

**A GEOMETRIC MORPHOMETRIC STUDY INTO THE ONTOGENY AND
SEXUAL DIMORPHISM OF THE HUMAN SCAPULA**

BY

Yvette Scholtz
[BSc(HONS): Physical Anthropology]

A thesis submitted in fulfilment of the requirements for the degree Master of Science
in Anatomy (M.Sc. Anatomy)
in the Faculty of Medicine, University of Pretoria, Pretoria.

Supervisor: Prof. M Steyn
Co-supervisor: Prof. E Pretorius

2006

DECLARATION

I, Yvette Scholtz, declare that this thesis is my own unaided work. This thesis is being submitted for the degree of Master of Science in Anatomy at the University of Pretoria, Pretoria. It has not been submitted before, for any degree or examination at any other University.

_____ day of _____ 2007

For Evert and Dora Scholtz

SUMMARY

Sex and age determination are vital when attempting to establish identity from skeletal remains. There are two methodological approaches to sex determination, namely morphological and metrical methods. In this study the shape of the scapula was studied in order to gain information on its development and sexual dimorphism. One drawback to studying the scapula is its fragility, making it difficult to obtain adequate osteometric measurements.

The aim of this study was to use geometric morphometrics to study the ontogeny and sexual dimorphism of the scapula. The sample consisted of 45 adult males and 45 adult females, as well as 81 juvenile scapulae of known individuals. The scapulae were photographed and 21 homologous landmarks were plotted to use for geometric morphometric analysis with the 'tps' series of programs, as well as the IMP package. The consensus thin-plate splines, as well as the vector thin-plate splines for adult males and females, as well as each consecutive year of growth in juveniles were compared with each other.

The CVA and TwoGroup analyses yielded significant differences between males and females. The lateral and medial borders of females are straighter and the supraspinous fossa of females was more convexly curved than those of males. More than 91% of the adult females and 95.6% of the adult males were correctly assigned. Goodall's F- test yielded a p- value of 0.20014 which was not significant. Hotelling's T^2 - test yielded a significant p- value of 0.00039.

Geometric morphometrics were found to be a valuable tool in the study of changes in shape in the growing years and it was found that the lateral border of juvenile scapulae remained constant with advancing age, while the medial border remained constant during early childhood up to the age of six, varying during older childhood and early adolescence and once again becoming constant from age 15 upwards.

The largest changes in the juvenile shape could be seen in the supraspinous fossa, with the superior border having a concave shape up to the age of 10, and then displaying a convex shape from 12 to 19 years of age.

Differences between the sexes in juveniles were not significant, but a larger sample may yield different results.

In conclusion it was found that significant differences between the shapes of adult male and female scapula exist.

OPSOMMING

Geslag- en ouderdombepaling is noodsaaklik wanneer identiteit vanaf skeletale oorblyfsels bepaal word. Twee tipes metodes word gebruik in geslagsbepaling, naamlik morfologiese en metriese metodes. In hierdie studie is die skapula bestudeer om inligting te bekom aangaande die ontwikkeling en seksuele dimorfisme van hierdie struktuur. Een probleem wat ondervind word wanneer die skapula bestudeer word, is die feit dat dit 'n baie delikate struktuur is, wat dit moeilik maak om voldoende osteologiese afmetings te bekom.

Die doel van hierdie studie was om geometriese morfometrie te gebruik om die ontogenie en seksuele dimorfisme van die skapula te bestudeer. Die steekproef het bestaan uit die skapulas van 45 volwasse mans, 45 volwasse vroue en 81 jongmense waarvan die geslag en ouderdom bekend was. Die skapulas is gefotografeer en 21 homoloë landmerke is toegeken vir gebruik met geometriese morfometriese analise, asook met die IMP- pakket. Die konsensus “thin- plate splines” van die volwasse mans en vroue is vergelyk, asook dié van elke opvolgende groeijaar in die jongmense.

Die “CVA” en “TwoGroup” analyses het statisties betekenisvolle verskille tussen volwasse mans en vroue gevind. Die laterale en mediale grense van vroulike skapulas is meer reguit en die supraspineuse fossa meer konveks gekurf as dié van die manlike skapulas. Meer as 91% van die volwasse vroue en 95.6% van die volwasse mans is korrek geklassifiseer. Goodall se F- toets het 'n p- waarde van 0.20014 gelever, terwyl Hotelling se T²- toets 'n betekenisvolle p- waarde van 0.00039 gelever het.

Geometriese morfometrie is 'n waardevolle hulpmiddel in die studie van vormverandering. Dit is bevind dat die laterale grens van die skapula konstant gebly het in jongmense, terwyl die mediale grens konstant was tydens die vroeë kinderjare, gevarieër het tydens die latere kinderjare en weer konstant geraak het vanaf 15jarige ouderdom.

Die grootste veranderinge in die vorm van die van jongmense kon gesien word in die supraspineuse fossa, wat 'n konkawe vorm gehad het in kinders tot die ouderdom van 10 jaar en 'n konvekse vorm gehad het in jongmense van 12 jaar en ouer.

Geslagsverskille in die skapulas van jongmense was nie betekenisvol nie, maar 'n groter steekproef mag ander resultate lewer.

Ter opsomming is dit bevind dat daar betekenisvolle verskille tussen die skapulas van volwasse mans en vroue bestaan.

ACKNOWLEDGEMENTS

This work was supported by grants from the South African National Research Foundation (NRF), as well as the Research Committee of the University of Pretoria (NAVKOM).

I would like to thank the Department of Anatomy, University of Pretoria for use of the Pretoria Bone Collection, as well as the University of the Witwatersrand for use of the Raymond Dart Collection.

Thank you to my supervisors Prof M Steyn and Prof E Pretorius for their guidance, assistance and patience. Thanks are also owed to V Wanek for help with the testing of inter- observer repeatability of my landmarks.

I would also like to express my immense gratitude towards my family and friends for their support and patience during the preparation of this dissertation.

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CHAPTER 1

INTRODUCTION

The correct determination of sex is vital when attempting to establish identity from skeletal remains, since this can cut the number of possible matches in half. Furthermore, determining age especially from juvenile skeletal remains is difficult. Traditionally, the skull, pelvis and long bones are used for identification and metric methods are employed as identification tool. However, other bones in the body may also provide useful information about sex and ontogeny. Therefore, in this study, the shape of the scapula was studied in order to gain information on its development and sexual dimorphism.

Although several studies have already been performed on the scapula and its sexual dimorphism, there are currently no existing methods for determining sex using the shape of the scapula. If such a difference can be found it could improve the results obtained when skeletal material is analyzed for identification of the individual.

As part of the study of scapular shape, its ontogeny was also investigated. Ontogeny can be defined as a process composed of three interrelated factors: growth (changes of size with age), development (changes of shape with age) and ontogenetic allometry (changes of shape with size) ¹. Several studies have been carried out on the ontogeny of the facial skeleton, but little research is available on the ontogeny of the postcranial skeleton ¹⁻³.

A study of the ontogeny of the scapula can provide valuable information relating to human growth and development, as well as the development of sexual dimorphism of this bone in adulthood. The obtained information will also be valuable in the study of human evolution, where the upper limb developed from being used for locomotion and weight bearing, to being able to conduct fine manipulation.

Differences in the shape of the scapula in juveniles will be analyzed on a year-by-year basis, in order to assess in which part of the scapula the shape changes occur, and at what age this takes place. The pattern of the shape change will also be investigated in order to determine whether changes in shape with age follow a constant uni-directional pattern. The age when the scapula reaches adult morphology will also be investigated, as well as the sexual dimorphism of the juvenile scapula.

One problem that is frequently encountered by researchers when analyzing biological data is the assessment of similarity between groups of objects. Methods that produce qualitative results do not provide statistical tests of group differences and researchers may draw different conclusions from the same results⁴. Morphological analysis is dependent on the experience of the observer, can be influenced by inter- and intra-observer errors, as well as problems with standardization and statistical analysis⁵. Two methodological approaches to sex determination exist: morphological and metrical⁵. Morphological techniques are qualitative and focus on shape. These techniques usually involve the pelvis and cranium. Metrical analysis is quantitative, focusing on bone dimensions. It is usually employed when the bones are in a fragmentary state, or when analyzing long bones that do not show many morphological differences^{5, 6}. A combination of measurements can also be selected to maximize sex diagnosis by using discriminant function statistics. A major problem with this technique is that standards are population specific, making it impossible to use standards for American or European populations on South African populations⁵.

Another technique, namely geometric morphometrics, has lately been used successfully to determine morphological similarities and differences in biological material^{1-3, 7-12}. This technique uses x/y co-ordinates or landmarks to quantify shape,

and is particularly valuable when studying shape that forms bulges and curves that is difficultly quantified using traditional metric measurements^{7, 13–15}.

The studies that have previously been performed on the scapula, specifically to investigate its sexual dimorphism and ontogeny have yielded mixed results. Studies into the sexual dimorphism of the scapula include that of Graves (1921), Hrdlička (1942), Bainbridge and Genovés (1956), Iordanidis, Getz *et al.* (1996), Prescher and Klümpen (1995 and 1997), Frutos (2002) and Churchill *et al.* (2001)^{6, 16–25}.

Studies into the ontogeny of the scapula include that of Graves (1922) and Hrdlička (1942), who studied the complete scapula. Graves investigated the morphological characteristics, while Hrdlička studied both morphological, and metric techniques, while also investigating the sexual dimorphism of the juvenile scapula^{17–19, 26}.

Studies using geometric morphometrics to investigate sexual dimorphism include that of Steyn *et al.* (2004), Oettlé *et al.* (2005) and Pretorius *et al.* (2006)^{22–24}. Pretorius *et al.* (2006) investigated the usability of sexual dimorphism in South African Negroid populations. Orbital shape, mandibular ramus flexure (using data obtained by Oettlé *et al.* in 2005) and greater sciatic notch shape (using data obtained by Steyn *et al.* in 2004) were assessed and their accuracies compared^{8–10}.

Although there have been previous studies into the sexual dimorphism, as well as the ontogeny of the scapula, none of these studies were performed on South African samples, and none used geometric morphometrics. Therefore, the aim of this research was to use geometric morphometrics to determine differences or similarities between male and female scapular shape as well as to apply the technique to study the ontogeny of the scapula. This study will only investigate scapular shape and not size. It will also

investigate the usability of geometric morphometric in order to determine whether it is a useful “tool” in the two- dimensional study of shape.

