos are predicted from the functions presented with Figures 113 and 114 and tabulated as Table 19.

Sheep are of a similar body size to the kangaroo and are the traditional grazing animal of western N.S.W. A comparison then of the carcass composition of sheep and kangaroos is pertinent to the potential of the kangaroo as a meat producing animal.

The sheep used in this comparison are Border Leicester x Merino wethers. They were animals used by Hilmi (1976) to demonstrate the effects of fast and slow growth on body composition and represent sheep raised on high and low planes of nutrition. They were slaughtered over the empty body weight range of 20 - 40 kg.

The regression equations and comparisons for carcass dressed weight on empty body weight are given in Table 20. The 'b' values for the sheep and kangaroos are not significantly different. The 'a' values are significantly different, the kangaroo carcasses being heavier.

The regression equations and comparisons for half-carcass bone on empty body weight are given in Table 21. The 'b' values for the sheep are highly significantly less than for the kangaroos. At 20 kg empty body weight, the carcasses from sheep contained more bone than those of kangaroos. The converse is true for animals at 30 and 40 kg empty body weight.

CARCASS DRESSED WEIGHT

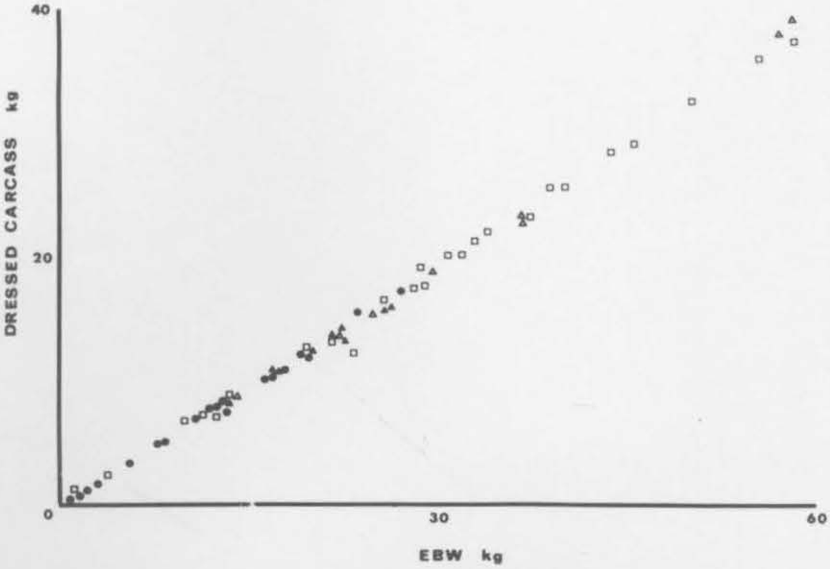

Figure 113 Relationship of carcass dressed weight to empty body weight in grey and red kangaroos.

● Female Grey Kangaroo $Y = -.187 + .646\ X$
$n = 19 \quad r = .998 \quad SE\ b = .009 \quad P$ ***

□ Male Grey Kangaroo $Y = -.463 + .657\ X$
$n = 25 \quad r = .998 \quad SE\ b = .010 \quad P$ ***

▲ Female Red Kangaroo $Y = .782 + .583\ X$
$n = 9 \quad r = .993 \quad SE\ b = .025 \quad P$ ***

△ Male Red Kangaroo $Y = -1.555 + .694\ X$
$n = 8 \quad r = .998 \quad SE\ b = .016 \quad P$ ***

Comparison of differences between the two sexes and species

Comparison	b	a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	*	–
Female Grey/Female Red	*	–
Male Grey/Male Red	NS	NS

Overall Equation $Y = -.509 + .660\ X$
Two Sexes and Species $n = 61 \quad r = .998 \quad SE\ b = .005 \quad P$ ***

Half-Carcass Muscle

Comparison of differences between the two sexes and species

Comparison	b	a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	NS	NS
Female Grey/Female Red	*	–
Male Grey/Male Red	*	–

Half-Carcass Fat

Female Grey Kangaroo	$Y = -9.875 + 2.819\ X$	
	$n = 19$ $r = .792$ SE $b = .527$	P ***
Male Grey Kangaroo	$Y = 7.283 + .946\ X$	
	$n = 25$ $r = .540$ SE $b = .307$	P **
Female Red Kangaroo	$Y = 97.944 + 2.884\ X$	
	$n = 9$ $r = .137$ SE $b = 7.899$	P NS
Male Red Kangaroo	$Y = 39.890 + 1.448\ X$	
	$n = 8$ $r = .395$ SE $b = 1.376$	P NS

Comparison of differences between the two sexes and species

Comparison	b	a
Female Grey/Male Grey	*	–

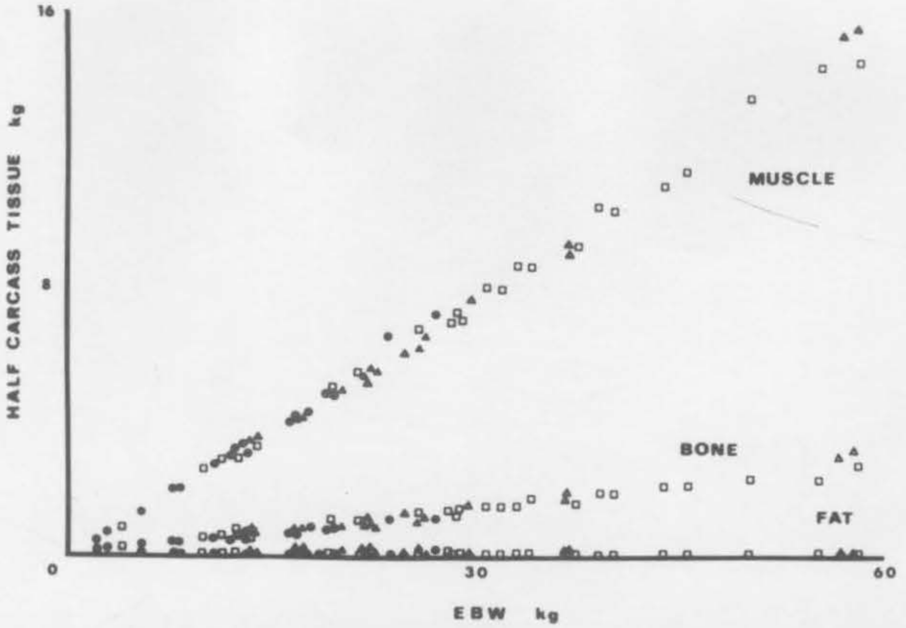

Figure 114 Relationship of half carcass bone, half carcass muscle and half carcass fat to empty body weight in grey and red kangaroos.

Half Carcass Bone

● Female Grey Kangaroo $Y = .064 + .040\,X$
$n = 19 \quad r = .995 \quad SE\ b = .001$ P ***

□ Male Grey Kangaroo $Y = .068 + .044\,X$
$n = 25 \quad r = .990 \quad SE\ b = .001$ P ***

▲ Female Red Kangaroo $Y = .123 + .038\,X$
$n = 9 \quad r = .950 \quad SE\ b = .005$ P ***

△ Male Red Kangaroo $Y = -.096 + .053\,X$
$n = 8 \quad r = .997 \quad SE\ b = .002$ P ***

Comparison of differences
between the two sexes and species

Comparison	b	a
Female Grey/Male Grey	NS	NS
Female Red/Male Red	*	-
Female Grey/Female Red	NS	NS
Male Grey/Male Red	***	-

Half Carcass Muscle

● Female Grey Kangaroo $Y = -.188 + .265\,X$
$n = 19 \quad r = .996 \quad SE\ b = .006$ P ***

□ Male Grey Kangaroo $Y = -.287 + .261\,X$
$n = 25 \quad r = .996 \quad SE\ b = .005$ P ***

▲ Female Red Kangaroo $Y = .153 + .235\,X$
$n = 9 \quad r = .997 \quad SE\ b = .007$ P ***

△ Male Red Kangaroo $Y = -.875 + .281\,X$
$n = 8 \quad r = .997 \quad SE\ b = .009$ P ***

TABLE 19

Carcass weight and half-carcass tissue weights for grey and red kangaroos. Values predicted from functions presented with Figures 113 and 114.

	EMPTY BODY WEIGHT (kg)					
	15	20	30	40	50	55
PREDICTED CARCASS DRESSED WEIGHT (kg)						
Female Grey	9.5	12.7	19.2			
Male Grey	9.4	12.7	19.2	25.8	32.4	35.7
Female Red	9.5	12.4	18.3			
Male Red	8.9	12.3	19.3	26.2	33.1	36.6
PREDICTED HALF-CARCASS MUSCLE WEIGHT (kg)						
Female Grey	3.79	5.11	7.76			
Male Grey	3.63	4.93	7.54	10.15	12.76	14.07
Female Red	3.68	4.85	7.20			
Male Red	3.34	4.75	7.56	10.37	13.18	14.58
PREDICTED HALF-CARCASS BONE WEIGHT (kg)						
Female Grey	0.66	0.86	1.26			
Male Grey	0.73	0.95	1.39	1.83	2.27	2.49
Female Red	0.69	0.88	1.26			
Male Red	0.70	0.96	1.49	2.02	2.55	2.82
PREDICTED HALF-CARCASS FAT WEIGHT (kg)						
Female Grey	.032	.047	.075			
Male Grey	.021	.026	.036	.045	.055	.059
Female Red	.141	.156	.184			
Male Red	.062	.069	.083	.098	.112	.119

NOTE. Difference between sum of carcass tissue weights and carcass weight represents loss due to fluid drip and connective tissue classed as waste.

The regression equations and comparisons for half-carcass muscle on empty body weight are given in Table 22. The 'b' values for the sheep are highly significantly less than for the kangaroos. The carcasses of kangaroos are heavier muscled than those of sheep.

The regression equations and comparisons for half-carcass fat on empty body weight are given in Table 23. The 'b' values for the sheep are highly significantly greater than for the kangaroos. The carcasses of sheep are fatter than those of kangaroos.

The predicted carcass weight and percentage carcass composition of bone, muscle and fat for sheep and kangaroos of 20, 30 and 40 kg empty body weight are given in Table 24. The values are predicted from the regressions presented in Tables 20, 21, 22 and 23.

Sheep yield less carcass than kangaroos of the same weight. If the kangaroo's tail is included with the carcass, the difference in carcass yield is further increased in favour of the kangaroo. Within the carcass, kangaroos maintain a constant percentage of bone, while the bone percentage fell as the carcass weight increased in sheep. Thus, lighter body weight sheep yield more bone and heavier body weight sheep less bone from their carcasses than kangaroos of the same empty body weight.

Kangaroos maintain a constant percentage of muscle, while the percentage carcass muscle decreases as the empty body weight increases in sheep. Thus, while kangaroo carcasses yield approximately 79% of the carcass as muscle irrespective of carcass or empty body weight, the carcass muscle in sheep decreases from 57% at 20 kg empty body weight to 49% at 40 kg empty body weight.

Carcass fat was less than 1% irrespective of the carcass or empty body weight of the kangaroo. In the sheep, carcass fat increases from

20% of the carcass at 20 kg empty body weight to 32% of the carcass at 40 kg empty body weight.

As a generalization, when kangaroos are compared with sheep in the empty body weight range 20 - 40 kg, the carcasses of both species yield approximately 14% bone, 6% waste, 80% muscle in the kangaroo, and 80% muscle plus fat in sheep. The increasing fat percentage in heavier sheep carcasses decreases the muscle and bone percentage, but the muscle percentage decrease is the greater.

Apart from total muscle yield, the muscle-weight distribution within a carcass will affect the value of the carcass. Traditional selection on domestic animals of a meat type has been aimed at improving the percentage of muscle in the high value areas of the loin, rump and thigh. Table 25 was taken from Lohse's (1971) study on the merino sheep. Table 26 gives the percentage of the individual muscle groups of total muscle in immature and mature kangaroos. Table 27 gives a resumé of the % distribution of total muscle in the various muscle groups of kangaroos and sheep.

If proximal hindlimb and spinal muscle are considered to be the "highest quality" muscle, then these two groups contribute 62% and 45% of total carcass muscle in kangaroos and sheep respectively.

In brief, a kangaroo yields more dressed carcass than a sheep of the same empty body weight. Kangaroo dressed carcass yields more muscle than a sheep dressed carcass of the same carcass weight, and the muscle of the kangaroo carcass is concentrated in the more "valuable" carcass areas.

TABLE 20

Comparisons of the linear regressions for carcass dressed weight on empty body weight of sheep grown at two rates and of two species and sexes of kangaroo.

	a	b	SE b	P	n	r	Comparison of Differences		
	(kg)						Group	b	a
Fast Growth Sheep	-2.691	0.675	.022	***	17	.992	Fast/Slow	NS	*
Slow Growth Sheep	-2.725	0.695	.024	***	17	.991			
Female Grey Kangaroo	-0.187	0.646	.009	***	19	.998	Female Grey/Male Grey	NS	NS
Male Grey Kangaroo	-0.463	0.657	.010	***	25	.998	Female Red/Male Red	*	-
Female Red Kangaroo	0.782	0.583	.025	***	9	.993	Female Grey/Female Red	*	-
Male Red Kangaroo	-1.555	0.694	.016	***	8	.998	Male Grey/Male Red	NS	NS
Combined Sheep	-2.544	0.679	.017	***	34	.990	Kangaroo/Sheep	NS	***
Combined Kangaroo	-0.509	0.660	.005	***	61	.998			