CHAPTER 2

LITERATURE REVIEW

In the following literature review, general background regarding the anatomy of the scapula, an overview on previous research on the scapula, geometric morphometrics and its uses within Anthropology, as well as ontogeny will be discussed.

2.1 ANATOMY OF THE SCAPULA

The scapula is a triangular bone with thick margins and thin central parts. It is situated on the posterolateral aspect of the thoracic wall and articulates with the humerus at the glenohumeral joint (shoulder joint) and with the clavicle at the acromioclavicular joint. It is suspended from the vertebral column, ribs and skull by various muscles.

A concave depression, namely the fossa subscapularis, can be seen on the costal or anterior surface of the scapula. The scapular spine divides the dorsal surface into two parts, the fossa supraspinata and fossa infraspinata. The inferior angle of the scapula is sharp, while the superior angle is blunt. Modification of the lateral angle of the scapula forms the glenoid fossa, which is pear-shaped with the apex towards superior. A triangular bony plate, namely the spinous process, stretches backward from the dorsal surface of the scapula. The acromion runs continuous with the spine, hooking around the acromial angle, while the coracoid process is divided into a horizontal, as well as a vertical part. Functions of the scapula include providing an articular surface for the upper limb, as well as providing a large surface area for muscles which facilitate mobility at that joint (Figure 2.1) ²⁷⁻³².

The scapula has the following borders:

◆ Superior border

The superior border is the shortest of the three scapular borders. It slopes downwards from the superior angle at the junction with the medial border to the root of the coracoid process laterally. The superior border of the scapula is interrupted by the scapular notch which lies medial to the coracoid process. It is converted into a foramen for nervus suprascapularus in the living by the transverse scapular ligament, which may occasionally become ossified to form a bony suprascapular foramen.

◆ Medial border

The medial border of the scapula lies adjacent to thoracic vertebrae 2 – 7 and dorsal to the outer surfaces of the corresponding ribs. It is usually convex and runs from the superior to the inferior angles of the scapula. The upper one third of the medial border lies opposite the supraspinous fossa and the lower two thirds opposite the infraspinous fossa. The posterior side of the medial border includes sites of implantation for three muscles, namely musculus levator scapulae (supraspinous fossa), musculus rhomboideus minor and musculus rhomboideus major (infraspinous fossa).

◆ Lateral border

The lateral border of the scapula is sharp and somewhat concave. It stretches from the infraglenoid tubercle to the inferior angle of the scapula. A roughened area for the attachment of the long head of musculus triceps brachii can be found below the neck of the scapula at the upper limit of the lateral border. The lateral border of the scapula also provides attachment for musculus teres minor and musculus teres major

27, 28, 32

The primary ossification centre of the scapula appears at around eight weeks of foetal life in the vicinity of the surgical neck of the scapula. The surgical neck of the scapula is represented by line drawn on the ventral surface of the scapula from below the glenoid mass to the lateral boundary of the suprascapular notch. The primary ossification centre spreads through the body and spina, so that these areas are ossified at birth. Ossification expands bidirectionally and reaches the level of the base of the spine by week 9 and the glenoid mass by week 12. This ossification pattern leads to the formation of proximal (vertebral) and distal (glenoid) epiphyses at the end of the radiating cones of endochondral ossification. Growth rate is accelerated in the vertebral cone and causes greater expansion of the medial border compared to that of the lateral mass. The spaces between the two endochondral cones are filled by membranous ossification to form the blade of the scapula. By 12 – 14 weeks scapular morphology is close to that of the adult and changes little until birth^{27, 28}.

The coracoid process shows a secondary ossification centre for the horizontal part, which appears during the first year, as well as one in the base which appears during the tenth year. Fusion of the coracoid to the scapula occurs at around 14 – 15 years^{27, 28}.

The scapula has seven secondary ossification centres – three associated with the coracoid process, one for the inferior aspect of the glenoid, one at the inferior angle, one associated with the vertebral border and one for the acromion process^{27, 28}.

The subcoracoid (or infracoracoid) centre is the first secondary ossification centre to appear between 8 and 10 years of age. The coracoid, subcoracoid and body of the scapula start to fuse at 13 – 16 years and epiphyses for the glenoid rim, the angle and apex of the coracoid, as well as the acromial epiphysis appears. At 15 – 17 years the fusion of the coracoid, subcoracoid and scapular body is complete and epiphyseal islands appear along the medial border. The epiphysis for the inferior angle also appears at this

time. The fusion of the glenoid epiphyses is complete at 17 – 18 years and fusion of the acromial and coracoid epiphyses is complete by 20 years. By 23 years all scapular epiphyses are fused and the adult form is achieved^{27, 28}.

2.2 PREVIOUS RESEARCH ON THE SCAPULA

Graves (1921) performed a comparative study on the scapulae of males and females of different population groups, looking at several characteristics of the scapula and found that there was wide variation in the contour, as well as the thickness of the vertebral border below the scapular spine. He also found that the contour of the infraspinous vertebral border enabled him to classify scapulae into distinguishable types that were applicable to both living and skeletal material. It is based on the relation of a straight line to the character of the greater portion of the vertebral border below the scapular spine, starting at the point where the scapular spine merges with the vertebral border and ending at the inferior angle¹⁶.

Three distinct scapular types were recognised by Graves:

- ◆ Type A (“convex”) : This type was found to be the most common, with the infraspinous vertebral border being slightly, moderately or markedly convex.
- ◆ Type B (“straight”) : This was described as scapulae where the infraspinous vertebral border was straight or nearly straight tending to be more concave than convex.
- ◆ Type C (“concave”) : This type was found to be the least common, with the infraspinous vertebral border being slightly, moderately or markedly concave¹⁶.

Graves' sample consisted of 198 mature scapulae from the Department of Anatomy of the St. Louis University and Washington University Schools of Medicine, as well as another 150 scapulae from the Department of Anatomy of the University of Berlin. He found that 61% of the scapulae were convex, 26% were straight and 13% were concave ¹⁶.

A further 1219 scapulae obtained from the Wistar Institute of Anatomy and Biology (602 mature scapulae), as well as the U.S. National Museum (269 scapulae) were studied by Graves. Of these scapulae 54.3% were found to be convex, 27% straight and 18.7% were found to be concave ¹⁶.

Graves (1922) stated that the scapula had importance in estimating the age of skeletal material during growth periods up to maturity, as the ossification centres unite in different parts of the bone in sequence at different ages to produce a complete adult scapula by approximately 22 years of age. He also stated that the various anatomical and architectural characters (e.g., its thickened borders and thinned body, its angles, spine, acromion, etc.) combine to give the scapula definite value in skeletal age change studies during age periods after 25 years of life ²⁶.

Gray (1942) studied 1239 human scapulae in order to determine the frequency of features that were either omitted from classical accounts or deviated from descriptions found in textbooks of gross anatomy. His sample consisted of 1152 scapulae from dissecting room material with an average age of over 60 years, as well as 87 specimens from California Digger Indian skeletons ³³.

Different features of the scapula were studied by, e.g. muscular cristae, the sulcus for the circumflex scapular artery, scapular foramina, costal facets, suprascapular foramina, the shapes of the acromion and glenoid fossa, the shape of the vertebral border etc ³³.

Gray found that among the 1151 scapulae 706 had convex vertebral borders (61.3%) 329 were straight (28.6%), 114 were concave (9.9%) and two were unclassifiable (0.17%). Among the 87 American Indian scapulae 77 were found to have convex vertebral borders (88.5%), nine were straight (10.3%) and one was concave (1.1%)³³.

Hrdlička (1942) studied the scapular shape of males, females and juveniles from different population groups. The juvenile scapulae were studied, as no systematic or extended study had been performed on juveniles before, due to a lack of juvenile collections. His sample consisted of 877 juvenile scapulae of different population groups, ranging from foetus to adolescent, as well as 2322 adult male and 1326 adult female scapulae. Visual morphological, as well as metrical studies were performed on the adult and juvenile scapulae¹⁷⁻¹⁹.

Five scapular body shapes were identified by Hrdlička: triangular or wedge-shaped with a straight vertebral border (type 1), concave or bi-concave with a concave vertebral border (type 3) and convex with a convex vertebral border (type 6). The body of the scapula was also found to sometimes be quadrilateral with the axillary border augmented by a distinct inferior border (type 4). The pentagonal shape occurs when the type 4 scapula is augmented by a distinct angle in the vertebral border at the terminal point of the spine to form two well-marked borders (type 5). Hrdlička named types 1, 3 and 6 the main scapular shapes and noted that any of these three types may be accompanied by one or both of the additional fourth (antero-inferior) and fifth (postero-superior or epispinous) borders¹⁶⁻¹⁹.

Hrdlička found that the shape of the adult scapula varied in different population groups. In all the population groups the triangular (type 1) and convex (type 6) shapes were more frequently seen than the concave shape (type 3). In the Caucasoid, American

Indian, Ancient Egyptian and Eskimo groups, both males and females were found to have mostly triangular shaped scapulae (type 1). In all cases the females showed a greater percentage of type 1 scapulae than the males (except in the American Indian group, where the majority of the females had type 6 scapulae). Caucasoid, American Indian and Eskimo males showed similar occurrences of types 6 and 1 scapulae. Type 6 occurred in 37.8% of Caucasoid males, 38.9% of American Indian males and 35.9% of Alaskan Eskimo males, while type 1 occurred in 41.3% of Caucasoid males, 43.9% of American Indian males and 49.1% of Alaskan Eskimo males. The males of these groups differed in the occurrence of type 3 scapulae, while the females of these groups differed in the occurrence of all three scapular types^{17, 19}.

In the Negroid and Aleut groups, as well as in the Melanesian and Australian group, both sexes were found to have mostly the convex shaped scapulae (type 6). In the Negroid group, the females showed a greater percentage of type 6 scapulae, while in the Aleut, as well as the Melanesian and Australian groups, the males showed a greater percentage of type 6 scapulae. The Negroid and Aleut groups also showed similarities in the occurrence of types 6 and 1 scapulae. Type 6 scapulae occurred in 46.6% of Negroid males and in 56.3% of Aleut males, while type 1 scapulae occurred in 27.8% of Negroid males and in 36.1% of Aleut males. Again there were no similarities in the occurrence of type 3 scapulae in the males of these two groups, while the females showed no similarities in any of the three groups^{17, 19}.