NS Not significant at the 5% level

* Significant at the 5% level

*** Significant at the 0.1% level

TABLE 21

Comparisons of the linear regressions for half-carcass bone on empty body weight of sheep grown at two rates and of two species and sexes of kangaroo.

	a (kg)	b	SE b	P	n	r	Comparison of Differences Group	b	a
Fast Growth Sheep	0.367	0.027	.002	***	17	.951	Fast/Slow	NS	NS
Slow Growth Sheep	0.219	0.035	.003	***	17	.952			
Female Grey Kangaroo	0.064	0.040	.001	***	19	.995	Female Grey/Male Grey	NS	NS
Male Grey Kangaroo	0.068	0.044	.001	***	25	.990	Female Red/Male Red	*	-
Female Red Kangaroo	0.123	0.038	.005	***	9	.950	Female Grey/Female Red	NS	NS
Male Red Kangaroo	-0.096	0.053	.002	***	8	.997	Male Grey/Male Red	***	-
Combined Sheep	0.320	0.030	.002	***	34	.941	Kangaroo/Sheep	***	-
Combined Kangaroo	-0.006	0.047	.001	***	61	.988			

NS Not significant at the 5% level

* Significant at the 5% level

*** Significant at the 0.1% level

TABLE 22

Comparisons of the linear regressions for half-carcass muscle on empty body weight of sheep grown at two rates and of two species and sexes of kangaroo.

	a (kg)	b	SE b	P	n	r	Comparison of Differences Group	b	a
Fast Growth Sheep	0.182	0.145	.077	***	17	.984	Fast/Slow	NS	*
Slow Growth Sheep	0.113	0.154	.008	***	17	.982			
Female Grey Kangaroo	-0.188	0.265	.006	***	19	.996	Female Grey/Male Grey	NS	NS
Male Grey Kangaroo	-0.287	0.261	.005	***	25	.996	Female Red/Male Red	NS	NS
Female Red Kangaroo	0.153	0.235	.007	***	9	.997	Female Grey/Female Red	*	-
Male Red Kangaroo	-0.875	0.281	.009	***	8	.997	Male Grey/Male Red	*	-
Combined Sheep	0.204	0.147	.005	***	34	.980	Kangaroo/Sheep	***	-
Combined Kangaroo	-0.275	0.263	.003	***	61	.997			

NS Not significant at the 5% level

* Significant at the 5% level

*** Significant at the 0.1% level

TABLE 23

Comparisons of the linear regressions for half-carcass fat on empty body weight of sheep grown at two rates and of two species and sexes of kangaroo.

	a (kg)	b	SE b	P	n	r	Comparison of Differences		
							Group	b	a
Fast Growth Sheep	-1.890	0.147	.010	***	17	.970	Fast/Slow	NS	NS
Slow Growth Sheep	-1.450	0.131	.008	***	17	.974			
Female Grey Kangaroo	-0.010	0.003	.001	***	19	.792	Female Grey/Male Grey	*	-
Male Grey Kangaroo	0.007	0.001	.0003	**	25	.540			
Female Red Kangaroo	0.098	0.003	.008	NS	9	.137			
Male Red Kangaroo	0.040	0.001	.001	NS	8	.395			
Combined Sheep	-1.704	0.141	.006	***	34	.970	Kangaroo/Sheep	***	-
Combined Kangaroo	0.029	0.001	.001	*	61	.275			

NS	Not significant at the 5% level
*	Significant at the 5% level
**	Significant at the 1% level
***	Significant at the 0.1% level

TABLE 24

Carcass weight and percentage of carcass bone, muscle and fat for kangaroos and sheep at three empty body weights. Values predicted from regressions in Tables 1 - 4.

Empty Body Weight (kg)	Species	Carcass Weight (kg)	Bone (%)	Muscle (%)	Fat (%)	Waste (%)
20	Sheep	11.04	16.7	57.0	20.2	6.1
	Kangaroo	12.69	14.7	78.6	0.8	5.9
30	Sheep	17.83	13.7	51.8	28.3	6.2
	Kangaroo	19.29	14.6	79.0	0.6	5.8
40	Sheep	24.62	12.3	49.4	32.0	6.3
	Kangaroo	25.89	14.5	79.1	0.5	5.9

TABLE 25

Mean percentages of muscle groups in relation to half-carcass muscle for 7 ewes, 9 rams and 9 wethers at birth and 2 ewes, 2 wethers and 2 rams at 2 years. After Lohse (1971).

Muscle Group	Ewes		Rams		Wethers	
	% at birth	% at 2 years	% at birth	% at 2 years	% at birth	% at 2 years
Proximal Hindlimb	24.614	29.441	24.131	26.558	24.718	28.248
Distal Hindlimb	6.272	5.026	6.074	4.683	6.175	5.109
Spinal	14.210	16.297	13.729	17.375	13.688	16.537
Abdominal	7.378	8.375	7.514	9.361	6.882	9.381
Intrinsic Proximal Forelimb	12.883	11.809	12.556	11.169	12.770	11.419
Distal Forelimb	4.356	3.055	4.480	2.982	4.638	3.140
Foreleg-Thorax	7.128	6.328	6.932	6.016	7.199	6.642
Foreleg-Neck	6.800	7.885	7.292	7.620	7.084	7.428
Intrinsic Neck and Thorax	11.072	8.847	11.864	11.197	11.558	9.337

NOTE: Numbers of muscle groups 7 and 8 reversed to conform with the notation of this study and the original notation of Butterfield (1963).

TABLE 26

The percentage contribution of each muscle group to total carcass muscle for grey and red kangaroos. Values are mean value of the two lightest or heaviest animals in each group.

	Immature Female Grey % Total	Immature Male Grey % Total	Mature Female Grey % Total	Mature Male Grey % Total	Mature Female Red % Total	Mature Male Red % Total
Forequarter	27.7	29.1	24.8	35.9	28.8	39.3
Hindquarter	61.0	66.1	73.8	62.5	70.2	58.9
Proximal Hindlimb	38.4	40.3	44.7	37.1	42.3	35.7
Distal Hindlimb	13.6	14.2	11.3	10.4	8.8	7.6
Spinal	19.1	20.0	22.5	19.1	25.3	21.1
Abdominal	2.5	3.6	9.8	8.5	9.9	8.3
Intrinsic Proximal Forelimb	4.7	4.5	2.5	7.9	3.1	9.0
Distal Forelimb	0.75	0.89	0.39	2.0	0.76	2.9
Foreleg-Thorax	3.4	2.9	1.9	5.7	2.1	6.0
Foreleg-Neck	0.80	0.57	0.30	0.87	0.43	0.76
Intrinsic Neck and Thorax	6.6	8.2	5.2	7.0	6.3	6.7

Values stated are the average of the 2 heaviest or 2 lightest animals in each group.

Specimens Immature grey Female F102 and F214, Male F213 and F273. Mature grey Female F226 and F267 Male F261 and F218. Mature red Female F310 and F308. Male F316 and F317.

TABLE 27

The percentage contribution of each muscle group to total carcass muscle for sheep and kangaroos. Sheep data adapted from Lohse (1971). Kangaroo data extracted from Table 26.

Muscle Group	% Total Muscle Mature Sheep All Sexes	% Total Muscle Mature Kangaroos 2 Sexes and Species
Proximal Hindlimb	28.1	40.0
Distal Hindlimb	4.9	9.5
Spinal	16.7	22.0
Abdominal	9.0	9.1
Intrinsic Proximal Forelimb	11.5	5.6
Distal Forelimb	3.1	1.5
Foreleg-Thorax	6.3	3.9
Foreleg-Neck	7.6	0.6
Intrinsic Neck and Thorax	9.8	6.3

NOTE. Lohse's muscle group numbers 7 and 8 reversed to conform with the notation of this study and with the original notation of Butterfield (1963).

CHAPTER 10

GENERAL DISCUSSION

A. SEXUAL DIMORPHISM IN THE KANGAROO.

Male and female grey and red kangaroos differ markedly in their adult size and in their tissue distribution within the body.

The heaviest female grey and red kangaroo studied were specimens F267 and F308 respectively. F267 weighed 27 kg empty body weight at an estimated age of 2.830 days and F308 weighed 26 kg empty body weight at an estimated age of 4,124 days. In comparison, the heaviest male grey and red kangaroos studied were specimens F218 and F317 respectively. F218 weighed 58 kg empty body weight at an estimated age of 3,023 days and F317 weighed 58 kg empty body weight at an estimated age of 2,726 days. Figure 13 of body weight against age for the grey and red kangaroos in this study, and Figure 115 after Frith and Calaby (1969) illustrate the sexual dimorphism in absolute size in the grey and red kangaroo.

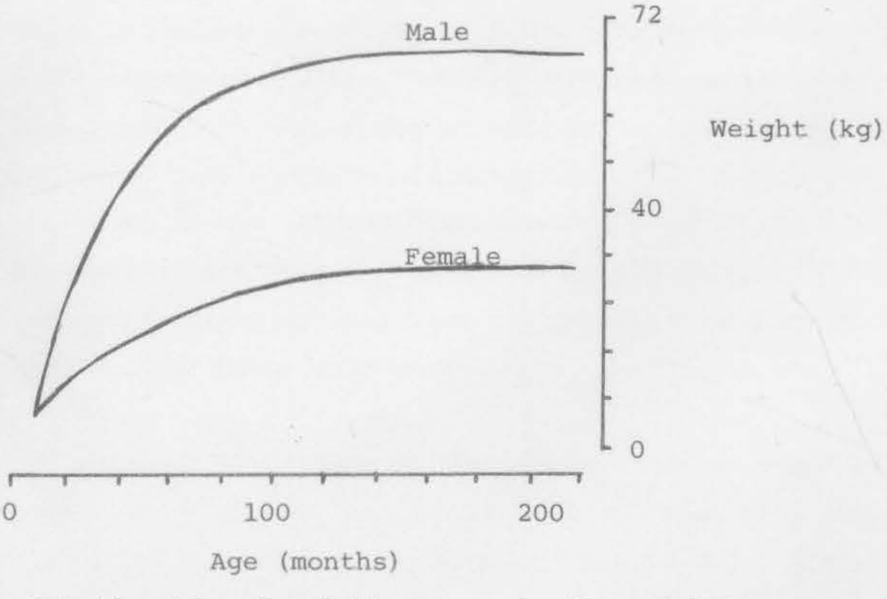

Figure 115. Relationship of weight to age in the red kangaroo. After Frith and Calaby (1969).

The largest kangaroo known to the author was a male red kangaroo captured by Dr. M. Denny at Sturt National Park, N.S.W. This specimen, weighed in the author's presence, weighed 96 kg liveweight. Mature male grey and red kangaroos grow to 2-3 times the size of mature females.

Sexual dimorphism is evident in the distribution of the body tissues as well as in absolute body size. In general, sexual dimorphism is less pronounced in the linear body measurements and more pronounced in body weight distribution. Linear body measurements are early maturing in both female and male kangaroos, while in males but not females much of the musculature exhibits a late maturing growth pattern. In particular, if body length is compared between animals at the same body weight, no significant differences are found between sexes within species for grey and red kangaroos. The nett effect of early maturity in body length in both sexes but late maturity in parts of the male musculature is to produce a thickening of the body form in the adult male.

If females and males are compared at the same body weight, then the forequarter region as a whole, and the component manus, antebrachium, omobrachium and thorax are significantly heavier for males; conversely, females have a heavier hindquarter. The forequarter is less than one-third of the carcass (considerably less in animals at lighter body weights) and thus the increase in size of the male forequarter is proportionately greater than the increase in size of the female hindquarter and hence more obvious.

Sexual dimorphism is evident in the carcass muscle, bone and fat of the kangaroo. When animals are compared at the same body weight, females are found to have a greater amount of muscle and a greater amount of fat in their bodies than do males. Males have a greater amount of bone. The differences between the sexes in weight of total carcass muscle, bone and fat while statistically significant, are of a small magnitude. The forequarter of males is heavier muscled and heavier boned than the forequarter of females. The converse holds for the hindquarter of the grey kangaroo.

Sexual dimorphism is not pronounced amongst the viscera. Except for the genitalia and bladder, sexual dimorphism was not demonstrable in both grey and red kangaroos for any of the visceral relationships investigated. An hypothesis that the bladder of the male kangaroo acts as an accessory sex gland (storage of seminal fluid) has been proposed as a functional explanation of the observed sexual dimorphism in bladder weights.

B. DOMESTICATION AND BODY COMPOSITION.

Domestication is the subjection to or dependence of an animal species on man. The usefulness of a domestic species to man is determined on characteristics considered to be of "merit". In the hope of "improving" the usefulness of a species, man imposes arbitrary selection. The potential for genetic improvement and the nature of the growth principles underlying development are of considerable importance to the animal breeder. It is proposed that one may look at the body composition data available for a wide range of mammals and deduce the probable limits to changes in body composition that may be effected by artificial selection.

The proportion of fat present in the bodies of domestic and wild animals is the most striking difference in their body composition. On the basis of this general observation, an hypothesis consistent with available body composition data, would be that, the affect of domestication on an animal is to reduce the proportion of muscle in its carcass in favour of fat. Objections may be raised against this hypothesis based on body composition data available for draft breeds of cattle, the thoroughbred horse and the elephant seal Mirounga leonina. By qualifying the hypothesis with a functional basis, that is, the locomotion required by a domestic animal is less than that required by wild animals - the means of locomotion being the musculature, these objections may be overcome. Athletic types of domestic animals would be expected to have a relatively high proportion of their carcass as muscle and low proportion of carcass as fat, when compared to the non-athletic types. An exceptionally fat wild animal, the elephant seal, may be explained on the basis of the thermoregulatory function of its subcutaneous fat deposit (Bryden 1967). This functional basis for the major difference between domestic and wild animals may be expected to lead to the establishment of a genetic difference, selection for survival in the wild reflecting muscular prowess and selection by man, fatness.