Hrdlička hypothesized that the reasons for these similarities and differences were ontogenetic and that this was as a result of the persistence of the juvenile conditions with further differentiation in later life¹⁹.

The juvenile sample could not be subdivided according to age of the foetuses or later specimens, as there were too many uncertainties. Hrdlička did subdivide them,

however, by the length of the dry femoral diaphysis, as the rest of the skeletal parts of these bodies were available. Although the sex of the specimens was known, the sample was not large enough to study sexual dimorphism after the subdivisions were made. The researcher stated, however, that there were no obvious differences between the sexes. The three main shapes of the scapular body were again identified as triangular (type 1), concave (type 3) and convex (type 6)¹⁶⁻¹⁹.

The majority of the Caucasoid and Negroid foetal and infant scapulae were found to be type 6. The scapulae were found to be convex up to the fifth month of foetal development, where the straight and concave forms started to develop. The straight form occurred more frequently than the concave form, especially in the Caucasoid samples.

Although Hrdlička could not find skeletal material of Caucasoid and Negroid children or adolescents, specimens of American natives were used. From birth onwards until it reaches adult status, type 6 scapulae diminished, indicating that this form was lost or, more probably, changed. The triangular or wedge-shaped scapula (type 1) was found to develop from type 6 from early childhood onwards. The frequency of type 1 scapulae increased from birth to adulthood. The concave scapula (type 3) was found to be an inherent variation and the cause of this shape was not known. Type 3 scapulae mostly occurred from young childhood onwards. In some population groups it was found to diminish during adult life, while remaining constant in others¹⁸.

Hrdlička found that the forms of the scapular body were partly phylogenetic (due to evolutionary development) and partly ontogenetically determined. The phylogenetic scapular forms consisted of type 6 (convex) and possibly of type 3 (concave). Type 6 was thought to be the general primitive form, while type 3 occurred intermittently and without evident cause later in life. Type 1 scapular shape (straight) was thought to be ontogenetic, as it was thought to develop from type 6. It started to appear early, but was

mainly achieved during later adolescence and adulthood. Hrdlička found that sex differences existed, but were irregular¹⁹.

Hrdlička found that greater sexual dimorphism could be seen in the occurrence of the additional fourth (antero-inferior) and fifth (postero-superior or epispinous) borders. In all the population groups the majority of the males had the additional fourth border (except for the Ancient Egyptian group where the additional fourth border, as well as both additional borders both occurred in 27.3% of the males). In the Caucasoid, Negroid and Aleut groups the majority of the females had both of the additional borders. In the American Indian, Ancient Egyptian and Alaskan Eskimo groups the majority of the females had the additional fourth border, while most of the females in the Melanesian and Australian group had neither of the additional borders^{17, 19}.

Studies on the juvenile samples also shed light on the appearance of the fourth (antero-inferior) and fifth (postero-superior or epispinous) borders. Hrdlička found that the appearance of the fourth border was due to the teres major muscle, while the appearance of the fifth border was due to the combined effect of the serratus, levator scapulae and possibly rhomboideus muscles¹⁸.

In the Caucasoid foetal and infant group border 4 occurred in a type 3 scapula of a one year old and in the Negroid foetal and infant group also in a type 3 scapula of about the same age. Border 5 occurred in a Caucasoid foetal scapula of about 7 months and in a newborn Negroid scapula. Hrdlička found that these occurrences were isolated¹⁸.

In the older juvenile groups (American mainland Indian and Alaskan) border 4 only occurred during later childhood and earlier adolescence, while border 5 occurred in younger children. In general the appearance of these borders was late and continued infrequently until later adolescence was reached. The appearance of these borders,

especially border 4, increased during adult life. Although the additional fourth and fifth borders were found to occur in some cases during advanced foetal life, these borders were mainly manifestations of the later part of the growth period and of adult life. These borders, especially border 4, occurred as a result of muscular activity¹⁹.

According to Hrdlička, the superior border of the scapula is the most variable part of the scapula. He found that although it is affected by the development and action of the supraspinatus, omohyoid and serratus muscles, it also seemed to have morphological individuality¹⁷.

Hrdlička divided the shape of the superior border (from the suprascapular notch to the superior angle of the scapula) into six categories:

- 1) Horizontal or slightly rising, forming a right or nearly right angle with a vertical line passing upward from the base of the coracoid
- 2) Oblique or moderately rising, forming an angle of 85° – 55° with the coracoid
- 3) Steep or markedly oblique, forming an angle of less than 55° with the coracoid
- 4) Angular or deep saddle-shaped
- 5) Markedly concave or semi lunar
- 6) Markedly concavo-convex or wavy
- 7) Indeterminate shapes which cannot be classified¹⁷

Hrdlička found that while the different population groups yielded somewhat differing results, it seemed that sexual dimorphism was present in the superior border of all the population groups, with the females mostly displaying type 1, 2 and 4 borders and males mostly displaying type 3, 5 and 6 borders. This meant that the female superior border generally varied between horizontal, moderately oblique or angular, while the

male superior border generally varied between steep, concave and wavy¹⁷.

The superior border of the juvenile scapulae was also studied by Hrdlička. He found that form 5 (semilunar) was the most common superior border shape for Caucasoid and Negroid fetuses and infants. Forms 1 and 2 (horizontal to medium slope) were more common in foetal scapulae, especially in the early stages of foetal development. Form 3 (pronounced slope) was found to occur mainly in later stages of the growth period. Form 4 (deep saddle-shape) was found to occur rarely, and then only late in foetal life in the Caucasoid scapulae and not at all in the Negroid scapulae. He proposed that form 4 could be said to develop from form 5, which diminished in most groups from older childhood onwards. The sloping borders could in some cases develop from early foetal time, while in other cases they developed gradually. In the young they ranged from near horizontal to medium slope. The slope increased with age¹⁸.

Hrdlička found that the shapes of the superior scapular border were also partly hereditary and partly acquired. The slight to medium even slope (forms 1 and 2), the deep saddle-shaped (form 4) and semilunar shape (form 5) were thought to be hereditary, while the steeply sloping (form 3), wavy (form 6) and irregular (form 7) borders were acquired. He found small sex and race differences in the shape of the superior border, but stated that a larger sample would be necessary to determine these differences. He found, however, that when all features are considered, the female scapula inclined more to the juvenile shape¹⁹.

Hrdlička measured the total scapular height, infraspinous height, scapular breadth, glenoid point height and glenoid point breadth of adult scapulae. The total scapular height was measured from the superior to the inferior angle of the scapula. The infraspinous height was measured from the point where the axis of the spine intersects the vertebral border of the scapula to the lowest point of the inferior angle. The scapular

breadth was measured from the centre of the posterior lip of the glenoid fossa to a point he called “sv” on the vertebral border. The point “sv” was defined as a point to be determined visually on the vertebral portion of the scapular spine. The glenoid height was measured from the midpoint of the glenoid fossa to the lowest point of the inferior angle, while glenoid breadth was measured from the midpoint of the glenoid fossa to “sv” on the vertebral border ¹⁹.

From the measurements described above, the scapular index, infraspinous index, glenoid total index and glenoid lower index were calculated. The scapular index was calculated by expressing scapular breadth as a percentage of total scapular height, while the infraspinous index was calculated by expressing scapular breadth as a percentage of infraspinous height. The glenoid total index was calculated by expressing glenoid breadth as a percentage of total scapular height, while the glenoid lower index was calculated by expressing glenoid breadth as a percentage of glenoid height ¹⁹.

Hrdlička found that in all the population groups all indices were higher in females than in males. This means that the scapulae of the two sexes differed more in length than in breadth, with the female scapulae being shorter than those of males and thus nearer to juvenile conditions ¹⁹.

In the adult sample Hrdlička found the largest sex difference to be in the total and infraspinous height. He also found that when pairs of scapulae were compared with each other, the left scapula was larger and broader than the right in males, while in the female the left scapulae were slightly smaller than the right with the breadth of the two sides being almost equal. He could not explain this observation ¹⁹.

Hrdlička found that in all sexes and groups the most variable dimension and index seemed to be the infraspinous height and index. The lower glenoid index was found to be the least variable. In all groups the female bones were less variable in the

two breadths, but more variable where the scapular and infraspinous indices were concerned¹⁹.

The same measurements were performed on juvenile scapulae and Hrdlička found that the indices were of main interest, showing the changes in the relative proportions of the scapula, and the ways in which the attachments of the epiphyseal parts modify the bone. He found that all the indices diminished with age, indicating an increase in the length of the scapula. The most rapid change in the relative proportions of the bone was found to take place in infancy, and the change in the male bone progresses farther than in the female which remains more infantile¹⁹.

Some differences were found between the Caucasoid and Negroid foetal and infant scapulae with Caucasoid scapulae showing greater total and infraspinous heights, which were also reflected in the scapular, infraspinous and total glenoid indices¹⁹.

Hrdlička concluded that the scapula passes through a series of changes from its ossification until it reaches its final adult proportions. The changes progress unevenly on the axillary and vertebral sides of the bone¹⁹.

Kuhns (1945) stated that changes in shape are found more frequently in the scapula than in any other bone. He attributed these changes to muscular function³⁴.

Kuhns conducted a study on the variations of the scapula among over a thousand children seen in a children's clinic. He found that the vertebral border was straight in 61% and concave in 39% of cases. No examples of a convex vertebral border were found. Kuhns also found that scapulae with concave vertebral borders were found almost twice as frequently during the first decade as in the second decade and that the majority of the children who had scapulae with concave borders when first seen showed scapulae with straight vertebral borders later in adolescence³⁴.

Kuhns also investigated the variation in adult scapular shape. He found that the concave vertebral border was seen much less often than in the children. The straight vertebral border was observed in 81% of adults, the convex vertebral border in 10% and the concave in 9%. Kuhns found that the muscles attaching to scapulae with concave vertebral borders were not well developed. Scapulae with convex vertebral borders were found to have strong attaching muscles generally found in people who performed hard work³⁴.