Three hypotheses may be put forward to describe how fat levels are increased in domestic animals.

It may be postulated that fat is acquired as a surplus additive tissue. That is, there is a nett increase in the mature body weight of the species.

Alternately, it may be postulated that fat is acquired at the expense of, and by displacement of, another body tissue, that is muscle, there being no nett increase in the mature body weight of the species.

A third hypothesis that fattening will produce an increase in mature body weight, but that the increase is not a simple additive factor equivalent to the weight of extra fat acquired, would incorporate both the concepts outlined by the first two hypotheses.

In an attempt to ground the preceding assumptions on known body composition data, the body composition of cattle, sheep, pigs, fifteen wild species of African animals investigated by Ledger (1968), the elephant seal, feral buffalo and feral pig is available. It is admitted that the data presented will be heterogeneous. In discussing species values well documented factors such as breed, sex and nutrition, which are known to affect body composition, will be pooled into "average" species values. Further, the data presented is limited. The point of interest is really the limits within which carcass composition varies between species. The data presented is believed to be sufficiently representative to give approximations to the limits of body composition amongst the larger wild and domestic mammals.

Tables 28 and 29, adapted from Ledger (1968), contain body composition data on fifteen species of wild animal and analysis of the data (Table 30) indicate that:-

TABLE 28

Body composition of eleven species of wild animals. Females. Adapted from Ledger (1968).

Species	n	Live-weight kg	Empty Body Weight kg	Carcass Weight kg	Muscle as % of Carcass	Fat as % of Carcass	Soft Tissue as % of Carcass
Hippopotomus	4	1277	986	535	70.5	10.9	81.4
Wildebeest (k)	10	192	159	102	77.0	7.3	84.3
Waterbuck	10	181	155	107	78.9	4.0	82.9
Wildebeest (s)	10	160	131	82	75.1	6.4	81.5
Oryx	10	162	138	95	77.3	7.1	84.4
Kongoni	5	126	109	73	79.0	3.9	82.9
Topi	10	104	88	56	81.6	1.9	83.5
Kob	10	62	52	36	80.8	4.0	84.8
Warthog	10	60	52	34	83.9	1.8	85.7
Grants Gazelle	5	41	36	24	77.4	5.1	82.5
Impala	10	42	37	25	80.8	2.0	82.8
Thompsons Gazelle (n)	10	18	16	11	79.7	2.2	81.9
Thompsons Gazelle (s)	10	17	15	9	76.1	5.1	81.2

TABLE 29

Body composition of fifteen species of wild animals. Males. Adapted from Ledger (1968).

Species	n	Live-weight kg	Empty Body Weight kg	Carcass Weight kg	Muscle as % of Carcass	Fat as % of Carcass	Soft Tissue as % of Carcass
Hippopotomus	4	1490	1177	640	75.0	7.0	82.0
Buffalo	8	753	639	381	74.4	5.6	80.0
Eland	5	508	439	301	79.0	4.2	83.2
Wildebeest (k)	10	243	209	136	78.6	6.8	85.4
Waterbuck	10	238	205	140	82.3	1.0	83.3
Wildebeest (s)	10	203	161	102	78.3	2.7	81.0
Oryx	10	176	152	101	80.4	2.9	83.3
Kongoni	5	143	123	82	80.6	2.2	82.8
Topi	10	131	110	71	81.7	2.3	84.0
Kob	10	97	83	56	82.8	2.6	85.4
Lesser Kudu	10	92	84	57	80.5	3.3	83.8
Warthog	10	88	77	48	82.9	1.8	84.7
Grants Gazelle	6	60	54	36	79.6	2.8	82.4
Impala	10	57	51	33	81.4	1.9	83.3
Gerenuk	5	31	28	20	80.6	2.0	82.6
Thompsons Gazelle (n)	10	25	22	15	82.0	2.0	84.0
Thompsons Gazelle (s)	10	20	17	11	80.0	2.0	82.0

TABLE 30

Analysis of Tables 28 and 29.

Tissue	Group	Mean
Total soft tissue % Carcass	Females	83.1 (±.4)
	Males	83.1 (±.3)
Muscle % Carcass	Females	78.3 (±.9)
	Males	80.0 (±.6)
Fat % Carcass	Females	4.7 (±.7)
	Males	3.1 (±.4)

Comparisons

Total Soft Tissue % Carcass	Female/Male	NS
Muscle % Carcass	Female/Male	NS
Fat % Carcass	Female/Male	10% Females fatter
Total Soft Tissue % Carcass	Liveweight >100kg/<100 kg	
	Female	NS
	Male	NS
Muscle % Carcass	Liveweight >100kg/<100 kg	
	Female	NS
	Male	5% Smaller species heavier muscled
Fat % Carcass	Liveweight >100kg/<100kg	
	Female	10% Larger species fatter
	Male	10% Larger species fatter

NOTE: Each species is not equally weighted for numbers in the calculations.

1. Carcass soft tissue (muscle + fat) is a remarkably constant percentage of the carcass weight. Sex and mature body size are not found to affect carcass soft tissue percentage
2. Sex and mature body size affect carcass fat percentage. Females and larger animal species are, in general, fatter.
3. The carcass muscle/fat ratio ranged from 6/1 for the female hippopotomus to 82/1 for the male waterbuck.
4. A species with a relatively high carcass fat percentage has a relatively low carcass muscle percentage. The converse holds true.

Table 31 contains data on the carcass composition of cattle, sheep and pigs, and indicates that:-

1. Carcass soft tissue is a less constant and on the average, a greater percentage of the carcass than found in wild animals.
2. The fatter the animal, the greater the carcass soft tissue percentage.
3. An increase in the percentage of carcass fat is accompanied by a decrease in the percentage carcass muscle. Based on Hilmi's (1976) data for Border Leicester x Merino wethers in the empty body weight range 20 - 40 kg, a 1.6% increase in carcass fat is accompanied by an average 1% decrease in carcass muscle. Thus a nett increase in carcass soft tissue of 4.4% occurs between 20 - 40 kg empty body weight, accompanied by a decrease of approximately 7% in the carcass muscle.
4. The carcass muscle/fat ratio for these cattle is 2.3/1, sheep 2.1/1 and pigs 1.2/1.

Table 32, extracted from Bryden's (1967) data on the body composition of the elephant seal (Mirounga leonina) indicates that:-

1. Carcass soft tissue percentage is closer to the values obtained for domestic than wild animals.

TABLE 31

Body composition of cattle, sheep and pigs.

Domestic Species		n	Live-weight kg	Empty Body Weight kg	Carcass Weight kg	Muscle % Carcass	Fat % Carcass	Soft Tissue % Carcass	Bone % Carcass	
Immature										
Cattle	A.I.S. calves	7	62		35	63.6	4.6	72.3	27.7	Butterfield and Johnson (1971)
Sheep	Merino (Peppin) lambs	25	3.9		2	62.7	4.2	77.7	22.3	Lohse (1971) Adapted from Table 7.1 and 7.2
Mature										
Cattle	Shorthorn x Females	12	346		209	56.5	31.2	87.7	12.3	Berg (1969) Adapted from Tables 1 and 2
	Hereford Females	10	306		178	57.6	30.4	88.4	11.6	Berg (1969) Adapted from Tables 1 and 2.
	Shorthornx Steers	10	337		205	58.5	28.1	86.6	13.4	Berg (1969) Adapted from Tables 1 and 2
	Hereford Steers	9	360		212	59.6	27.6	87.9	12.1	Berg (1969) Adapted from Tables 1 and 2

TABLE 31 (CONT.)

Domestic Species	n	Live weight kg	Empty Body Weight kg	Carcass Weight kg	Muscle % Carcass	Fat % Carcass	Soft Tissue % Carcass	Bone % Carcass	
Hereford, Poll Hereford, Shorthorn, Angus, Brahman, ½ Brahman - Steers	6			220	61.5	15.7	80.9	19.1	Berg and Butterfield (1966)
Shorthorn x Males	12	386		234	65.0	21.1	86.1	13.9	Berg (1969) Adapted from Tables 1 and 2
Hereford Males	13	466		279	60.6	27.3	88.1	11.9	Berg (1969) Adapted from Tables 1 and2
Sheep Border Leicester (BL) x Blackfaced - Hoggets				24.4	52.2	33.9	88.1	11.9	Palsson (1940) Adapted from Table 88
BL x Cheviot (c) Hoggets				25.4	58.9	26.9	88.0	12.0	Palsson (1940) Adapted from Table 88
Cheviot Hoggets				25.2	53.5	32.5	88.0	12.0	Palsson (1940) Adapted from Table 88

TABLE 31 (CONT.)

Domestic Species	n	Live-weight kg	Empty Body Weight kg	Carcass Weight kg	Muscle % Carcass	Fat % Carcass	Soft Tissue % Carcass	Bone % Carcass	
Sheep Oxford x BL - C Hoggets				24.4	58.1	25.1	85.6	14.4	Palsson (1940) Adapted from Table 88
Suffolk x BL - C Hoggets				27.1	56.6	28.9	87.0	13.0	Palsson (1940) Adapted from Table 88
Merino (Peppin) ewes, wethers, rams	6	34		14	64.3	12.9	85.9	14.1	Lohse (1971) Adapted from Table 7.1 and 7.2
BL x Merino wethers	34		20	11.0	57.0	20.2	83.3	16.7	Hilmi (1976) Predicted values
			30	17.8	51.8	28.3	86.3	13.7	
			40	24.6	49.4	32.0	87.7	12.3	
Pigs			100	80.5	39.3	42.9	90.8	9.2	McMeekan (1940) Adapted from Tables 1 and 2 skin 4%

TABLE 31 (CONT.)

Domestic Species	n	Live-weight kg	Empty Body Weight kg	Carcass Weight kg	Muscle % Carcass	Fat % Carcass	Soft Tissue % Carcass	Bone % Carcass	
Pigs	24	69.5		52.8	55.7	33.8	89.5	10.5	Berg and Richmond (1969) Adapted from Table 1
	24	91.7		71.4	53.4	36.7	90.1	9.9	
	25	114.7		92.0	48.7	42.1	90.8	9.2	
	70	84-98		65.9	44.8	42.9	91.8	8.2	Smith and Carpenter (1973) skin 4%
Mature									
Cattle	72			220	59.9	25.9	86.5	13.5	
Sheep	>40			21.5	55.8	26.7	86.7	13.3	
Pigs	>143			72.5	48.4	39.7	90.6	9.4	

NOTE. Equal weighting given to individual reports despite inequality in animal numbers.

2. The carcass muscle fat ratio is 1.1/1 for females and 1/1 for males

3. The percentage of fat present in the elephant seal carcass is similar to that of the pig.

Table 33 presents data on feral water buffalo and feral pig. The data indicates that the carcass composition of these animals lay within the range of values found for wild and domestic animals and tended towards the carcass characteristics of wild animals.

It is evident that our hypothesis correlating domestication to increased levels of body fat is consistent with the data (Tables 28 to 33). It may be argued that the functional basis for this hypothesis, that is, the reduced requirement on the locomotory system under the management procedures used for domestic animals, is unnecessary, as the difference is a direct effect of nutrition. That is, domestication is concurrent with a full gut. An argument given to support nutrition as the factor involved is to point to wild animals, such as deer, which are known to fatten when fed in captivity. (Blaxter (pers comm)).

Until data is available which will answer this question objectively, a possible explanation is as follows. Wild animals fed in captivity, will fatten to a degree not found under unrestrained conditions. However, it is unlikely that they will reach the same levels of fatness found in our domestic animals until sufficient time has elapsed to allow selection towards genetic change in their fattening ability. Conversely, wild kangaroos grazing high quality improved pastures, or with access to grain crops, maintain very low carcass fat levels. Further, the elephant seal maintains large fat deposits despite the dietary vagaries imposed by natural habitat. Perhaps nutrition will be found, after further experimentation, to affect rate of growth more than the composition of such growth.

TABLE 32

Body composition of the Elephant seal. Adapted from Bryden (1967).

	n	Empty Body Weight kg	Carcass Weight kg	Muscle % Carcass	Fat % Carcass	Waste % Carcass	Total Soft Tissue % Carcass	Bone % Carcass
Elephant seal (*Mirounga leonina*)								
Female	10	298	195	43.9	39.9	3.0	86.8	13.2
Male	9	591	413	43.7	44.0	2.4	90.1	9.9
Male	1	3340	2535	53.1	36.3	2.3	91.7	8.3

Oldest 20 animals studied. Individual male listed separately due to extreme size.

TABLE 33

Body composition of the feral water buffalo and pig.

		n	Live-weight kg	Empty Body Weight kg	Carcass Weight kg	Muscle % Carcass	Fat % Carcass	Soft Tissue % Carcass	Bone % Carcass	
Water Buffalo (feral)	Male	3	282		129.4	71.3	4.9	80.4	19.6	Charles *et al* (1970)
Pig (feral)	Male	1	38		16.3	74.6	5.6	80.1	19.9	Thompson (pers comm). Poor condition. Carcass not including head & skin.