The scapulae of 72 cadavers were also studied by Kuhns. He found straight vertebral borders in 61%, convex vertebral borders in 30% and concave vertebral borders in 9%. Kuhns obtained similar results from 200 disarticulated scapulae for use of anatomy students. The large proportion of scapulae with convex vertebral borders was attributed to the fact that anatomical material was obtained mainly from the labouring class³⁴.

Wolffson (1950) attempted to determine whether the shape of the scapula could be influenced during postnatal growth by the removal of one or more attaching muscles at birth. Wolffson intended to test two theories regarding the development of the vertebral border of the scapula, namely genetic determination and muscle function. The muscles thought to be involved in the development of the vertebral border include rhomboid, trapezius and serratus anterior, as well as infraspinatus and subscapularis³⁵.

Rats were used in the study due to their short period of maturation. Wolffson performed unilateral operations on the first or second day of birth and muscles were either severed at the line of attachment (trapezius, serratus anterior and rhomboid) or completely removed (supraspinatus, infraspinatus and subscapularis). The non-operated side was used as control³⁵.

Wolffson divided the results into two groups namely those involving only the vertebral border and those involving the scapular spine and the sizes of the supra- and infraspinous fossae. Severing of rhomboid, serratus anterior and the brachial plexus were associated with straightening of the vertebral border. Removals of trapezius, infraspinatus and supraspinatus together and of supraspinatus alone, as well as paralysis of the forelimb were associated with reduction of the spine and a decrease in the size of the supraspinous fossa. Severing of serratus anterior and removal of trapezius, infraspinatus and supraspinatus together were found to correlate with reduction of the size of the infraspinous fossa³⁵.

Wolffson found that muscle function plays a role in the shaping of the vertebral border of the scapula and that the rhomboid and serratus anterior muscles played an important role. The influence of trapezius, infraspinatus and subscapularis either by themselves or in combination with other muscles could not be confirmed³⁵.

Bainbridge and Genovés (1956) assessed the scapulae from a collection of 17th – and 18th – century skeletons from St. Bride church in London, in order to design a scheme that would combine morphological and metrical characteristics for determining sexual dimorphism. Their sample consisted of 358 scapulae²⁰.

A number of morphological characteristics were examined (e.g. the costal facets, glenoid tubercles, clavicular facet of the coracoid, etc.). Bainbridge and Genovés found no notable differences in the lateral border or supraspinous fossa of males and females. They recognised the three main forms of the infraspinous portion of the medial border as convex, straight and concave and found that the male scapula was convex in 37 of the 45 male scapulae, while the medial border of females was straight in seven of the 13 female samples. They found the morphological method of the assessment of sexual dimorphism of the scapula to be unreliable. They also assessed a number of metrical characteristics

(e.g. maximum scapular length, maximum scapular breadth, maximum length of the spine, etc.), which were found to be more reliable than the morphological method²⁰.

Iordanidis studied sex differences in the scapula, and found scapular height to be more than 157 mm in males and less than 144 mm in females. Scapular breadth was found to be more than 106 mm in males and less than 93 mm in females. The total length of the spine was found to be more than 141 mm in males and less than 128 mm in females. The width of the glenoid cavity was found to be more than 29 mm in males and less than 26 mm in females. As can be seen, there is a large area of overlap²¹.

Prescher and Klümpen (1995) studied the area of the glenoid cavity to determine whether it shows sexual dimorphism. They measured the glenoid cavity of 214 scapulae (114 male and 100 female). Scapulae with a cavity area of more than or equal to 9.57 cm² were classified as male and less than or equal to 6.83 cm² as female using this method. Only 69.5% of the male scapulae and 36% of the female scapulae were correctly assigned, thus a large overlap exists²³.

Getz *et al.* (1996) studied the morphology of the acromion. They evaluated the relationship between acromial shape and age, sex, symmetry, the presence of subacromial enthesophytes and acromioclavicular osteophyte formation. Their sample consisted of 406 dried cadaveric scapulae. The scapulae were divided into sex and age groups ranging in decades from 20 – 29 years to 80 – 89 years with approximately 30 pairs of male and female scapulae per decade²².

The acromial morphology was typed according to the Bigliani classification (type I, flat; type II, curved; type III, hooked) and the presence and degree of subacromial enthesopathy was also recorded. They found that 22.8% (90 acromions) conformed to type I morphology, 68.5% (270 acromions) to type II and 8.6% (34 acromions) to type III. As far as sexual dimorphism was concerned, the greatest amount

of sexual dimorphism occurred in scapulae with type I and type III acromion morphology. More female acromions conformed to type I morphology, with 27.5% (52 out of 189) female acromions assigned type I in comparison with 18.5% (38 out of 205) male acromions. More male acromions conformed to type III morphology, with 10.2% (21 out of 205) of male acromions assigned to type III in comparison with only 6.9% (13 out of 189) of female acromions. Acromions assigned to type II morphology showed a large amount of overlap with 71.2% (146 out of 205) of male acromions and 65.6% (124 out of 189) of female acromions conforming to type II morphology²².

No relationship was found between acromial type and age. It was also found that acromial morphology was symmetric in 70.7% of the scapula pairs and asymmetric in 29.3% of the pairs²².

Prescher and Klümpen (1997) also studied the glenoid notch to determine how the notch affects the shape of the glenoid cavity and whether a sex or side preference existed for the presence of the notch. Their sample consisted of 236 scapulae (118 male and 118 female) of known sex and age. The difference between sexes for the prevalence of the glenoid notch was not significant. Out of the sample, 55% (129) of the scapulae had a glenoid notch, with 47% (61) of these being female and 53% (68) being male. Seventy seven (65%) of the scapular pairs were symmetrically shaped. Small but nonsignificant sexual dimorphism was found in these pairs with 32 (42%) of them being female and 41 (53%) male. Forty one (35%) of the scapular pairs showed asymmetric glenoid cavities. Clear sexual dimorphism existed in these pairs with 27 (66%) being female and 14 (34%) being male²⁴.

The anatomical size and orientation of the glenoid cavity was studied by Churchill and co-workers (2001), in order to quantify any variation based on sex or race. One hundred and seventy two pairs of scapulae of known sex and race were analysed.

The maximum width and height of the glenoid cavity were measured. Version (the extent to which the glenoid faces anteriorly or posteriorly with respect to the plane of the scapula) and inclination were also measured by placing the scapulae in a custom-made scapula holder. No variation was found between the two races, but difference was found between the two sexes. Males showed greater width and height of the glenoid cavity, while females showed greater inclination²⁵.

Monk *et al.* (2001) used laser morphometric techniques to assess the articular surfaces of the glenoid fossa. Their purpose was to develop a method for determining the surface topography of the articular surface of the glenoid by using 3D laser scanning. Eighteen cadaveric scapulae that showed no pathology were selected for scanning. Each scapula was securely clamped in a standardised position. The region of the glenoid fossa was scanned using a 780 nm wavelength infrared laser. The degree of version of five lines that were constructed in the horizontal plane was determined. These consisted of a transverse reference line (equatorial midline) midway between the superior and inferior tubercles of the fossa, lines at 45% of the height of the glenoid fossa above and below the equatorial line, as well as lines midway between these pairs. This method was found to be repeatable and reliable for the assessment of the three dimensional geometry of a bony surface³⁶.

Frutos (2002) analyzed 35 female and 65 male scapulae from rural Guatemala. Measurements of the length and breadth of the glenoid cavities of the left scapulae were taken and male values were found to be greater than female values. A statistically significant p-value of 0.001 was calculated⁶.

2.3 GEOMETRIC MORPHOMETRICS

“A Glossary for Geometric Morphometrics” by Slice *et al.* describes geometric morphometrics as a “collection of approaches for the multivariate statistical analysis of Cartesian coordinate data, usually (but not always) limited to landmark point locations”. It can also be called the morphometric methods that preserve complete information about the relative spatial arrangement of data throughout an analysis. These methods allow the researcher to visualize the group and individual differences, sample variation, as well as other results in the space of the original specimens³⁷.

Geometric morphometrics is a relatively new field that involves the quantitative study of form^{7, 13–15}. It is different from other biometrical methods, as a result of a triple role played by landmarks: the geometry of landmarks allows for a way to describe individual forms, pairs of forms and effects upon entire samples of forms^{13, 38}. Geometric morphometric analysis produces an exact geometric description of shape differences between the same structures in different individuals⁷.

Geometric morphometry was pioneered by Thompson, who used coordinates to express changes in shape^{39, 40}. Bookstein, however, is thought to be the “father” of applications of geometric morphometrics to problems in biology⁷. The technique was refined in the late 1980’s, but has only recently started to become popular in physical anthropology⁷.

James F. Rohlf developed the ‘tps’ series of programs which compute the statistics and provide visualizations of geometric morphometrics. The ‘tps’ series consists of various programs, among other the following three programs, which were used in this study: tpsDig, tpsSpln and tpsRelw. Other programs making use of geometric morphometric techniques have also been developed. These include Sheets’ Integrated Morphometrics Package (IMP), of which the following three programs were

used in this study: CoordGen, CVAGen6 and TwoGroup. Other programs also making use of geometric morphometric techniques include Edgewarp2, Edgewarp3, JSPLINE, VECTOR, Procrustes Statistics program (APS), Common Principal Components for dependent random vectors (dCPC), Linear Discriminant Analysis and Hotelling's T-Squared (LINDA) and Principal Components Analysis with jackknife (JACKIE)³⁷.

Geometric morphometrics is the analysis of sets of digitized landmark coordinates, with each set recording the form of the specimen (Form = Shape + Size)^{10, 41}. These landmarks eliminate the effects of variation in location, orientation and scale of specimens, with the remaining differences representing shape variation. Advantages of this approach include the fact that there seems to be a higher statistical power (with sufficient sample sizes) to detect shape differences as more information about shape can be obtained by landmark coordinates. These methods also yield different and perhaps better visualization of the results than traditional methods¹⁵.

Landmarks are precise locations on biological forms and are recorded as two – or three – dimensional coordinates. If the same landmarks are collected on a number of objects, they are known as corresponding, or homologous landmarks¹⁴.

Although form consists of size and shape, neither can be defined, and a size variable has to be found that is statistically independent of shape. When a great difference in the size of forms exists, the forms are scaled to adjust for these differences so that information relating to scale does not obscure other information intrinsic to the comparison¹⁴. Scaled landmark coordinates can be brought into alignment via translation, rotation or reflection^{14, 41}. Translation is the sliding of form in any direction while it remains stable in terms of rotation around the axis. Rotation is a change in orientation, along with movement around the axis and reflection is the flipping (or mirroring) of the object across one axis or plane¹⁴.

There are three morphometric methods of studying the differences between forms:

◆ Superimposition methods:

Landmark data from two forms are arranged into the same coordinate space. One form is named the reference form, while the other is named the target form. Form change is then determined by the displacement of the landmarks in the target form from the corresponding landmarks in the reference form. Superimposition methods include minimizing the sum of squared distances (e.g. least squares fitting), minimizing the sum of the distances (e.g. robust fitting), or matching a prespecified edge (e.g. Bookstein's edge matching)¹⁴.

◆ Deformation methods:

The area or volume of a reference form is deformed to correspond with that of the target form. These techniques include finite- element scaling analysis and thin- plate splines. In finite- element scaling analysis, landmarks located on an object are subdivided into groups that form elements. The locations of landmarks are mapped from the initial to the target form by a homology function. All the mathematically homologous points internal to each finite element in the initial form are mapped to a corresponding location in the target form. Thin- plate splines use chosen functions to map the relative location of points in the initial configuration to their corresponding locations in the target form exactly. The functions are also used to predict how points that lie in areas between landmarks in the initial form are arranged on the target form¹⁴.

◆ Linear distance- based methods:

These methods compare the linear distances that connect landmark pairs in one form to corresponding linear distances in another form. They also provide information regarding the differences in length of these linear distances ¹⁴.

Mullin and Taylor (2002) studied the effect of parallax on a grid to statistically establish whether all images would be distorted in the same manner when multiple pictures of the grid were taken using the same digital camera on separate occasions. They compared landmark data from standard and distorted grids to determine whether any differences existed between the two types. They found that, although a statistically significant difference existed between the grids, the parallax was consistent and the variation small enough with a constant error, so that the data were usable in geometric morphometric analyses ⁴².

2.4 GEOMETRIC MORPHOMETRICS IN ANTHROPOLOGY

Hennessy and Stringer (2002) investigated the characterization of the regional variability of craniofacial shape using geometric morphometrics. Their sample consisted of known adult crania from four regional groups, namely European (68 crania), Australian (35 crania), African (35 crania) and Inuit or Eskimo (29 crania). The European sample was sexed using cranial and postcranial features and consisted of 36 male, 23 female and 9 unclassified crania. These were used to test the effect of sexual dimorphism on the analyses ¹¹.

The surfaces of the crania were digitized and two photographs were taken of each skull. Nine homologous landmarks were assigned to each cranium and the dataset was divided into three subgroups, namely the sexed crania of the European group and six

possible combinations of two regional groups, and the whole sample together. These groups were then analyzed using geometric morphometric methods (including Goodall's F- test, Hotelling's T^2 - test, linear discrimination function analysis and multiple regression). Geometric morphometrics was found to provide accurate characterization of the overall face shape in each sample, as well as the variation within each sample, and the essential differences between samples ¹¹.

Strand Viðarsdóttir *et al.* (2002) also used geometric morphometry to examine interpopulation variations in the facial skeleton of 10 modern human populations to place them into ontogenic perspective. Their aim was to establish the extent to which distinctive features of adult representatives of the populations were present in the early postnatal period, and to what extent the population differences in ontogenetic scaling contributed to distinct facial forms. Their sample consisted of 334 individuals from infancy to adulthood, from 10 geographically distinct populations. Twenty six homologous landmarks were assigned to each skull and analyzed using geometric morphometrics ¹².

Strand Viðarsdóttir and co-workers found that modern human populations could be distinguished based only on facial shape and that some populations have statistically distinct facial ontogenetic trajectories that lead to the development of further differences later in ontogeny. They concluded that differences in facial form were caused by three interwoven ontogenetic mechanisms, namely early development of population- specific morphologies, dissimilarity in the direction of the ontogenetic trajectory, and ontogenetic scaling ¹².

Steyn *et al.* (2004) used geometric morphometric techniques to assess the shape differences in the greater sciatic notch of South African Negroid and Caucasoid samples of known sex and race. The left os coxa of each skeleton was positioned in a

standardised position. Photographs were taken of each greater sciatic notch and the images were entered into a computer. Five homologous landmarks were assigned to each greater sciatic notch. The tps series of programs were used to perform comparative morphological statistics and analysis. South African Negroid males were found to have the classic narrow shape, while Negroid and Caucasoid females had wide notches. Caucasoid males showed wide variation across the range, which meant that the size of the greater sciatic notch was not a reliable indicator of sex in Caucasoid samples ⁸.

An attempt was made by Oettlé and co-workers (2005) to assess the mandibular ramus by means of geometric morphometrics in order to determine whether sexual dimorphism existed in the shape of this structure. Seventy one mandibles of known South African Negroid individuals were used in the study. The left ramus of each specimen was photographed and the captured images were entered into a computer. Eleven homologous landmarks were assigned to each ramus. The tps series of programs, as well as the Integrated Morphometrics Package were used to analyze these landmarks. A statistically significant p- value of 0.014 for male- female shape differences was obtained using Hotelling's T- test. However, the CVA analysis assigned only 67.8% of the females and 69.9% of the males correctly, thus the presence or absence of mandibular ramus flexure was not found to be a good indicator of sex ⁹.

The usability of geometric morphometrics in the assessment of sexual dimorphism in South African Negroid populations was also investigated by Pretorius *et al.* (2006). Orbital shape, ramus flexure and greater sciatic notch shape were assessed in this study and their accuracies were compared. CVA analyses were carried out by Pretorius and co-workers and it was found that the shape of the sciatic notch was the most accurate feature, with 87.1% of females and 93.1% of males being correctly assigned. A p- value of 0.0 was obtained for sexual dimorphism of this feature,

indicating a high degree of significance. Orbital shape was second best with 80.0% of the females and 73.3% of the males correctly assigned. A p- value of 0.00129 was obtained for the orbits. Overlap was present in the mandibular ramus with 67.8% of the females and 69.9% of the males correctly assigned ($p = 0.031$)¹⁰.

Geometric morphometrics seems to be a useful tool for the study of the human skeleton. It provides a quantitative method of studying form and has been successfully used in order to study sexual dimorphism, as well as shape differences in different human populations.

2.5 GEOMETRIC MORPHOMETRICS AND ONTOGENY

O'Higgins *et al.* (2001) investigated postnatal facial growth, sexual dimorphism and adult differences within and between two primate species: *Cebus apella* and *Cercocebus torquatus*. Their aims were to describe postnatal growth (especially changes in shape with changes in size) and to recount differences in growth to adult differences between sex and species. Their sample consisted of 38 *C. apella* and 49 *C. torquatus* specimens. Thirty-one landmarks were selected that were thought to be developmentally homologous between the species and geometric morphometric techniques were used to quantify these landmarks³.

O'Higgins and co-workers found that sexual dimorphism differed noticeably between the two species, but that in both species it was caused by extension in males relative to females of a common size- shape trajectory and late deviation of growth between the sexes. This contrasted with the fact that they found that growth remodelling in the facial skeleton differed between species, as well as size- related shape changes in the face. It was concluded that the variations in facial form between the species were the result of prenatally established differences in form, as well as postnatal growth

diversions, while the different sexual dimorphisms of the two species were thought to occur through similar growth processes on divergent growth trajectories³.

Bookstein and co-workers (2003) attempted to compare two integrated factors, ontogeny and phylogeny, as they apply to a shared regionalization in a single sample of hominid crania. Their sample consisted of the crania of 20 modern adult *Homo sapiens*, 14 sub adult *H. sapiens* and four archaic *Homo*, giving a total of 38 crania. The specimens were CT-scanned except for two infant *H. sapiens* who were imaged by MR. Eighty four landmarks and semi landmarks were located on the midsagittal plane for each specimen. These were then converted to Procrustes shape coordinates. Integration was quantified by using the method of singular warps, which visualize correlations among regions. Evolutionary and ontogenetic integration were investigated by comparing analyses of overlapping subsamples that span the ranges of the different hypothetical factors. Evolutionary integration was expressed in the subsample of 24 adult *Homo* specimens and ontogenetic integration in the sub sample of the 34 *H. sapiens* specimens. The cranial vault, base and face demonstrated localized patterns of covariation over ontogeny².

Bookstein and co-workers found that traditional measurements of the cranial base angle could not distinguish between the ontogenetic and phylogenetic context of integration, as well as between either of these and a third integrative process that involved the relative elongation of the cranium. They also found that the overall shape of the cranium strongly influenced the posterior cranial base. They recommended that no set of cranial base features by itself would be adequate to explain evolutionary shape changes².

Bastir and Rosas (2004) defined ontogeny as a process composed of three interrelated factors: growth (changes of size with age), development (changes of shape

with age) and ontogenetic allometry (changes of shape with size). They investigated the ontogenetic, integrative and phylogenetic relevance of facial heights (the vertical distances between the gnathion and the nasion at the anterior face, and between the gonion and the postero-superior limit of the maxilla at the posterior face) and their consequences for the orientation and position of the adult viscerocranium and overall skull morphology in humans and chimpanzees ¹.