It is difficult to determine whether increase in carcass fat is additive or by displacement of carcass muscle. The data presented in this discussion is not conclusive. If we look at the elephant seal, an animal required to hunt for its food, one would expect a highly developed musculature and would predict that fat deposition would be additive. However, the muscle bone ratio of this species is closer to that of the domestic rather than the wild species. The data presented in Figure 116 for sheep and kangaroos implies a displacement effect, especially at the lower empty body weight.

The data presented for wild animals indicates that mammals can achieve 80 - 85% of their carcass as muscle. It is feasible that domestic animals may be selected towards a similar carcass muscle percentage. Perhaps the ideal animal has a carcass composition typical of the wild species and a daily weight gain typical of the domestic species.

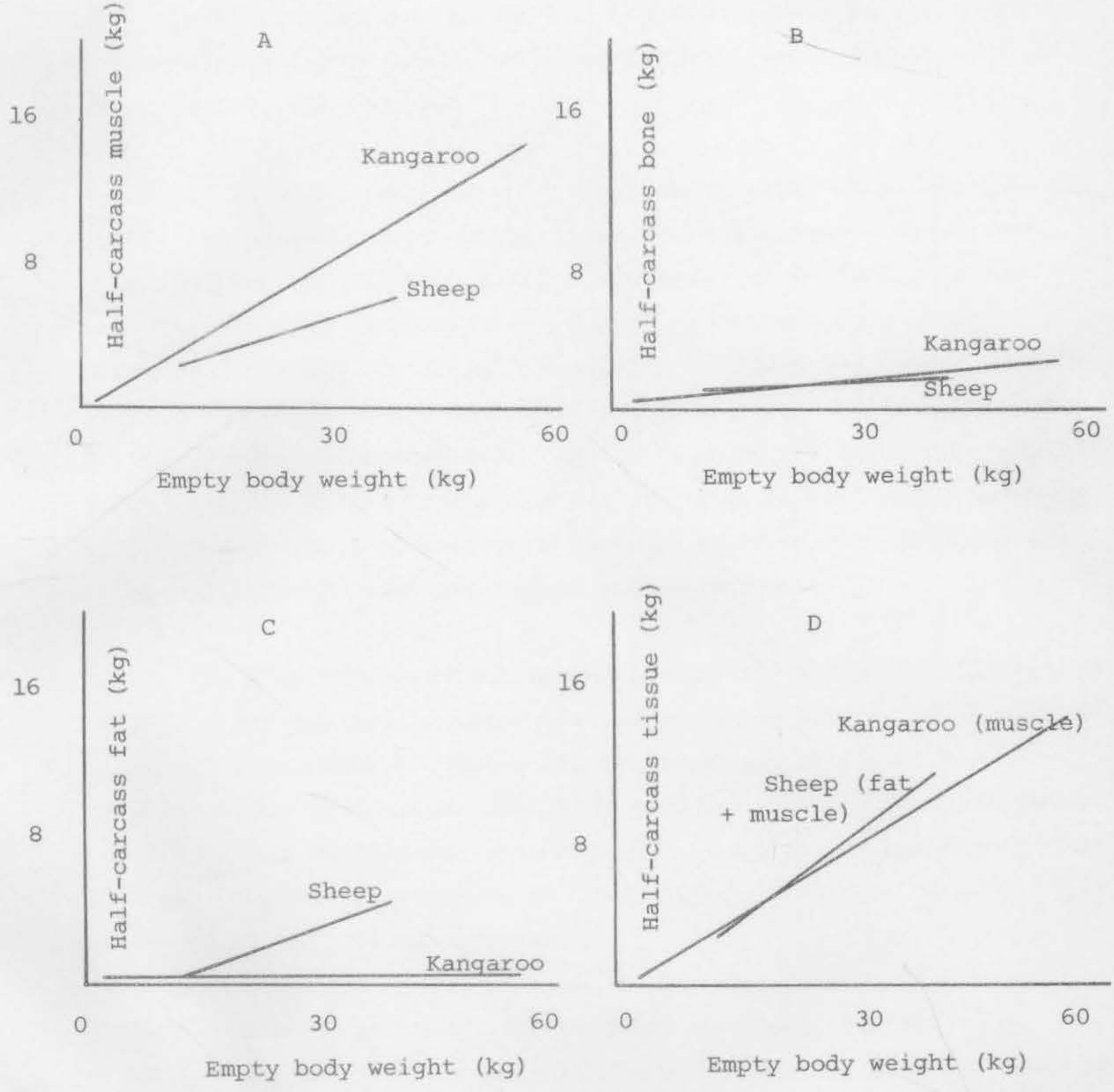

Figure 116. Relationships of half-carcass muscle, bone and fat to empty body weights for sheep and kangaroos.
Kangaroos from this study, sheep from Hilmi's (1976) study.

C. PHASIC TISSUE GROWTH

Chapter 1 introduced terms and their definitions as used in this study. In particular, monophasic and biphasic growth were discussed and alternate usage of these two terms was reviewed. The concept of tissue maturity was defined.

It may be argued that correct terminology requires no apologetics. However, the complexity of animal growth rarely allows a simple yet accurate description of the growth processes. It is difficult to envisage any mammal being able to grow at a constant rate from conception to death. It is also difficult to imagine a mammal growing at one constant rate from conception to a point in its life span and then growing at another rate for the rest of its life. The same argument applies to the tissues within the body as well as to the body regions. Development of body form is only conceivable within a framework of continuously altering tissue growth patterns.

The validity of terms such as monophasic and biphasic, is relative to the accuracy implied in their use. They are a simple and convenient terminology with which the major growth trends of an animal may be described. They also allow relatively simple mathematical description of growth. Thus in context, a description of growth as monophasic, may be a useful one for comparative or predictive inferences; out of context, it is biological nonsense.

Table 24 is surprising. As expected for sheep, carcass composition varies with body weight. However, for the kangaroo, carcass composition was constant irrespective of body weight! Similar to the sheep, Berg and Butterfield (1976) quoted Tulloh and Seebeck (pers comm) who summarized growth of the carcass components of cattle : "... if you consider the three carcass components - bone, muscle and fat - and relate them to body weight by the exponential equation $y = ax^b$ then fat is the only component contributing to increase in dressing percentage, because the 'b' value is approximately one for muscle, less than one for bone and greater than one for fat. Irrespective of carcass composition, the offal components taken together, have a 'b' value of less than one; therefore, they contribute (in a negative way!) to higher dressing percentage as body weight increases."

The situation in the kangaroo is different. In kangaroos, the 'k' values (synonymous with Tulloh and Seebecks' 'b' value) for carcass dressed weight, total viscera, carcass muscle and carcass bone are approximately one in each case. Thus the dressed carcass represents a constant proportion of the body weight. A further surprising result is that both muscle and bone represent a constant percentage of the carcass weight, irrespective of the weight of the carcass. The constant percentage of muscle and bone in the kangaroo carcass is a result of the monophasic growth of these two tissues, together with the negligible quantity of fat present.