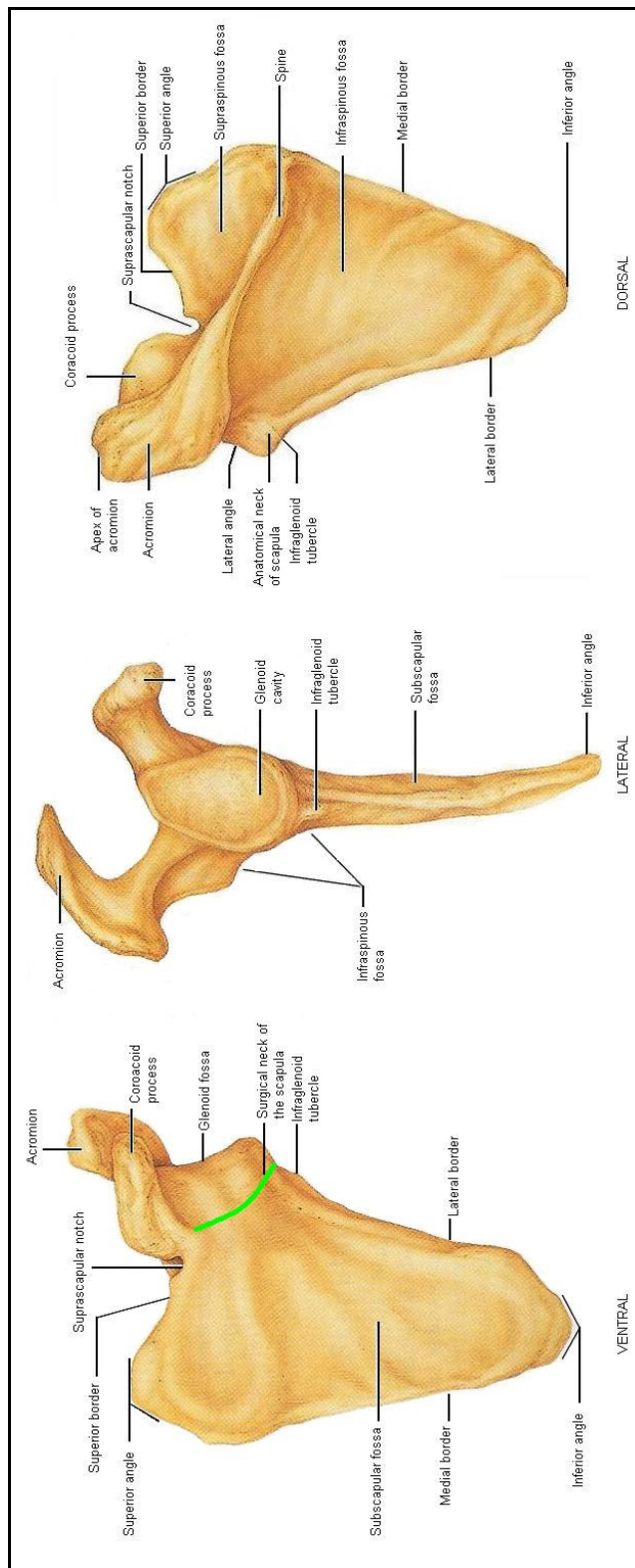
Bastir and Rosas hypothesised that if humans and chimpanzees shared a common postnatal ontogenetic growth trajectory, their growth allometries should be parallel. They tested early facial pattern determination and its biological independence from postnatal growth allometries, and also examined the covariation patterns of specific cranio-mandibular traits. Their sample consisted of complete juvenile and adult skulls of 89 humans and 86 chimpanzees of balanced sample composition. The specimens belonged to five dental age groups (namely Pre-M1, and any deciduous tooth erupted; M1-, M2-, M3- erupting, and adults with M3 fully erupted). Twenty-nine craniomandibular landmarks were digitized with the mandible in a fixed position. Geometric morphometric techniques were employed to study the shape and statistical analyses were also performed ¹.

Bastir and Rosas found that postnatal ontogeny follows significantly different trajectories in humans and chimpanzees. Postnatal growth contributed to adult skull proportions in both species by vertical facial expansion. In chimpanzees, the whole viscerocranium displayed reorientation, while in humans only the lower face was modified. In both species, the results supported a hypothesis of early facial pattern determination ¹.

Bastir and Rosas concluded that early developmental integration accounted for trait covariation among upper, mid and lower facial traits (which were found to be

independent from growth allometry), but that these factors differed taking into account which facial structures were involved ¹.

Figure 2.1: Anatomy of the scapula (Image available from: URL: <http://nsd.k12.mi.us/nwhs/staff/departments/science/patchett/images/Bones/Thumbnails/scapula.jpg>)²⁹



CHAPTER 3

MATERIALS AND METHODS

3.1 SAMPLE

The scapulae in this study originated from the Pretoria Bone Collection at the Department of Anatomy, University of Pretoria and the Raymond Dart Collection at the University of the Witwatersrand⁴³. The left scapulae of 45 adult males and 45 adult females were used. The ages ranged from 20 – 96 for males and 28 – 79 for females. The left scapulae of 79 juveniles of known age and sex were acquired from the Raymond Dart Collection. Ages ranged from one to 19 years. Only scapulae of known individuals were used. In addition, a further two scapulae, that of a three year old male and an eight year old female from forensic cases of known individuals were used. Damaged scapulae or scapulae showing pathology were excluded, since this could have influenced the shapes of the scapulae which, in turn, could have influenced the outcome. A full list of the adult and juvenile scapulae used in this study can be seen in Appendix A and B. According to the records of the two collections, all individuals were of Negroid descent.

The juvenile sample included all available specimens from the Raymond Dart Collection. Due to the fact that juvenile skeletons are rare, there is not necessarily a good representation of all age groups (Table 3.1). The Pretoria Bone Collection has no juvenile skeletons.

3.2 STANDARDIZATION AND LANDMARKS

In order to standardize the position of the scapulae, the bones were placed on graph paper on an osteometric board with the dorsal side facing upwards. The lateral border was placed against the vertical surface of the osteometric board, so that the glenoid fossa and inferior angle rested against the vertical surface.

Photographs were taken of the dorsal surface of the scapulae with an Olympus D – 395 digital camera which was mounted in a fixed position. The camera was positioned at a height of 470 mm directly above the scapulae. The viewfinder of the camera was focussed on a marked spot on the graph paper to ensure that the photographs would be taken in the same position each time. The captured images were entered into a computer and 21 homologous landmarks were assigned to each scapula to use for geometric morphometric analysis (Figure 3.1, Table 3.2). The landmarks were taken so that they would be easily identifiable on all scapulae, and would reflect the shape of the body of the scapula. The landmarks are as follows:

- ◆ Landmark 1 is situated on the glenoid fossa, where it touches the vertical surface of the osteometric board.
- ◆ Landmark 2 is situated at the position where the lateral border touches against the vertical surface of the osteometric board, near the inferior angle of the scapula.
- ◆ Landmarks 3 and 4 are situated at equal distances between landmarks 1 and 2 on the lateral border.
- ◆ Landmark 5 is situated on the most inferior part of the inferior angle, visualised using the graph paper as guide.
- ◆ Landmark 6 is situated at an equal distance between landmarks 2 and 5
- ◆ Landmark 7 is situated at the position where the spinous process ends on the medial border of the scapula. This landmark was assigned by following the scapular spine through to where it would reach the medial border of the scapula, taking into account the way in which it sometimes splits to form a triangular area.
- ◆ Landmarks 8 and 9 are situated at equal distances between landmarks 5 and 7 on the medial border.

- ◆ Landmark 10 is situated at the point where the superior border of the scapula reaches the spine. This landmark was assigned by following the superior border of the scapula laterally towards the scapular spine, at the point where the superior border “disappears” behind the scapular spine.
- ◆ Landmark 11 is situated along the superior border at an equal distance between landmarks 7 and 10.
- ◆ Landmarks 12 and 13 are situated at equal distances between landmarks 10 and 11, while landmarks 14 and 15 are similarly situated between landmarks 7 and 11.
- ◆ Landmark 16 is situated at an equal distance between landmarks 10 and 12, while landmark 17 is similarly situated between landmarks 12 and 13, landmark 18 between landmarks 11 and 13, landmark 19 between landmarks 11 and 14, landmark 20 between landmarks 14 and 15, and landmark 21 between landmarks 7 and 15.
- ◆ Landmarks 11 – 21 are not necessarily exactly equidistant, as it is almost impossible to assign equidistant landmarks on a curve. This fact is not really relevant, as these landmarks are only present to insure that along every few millimetres of the supraspinous border a landmark is present.
- ◆ Landmark 17 is not necessarily the highest point of the scapula, although on some scapulae it might seem that way – this depends on the shape of the supraspinous fossa.

3.3 GEOMETRIC MORPHOMETRIC ANALYSIS

3.3.1 Sexual dimorphism of the adult scapulae

In order to study the sexual dimorphism in adults, the following geometric morphometric methods were used:

3.3.1.1 Standardized landmarks were marked on the digitised scapular photos using the tps program tpsDig (F. James Rohlf, Version 1.31)

The homologous landmarks (described above) were digitized using the tpsDig program. In order to study the shape differences between males and females, the average, or consensus configuration of landmarks for each of these two groups (males and females) was computed using tpsSuper (F. James Rohlf, Version 1.03). From this it was possible to visually assess whether any differences existed between the males and females.

The tpsDig- program is used to assist the statistical analysis of landmark data in morphometrics by making it easier to collect and maintain landmark data from digitized images. It is used to mark the locations of landmarks in an initial file specifying the names of files containing the images of specimens. The data are saved as tps data- files and these files are then used with the other tps- programs (e.g. tpsSpln and tpsRelw)³⁷.

3.3.1.2 Two consensus configurations using tpsSpln (F. James Rohlf, Version 1.14) were determined

The two consensus configurations of the two groups were compared with each other in order to determine which landmarks were responsible for the variation. Thin – plate splines were calculated using tpsSpln. This program determined another consensus configuration representing the average shape of the two groups (This was nothing but the average of the whole population) and was represented by a perfect perpendicular grid.

Deformation of the grids of the two consensus configurations of the two groups made it possible to determine where the variation was. The consensus thin- plate splines were also viewed in “vector mode” to determine which landmarks were responsible for the greatest amount of variation.

The tpsSpln- program is used to compare the same landmarks in different individuals by making use of thin- plate spline transformations and principal and partial warps. A reference shape is given – this is the average shape of the whole sample population and is indicated by a perfect perpendicular grid. The thin- plate splines for each individual shows the deformation of this grid. The tpsSpln- program can also be used to compute vector thin- plate splines which indicate where and by how much the landmarks of two individuals in the sample group differ from each other ³⁷.

3.3.1.3 Differences in scapular shape of the sample were determined, using the tpsRelw (F. James Rohlf, Version1.25)

The Relative Warp Analysis (RWA) was performed in order to determine general trends in shape between the two sexes; in other words from this it was possible to see whether a definite separation between the male and female dataset existed or whether there was no clear distinction between the shape of the two sexes.