The situation may be represented graphically by Figures 117A and 117B.

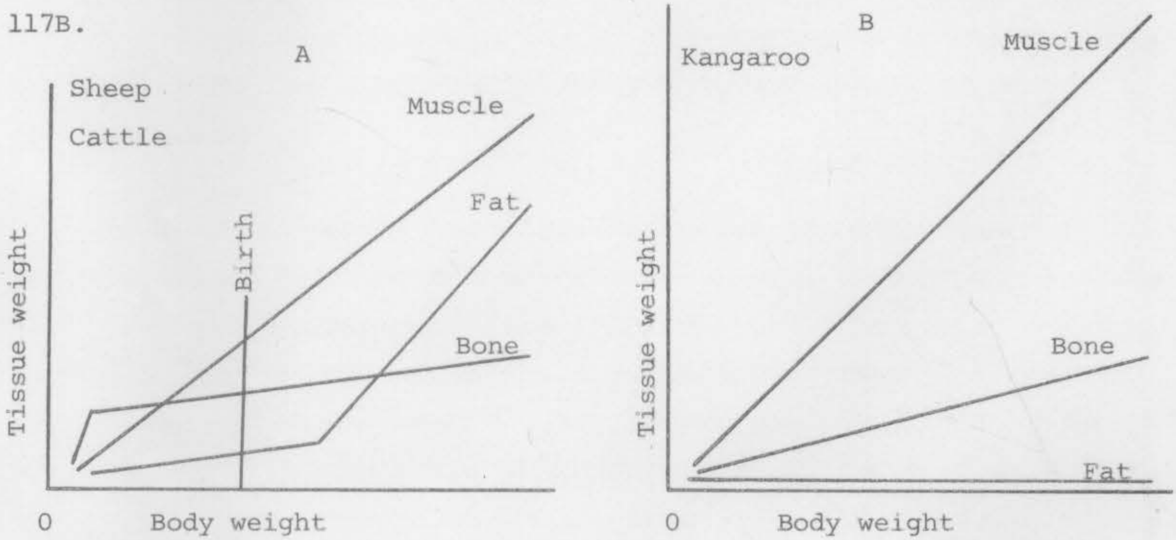

Figure 117A Figure 117B

Relationship of carcass tissues to body weight in domestic animals and in the kangaroo. A - Sheep and Cattle B - Kangaroo.

Thus for practical purposes, growth of carcass muscle and bone is monophasic in the kangaroo. That is, it is linear, being described by $y = a + bx$ where y is the carcass tissue weight, a is the intercept on the y axis and approximates zero, b is the slope of the line and x is the body weight. The monophasic relationship was found to hold between 1 - 60 kg empty body weight (Figure 114).

With cattle and sheep, growth of carcass bone and fat may be described within given weight limits by the equation $y = a + bx$. The difference being that $a \neq o$. Over wider weight limits in sheep and cattle, growth of carcass bone and fat may be described by the allometric relationship, whereas a linear relationship does not fit the data.

A possible explanation for the preceding observations is: in the kangaroo tissue, maturity may be similar to that found in sheep and cattle. That is, bone is early maturing, followed by muscle and fat is late maturing. The qualification would be that bone would be very early maturing, achieving its final growth rate at a low body weight, while fat is so late maturing, that it does not appear in any quantity. In other words, fat growth is latent under normal circumstances in wild kangaroos.

An inference may be drawn from the preceding observations. If we selected solely for animals that would fatten at a lighter body weight, i.e. take wild animals with latent fat growth potential and select for fattening ability, we must expect at least passive changes in percentage carcass muscle and bone, due to a displacement effect of the fat growth. It may be postulated that differences in carcass composition between wild and domestic animals are mainly real differences in fat levels and passive displacement differences in level of muscle and bone.

D. AN APPLICATION OF QUANTITATIVE ANATOMICAL GROWTH STUDIES TO THE FIELD OF BIOCHEMISTRY.

Quantitative anatomical growth studies may have an application in the study of tissue enzyme patterns. Needham (1931) stated that "the increasing and decreasing intensities of physico-chemical processes cannot be intelligently studied in the absence of a knowledge of the distribution of the whole mass among the different organs and tissues." Figure 118 was extracted from Ostwald's work on growth in metazoa by Needham (1931).

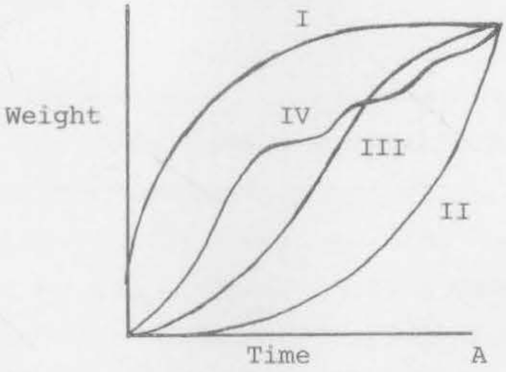

Figure 118. Relationship of increase in weight with time in metozoa. After Needham (1931).

At time A the weight of the organisms following four different growth patterns was the same. Needham (1931) concluded that "the four different curves in Ostwald's figure would imply four very different sets of conditions within the developing embryo and the chemical embryologist, engaged in the attempt to understand the processes which contribute to the final result, must pay detailed attention to the path by which this final result is arrived at."

Knox (1972) pointed to the paramount need for tissue standards. He advocated the acceptance of one gram of fresh tissue as the tissue base against which results should be expressed. Commenting further on the enzyme changes which occur during the differentiation of rat liver, he stated that the tissue base should be sampled from animals in "a standard physiological state".

From the growth data presented in this study, it is evident that a biochemist wishing to study say, muscle enzyme patterns, can hardly expect one gram of fresh muscle to be a constant tissue base. Within the musculature of the kangaroo, individual muscles have been shown to grow faster, slower or at the same rate as total muscle. Further, individual muscles have been demonstrated to grow at different rates in different stages of body development.

A quantitative anatomical growth study will define the way in which tissues grow. A biochemist may thus look on a quantitative anatomical study as a timetable, directing him to the tissue and the stage of development of the animal at which that tissue should be sampled in order to gain a standard tissue base. For example, one gram of muscle to be considered as a standard tissue base must be qualified not only by the species, sex and strain of animal from which it was selected, but also by the actual muscle from which it was sampled and the body weight or total muscle weight of the animal at the time of sampling.

To the scientist who considers the above suggestion as tedious and impractical, the comment by Needham (1931) that "a rich harvest awaits the investigator who discovers the relation between chemical constitution and differential growth ratios" is pertinent.

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