This program facilitates the statistical analysis of landmark data in morphometry. It shows the distribution of individuals within the population group in order to investigate intra- sample variation. This is given on a graph to make it possible to determine whether any variation occurs between the different groups in a sample population. The distribution of the various groups is the most important aspect of this program, therefore the axes of the graph are usually not labelled as the scale itself is not usually of interest ³⁷.

3.3.1.4 Canonical variates analysis using the Canonical Variates Analysis-program (CVAGen6) – IMP

The CoordGen- program is used to convert tps data- files to BC format which is then used with other programs in the IMP package (e.g. CVAGen6 and TwoGroup) ⁴³.

Canonical Variates Analysis (CVA) is a method for finding the set of axes that allows for the greatest possible ability to discriminate between two or more groups. This program uses a BC file for the pooled sample population, as well as a grouplist for the groups within the sample. BC is the abbreviation of “Bookstein Coordinates (also known as Bookstein’s shape coordinates or Two point shape coordinates). Bookstein Coordinates are described as a system of shape coordinates (originally from Francis Galton, but rediscovered by Bookstein) consisting (for two-dimensional data) of the coordinates of landmarks 3, 4... 21 after the forms are rescaled and repositioned so that landmarks 1 and 2 are fixed at (0,0) and (1,0) respectively, in a Cartesian coordinate system ^{37, 44}.

CVAGen6 can generate a plot indicating the similarities or differences in the clusters of landmarks of the different groups. This plot can be given in the shape of the structure that is being investigated, or the program can generate a CVA- plot that simply shows whether any overlap is present in the clusters of landmarks by grouping all the individuals in the different groups on separate sides of their mean shape. The amount of overlap can be used to determine whether any differences can be seen. CVAGen6 can also calculate a p- value to show if the differences between the two groups are statistically significant. A CVA assesses the ability to assign specimens in a dataset to groups (e.g. male or female), rather than asking if the two groups have a different shape. The program computes partial warp scores to a common reference and determines how

many CVA axes there are in the data at a $p=0.05$ level of significance and computes the canonical variate scores of all the specimens entered^{37, 44}.

3.3.1.5 Determining statistically significant differences between males and females, using CVAGen6 – IMP

A discriminant function analysis (or CVA) was performed using the CVAGen6-program. A CVA assesses the ability to assign specimens in a dataset to groups (e.g. male or female), rather than asking if the two groups have a different shape. The program computes partial warp scores to a common reference and determines how many CVA axes there are in the data at a $p=0.05$ level of significance and computes the canonical variate scores of all the specimens entered.

3.3.1.6 Determining how the males and females group using TwoGroup-program – IMP TwoGroup6

The TwoGroup program also uses BC files to compare two groups in the sample population. TwoGroup results are visualized by a TwoGroup BC Superimposition plot. On this plot the clusters of landmarks of the two groups are superimposed onto one another (in different colours) and the differences and/or similarities can be seen according to how tightly the landmarks are clustered together^{37, 44}.

This program also uses Hotelling's T^2 - test and Goodall's F- test to calculate p-values in order to determine statistical significance. Goodall's F- test tests for inter-group shape difference between the population groups. It tests for overall shape difference between groups taking sample variance into account. It compares the Procrustes distance between the means of two samples to the amount of variation found in the samples. Generalized least- squares Procrustes analysis is used to compute the

average shape for each sample^{11, 45, 46}. Hotelling's T^2 - test compares an observed mean vector to a parametric mean; or the difference between two mean vectors to a parametric difference³⁷.

The inter-group shape differences between the males and females were tested by means of the TwoGroup-program. Hotelling's T^2 - test and Goodall's F- test were used to test for statistical significance and the results were visualized by means of a TwoGroup BC Superimposition.

3.3.2 Sexual dimorphism of the juvenile scapulae

Due to the growth changes taking place in the scapulae of juveniles, the juvenile sample was divided into three age groups in order to determine whether any sexual dimorphism could be observed in the juvenile scapula in the various age groups. The three age groups are ages 1 – 6, 7 – 12 and 13 – 19. They could not be divided into smaller groups due to the small sample size. The number of juvenile males and females in each of these three groups can be seen in Table 3.3. In order to study the sexual dimorphism of juveniles, the same methods were followed as for the adult male and female scapulae.

3.3.3 Ontogeny of the scapula

The juvenile sample was separated into consecutive age groups, in other words, all the one year old juveniles were grouped together, all the two year olds, all the three year olds etc., up to 19 year olds. Because shape differences between age groups were studied, the average, or consensus configuration of landmarks for each of these age groups (one year old juveniles, two year old juveniles, three year old juveniles, ..., 19 year old juveniles) was computed using tpsSuper (F. James Rohlf, Version 1.03). From

this it was possible to visually assess whether any differences exist between the age groups. Because the sample is so small and little difference between the sexes was found, male and female juveniles were pooled. In order to determine whether geometric morphometrics could be used successfully to study the ontogeny of the scapula, the methods described in 3.3.1 were used.

3.3.4 Testing inter- and intra- observer repeatability

To test for intra- observer repeatability, 15 male and 15 female scapulae were randomly selected and re-assigned the chosen landmarks. The “new” landmark data were statistically compared to the “old” dataset using Hotelling’s T^2 -test and Goodall’s F-test of the TwoGroup program.

To test for inter- observer repeatability, the 30 scapulae mentioned above, were once again selected. The landmarks were re-assigned by an independent observer who wasn’t involved in this study, but had some experience with geometric morphometrics. The “new” landmark data (as assigned by the independent observer) were once again statistically compared to the original dataset using Hotelling’s T^2 - test and Goodall’s F-test of the TwoGroup program.

Figure 3.1: Dorsal view of left scapula of an adult female to illustrate landmarks



Table 3.1: Number and sex of juveniles in each age group

AGE GROUP	NUMBER OF JUVENILES IN AGE GROUP	MALE	FEMALE
0 – 1 year	6	2	4
1 – 2 years	2	1	1
2 – 3 years	3	3	0
3 – 4 years	3	2	1
4 – 5 years	0	0	0
5 – 6 years	1	1	0
6 – 7 years	2	1	1
7 – 8 years	1	0	1
8 – 9 years	1	1	0
9 – 10 years	1	1	0
10 – 11 years	0	0	0
11 – 12 years	3	0	3
12 – 13 years	7	5	2
13 – 14 years	3	1	2
14 – 15 years	8	5	3
15 – 16 years	8	7	1
16 – 17 years	10	9	1
17 – 18 years	11	9	2
18 – 19 years	11	3	8
Total	81	51	30

Table 3.2: Assignment of landmarks

LANDMARK	POSITION
Landmark 1	On the glenoid fossa, where the glenoid fossa touches the vertical surface of the osteometric board
Landmark 2	Point where the lateral border touches against the vertical surface, near the inferior angle of the scapula
Landmarks 3 and 4	At equal distances between landmarks 1 and 2 on the lateral border
Landmark 5	Most inferior part of the inferior angle, visualised using the graph paper as guide
Landmark 6	At equal distances between landmarks 2 and 5
Landmark 7	Where the spinous process ends on the medial border of the scapula (following the scapular spine through to where it reaches the medial border, taking into account the way in which it sometimes splits to form a triangular area)
Landmarks 8 and 9	At equal distances between landmarks 5 and 7 on the medial border
Landmark 10	At the point where the superior border of the scapula reaches the spine (following the superior border laterally towards the scapular spine, at the point where the superior border “disappears” behind the scapular spine)
Landmark 11	At equal distances between landmarks 7 and 10
Landmark 12 and 13	At equal distances between landmarks 10 and 11
Landmarks 14 and 15	At equal distances between landmarks 7 and 11
Landmark 16	At equal distances between landmarks 10 and 12
Landmark 17	At equal distances between landmarks 12 and 13
Landmark 18	At equal distances between landmarks 11 and 13
Landmark 19	At equal distances between landmarks 11 and 14
Landmark 20	At equal distances between landmarks 14 and 15
Landmark 21	At equal distances between landmarks 7 and 15

Table 3.3: Number of juvenile males and females in each age group

AGE GROUP	NUMBER OF JUVENILES IN AGE GROUP	FEMALE	MALE
1 - 6 years	15	7	8
7 - 12 years	8	5	3
13 - 19 years	58	19	39
Total	81	31	50

CHAPTER 4

RESULTS

Results for both sexual dimorphism and ontogeny were obtained first for the complete scapula, and thereafter for the three borders separately (lateral border – landmarks 1 – 6, medial border – landmarks 5, 7 – 9 and the supraspinous fossa – landmarks 7, 10 – 21).

4.1 SEXUAL DIMORPHISM IN THE ADULT SCAPULA

4.1.1 The complete scapula

The relative warp analysis for adult males and females is presented in Figure 4.1. Females are indicated in green and males in blue. From the relative warp analysis it can be seen that there are some differences between males and females, however no distinct pattern can be observed, and there is a large degree of overlap with no clear separation between males and females.

The reference for the consensus thin- plate splines is presented in Figure 4.2. This is the average shape of the two groups and is represented by a perfect perpendicular grid. Figures 4.3 and 4.4 represent the thin- plate splines for adult female and male scapulae respectively. When these images are compared, it is clear that there are differences between the two sexes, especially along the superior border of the scapula, but these differences can be seen more clearly when the male and female scapular shapes are compared in vector mode (Figure 4.5). From this vector thin- plate spline it can be seen that adult males differ from adult females at most landmarks.

The female shape is slightly narrower, with the male shape being slightly broader. The male lateral border is slightly more curved than that of the female, while

the inferior angle of the female seems less sharp than that of the male. The female medial border is straighter than in males, while the superior border seems slightly more convex than that of the males.

Figure 4.6 is a representation of the TwoGroup BC Superimposition plot for adult males and females. Males are indicated by red squares and females by blue circles. The scapula is rotated so that the lateral border is on the horizontal (x-) axis, with landmark 1 represented by the point (0,0) and landmark 2 by the point (0,1). Separation exists between the two sexes with the landmarks indicating the medial and superior borders being less tightly clustered than the landmarks indicating the lateral border. These results correspond to some extent with the results obtained from the thin- plate splines. The superior border of females seems slightly more convex than that of males according to the thin- plate splines. This was reflected in the TwoGroup BC Superimposition plot, where the landmarks indicating males (red squares) seemed more concave than the landmarks indicating females (blue circles). Differences could also be seen in the medial border where the thin- plate splines indicated that the female medial border was straighter than that of the male. This was reflected in the TwoGroup BC Superimposition plot, where the landmarks indicating the two sexes were not tightly clustered. The differences along the lateral border were seen more clearly on the thin-plate splines than on the TwoGroup BC Superimposition plot, probably due to the fact that landmarks 1 and 2 are situated at fixed coordinates.

Goodall's F- test and Hotelling's T^2 - test were performed using the TwoGroup program. Goodall's F- test yielded a p- value of 0.20014 which was not significant. Hotelling's T^2 - test, however, yielded a significant p- value of 0.00039. These values indicate that there is a statistically significant difference between the shapes of adult male and female scapulae. The reason for the differing values from Goodall's F- test and

Hotelling's T^2 - test might be as a result of the different nature of these two tests. Goodall's F- test tests for inter-group shape differences between population groups, taking sample variance into account. Hotelling's T^2 - test compares an observed mean vector to a parametric mean; or the difference between two vectors to a parametric difference.

Figure 4.7 is a representation of the CVA plot for adult females and males, with adult females indicated by black dots and adult males indicated by blue crosses. The scapula has been rotated so that the lateral border is situated on the x- axis. Separation can be seen, especially along the superior border with the convex shape of the females and the more concave shape of the males clearly visible.

Figure 4.8 is a representation of the mean CVA plot for adult females and males, with the females once again indicated by black circles and the males by blue crosses. The larger black circle and blue cross in the centre represent the mean shape for the adult females and males respectively. On this CVA plot the separation between males and females can clearly be seen with almost no overlap present.

Based on the above mentioned differences, a CVA analysis was carried out to test the accuracy with which a scapula can be categorised as male or female. Table 4.1 represents the accuracies obtained from this analysis. Forty one of the female scapulae were correctly assigned as female (giving a percentage of 91.1%), while 43 of the male scapulae were correctly assigned as male (giving a percentage of 95.6%). The p- value obtained by the CVA analysis was 0.00015, which indicates that the sexual dimorphism of the adult scapula is statistically significant.

In order to understand the observed differences better, the three borders of the adult male and female scapula were studied separately:

4.1.2 The lateral border (landmarks 1-6)

The relative warp analysis for the lateral border of adult males and females is presented in Figure 4.9. Landmarks 1 – 6 were included here. Females are indicated in green and males in blue. From the relative warp analysis it can be seen that there is little difference between the sexes.

The reference for the consensus thin- plate splines is presented in Figure 4.10. Figure 4.11 is the consensus thin- plate spline in (vector mode) to indicate the differences between the adult female and male lateral border. From this vector thin- plate spline it can be seen that adult males differ most from adult females at landmarks 1 – 3, 5 and 6. Landmark 4 is situated in the same position for males and females. The male lateral border seems slightly more curved than that of the female.

Goodall's F- test was performed using the TwoGroup program. Goodall's F- test yielded a p- value of 0.342, which is not significant.

Figure 4.12 is a CVA plot for the lateral border of adult females and males, with the females indicated by black circles and the males by blue crosses. The landmarks are grouped closely together and no clear differences can be seen between the two sexes.

Figure 4.13 is the mean of the CVA plot for the lateral border of adult females and males with females once again indicated by black circles and the males by blue crosses. The larger black circle and blue cross in the centre represent the mean shape of the lateral border of females and males respectively. No separation can be seen between the two sexes and a large degree of overlap can be seen.

From the results obtained from these two CVA plots, as well as the p- value obtained from the TwoGroup program, it was decided not to perform a CVA analysis in

order to determine the accuracy with which a lateral border could be classified as male or female, as no differences could be seen between the two sexes.

4.1.3 The medial border (landmarks 5, 7-9)

The relative warp analysis for the medial border of adult males and females is presented in Figure 4.14. Landmarks 5, as well as 7 – 9 were included. Females are indicated in green and males in blue. No clear separation can be seen.

The reference for the consensus thin- plate splines is presented in Figure 4.15. Figure 4.16 is the consensus thin- plate spline (in vector mode) to indicate the separation between the adult female and male medial borders. From this vector thin- plate spline it can be seen that adult males differ from adult females at all the landmarks, especially at landmarks 5 and 7. Landmark 5 is situated more superiorly and laterally in males than in females, while landmark 7 is situated more medially and lower in males than in females, suggesting that the medial border of males is broader than that of females towards the scapular spine, and narrower than that of females towards the inferior angle, while the female medial border seems straighter than that of the male.

No CVA or statistical analyses could be performed due to the fact that the four landmarks along the medial border are not enough.

4.1.4 The superior border (landmarks 7, 10-21)

The relative warp analysis for the superior borders of adult males and females is presented in Figure 4.17. Landmarks 7 as well as 10 – 21 were included. Females are indicated in green and males in blue. From the relative warp analysis it can be seen that there is little difference between males and females.

The reference for the consensus thin- plate splines is presented in Figure 4.18. Figure 4.19 is the consensus thin- plate spline (in vector mode) to indicate the separation between the adult female and male supraspinous fossa borders. From this vector diagram it can be seen that adult males differ from adult females at all the landmarks, especially landmarks 7, 10, 12, 15 – 17, 20 and 21. The superior border of the male supraspinous fossa seems to run along a downward slope towards the superior angle, while that of the female seems to have a convex shape. The medial border of the male is more curved towards the scapular spine, while that of females seem to be straighter.

Figure 4.20 is a representation of the TwoGroup BC Superimposition plot for the supraspinous border of adult males and females. Males are indicated by red squares and females by blue circles. The supraspinous fossa border has been rotated so that landmark 7 is represented by the point (0,0) and landmark 10 by the point (0,1). Separation between the two sexes is visible with the landmarks not at all tightly clustered. The results obtained from the TwoGroup BC Superimposition plot corresponded somewhat with the results obtained from the thin- plate splines. Separation between the two sexes could be seen on the TwoGroup BC Superimposition plot with the landmarks not tightly clustered. The shape differences were, however, more visible on the thin- plate splines. The males tend to cluster together, while the females are more variable and spread out.

Goodall's F- test and Hotelling's T^2 - test were performed using the TwoGroup program. Goodall's F- test yielded a significant p- value of 0.038, while Hotelling's T^2 - test yielded a p- value of 0.063 which was significant at the 0.1 level.

Figure 4.21 is a CVA plot for the supraspinous fossa of adult females and males, with females indicated by black circles and males by blue crosses. The landmarks are grouped closely together and no clear differences can be seen between the two sexes.

Figure 4.22 is the mean of the CVA plot for the supraspinous fossa of adult females and males, with females once again indicated by black circles and males by blue crosses. The larger black circle and blue cross in the centre represent the mean shape of the lateral border of females and males respectively. Some separation can be seen between the two sexes, but a large degree of overlap is present.

From the above mentioned results (obtained from the TwoGroup analysis, as well as the TwoGroup BC Superimposition plot and the two CVA plots) it was decided not to perform a CVA analysis for the accuracy with which a supraspinous fossa can be classified as male or female, as the differences between the two sexes are not large enough.

4.1.5 Testing intra- and inter- observer repeatability

To test for intra- observer repeatability, 15 male and 15 female scapulae were randomly selected and re-assigned the chosen landmarks. The “new” landmark data were statistically compared to the “old” dataset using Hotelling’s T^2 -test and Goodall’s F-test of the TwoGroup program.

Hotelling’s T^2 - test yielded a p- value of 0.030152, while Goodall’s F- test yielded a p- value of 2.9763, indicating that there is no statistically significant difference between the two sets of landmarks and, thus, that intra- observer repeatability is possible.

To test for inter- observer repeatability, the 30 scapulae mentioned above, were once again selected. The landmarks were re-assigned by an independent observer who wasn’t involved in this study, but had some experience with geometric morphometrics. The “new” landmark data (as assigned by the independent observer) were once again

statistically compared to the original dataset using Hotelling's T^2 - test and Goodall's F- test of the TwoGroup program.

Hotelling's T^2 - test yielded a p- value of 3.149, while Goodall's F- test yielded a p- value of 3.052. Both of these p- values indicate that there is no significant difference between the “new” and “old” landmark datasets, which means that the assigned landmarks are repeatable.

As the landmarks were found to be repeatable in adults and the same landmarks were used for adult and juvenile scapulae, it was accepted that the landmarks would also be repeatable in juvenile scapulae.

4.2 SEXUAL DIMORPHISM IN JUVENILE SCAPULAE

Figure 4.23 is the Relative Warp Analysis for juvenile males and females for the whole juvenile sample (ages ranging from 1 – 19). From this figure no clear separation between the juvenile males and females can be observed. This can be as a result of the sample size, as well as the large number of age groups represented in the sample (1 – 19 years old).

Because of the growth changes taking place in the scapulae of juveniles, the juvenile sample was divided into three age groups in order to determine whether any sexual dimorphism could be observed in the juvenile scapula in the various age groups. The three age groups are ages 1 – 6, 7 – 12 and 13 – 19. They could not be divided into smaller groups due to the small sample size. The number of juvenile males and females in each of these three groups can be seen in Table 3.3.

Figure 4.24 is the Relative Warp Analysis for the consensus of the three juvenile age groups, with numbers 1 – 3 indicating juvenile females (with 1 indicating 1 – 6 year old females, 2 indicating 7 – 12 year old females and 3 indicating 13 – 19 year old

females). Numbers 4 – 6 indicate the juvenile males (with 4 indicating 1 – 6 year old males, 5 indicating 7 – 12 year old males and 6 indicating 13 – 19 year old males). When the three age groups are compared it can be seen that some separation exists. In the age group 1 – 6 years (females and males indicated by numbers 1 and 4 respectively) separation can be seen between the two groups, although both are situated in the lower right quadrant. In the 7 – 12 year age group (females and males indicated by numbers 2 and 5 respectively) some separation (although not as much as in the 1 – 6 year age group) can be observed with females situated in the upper left and males in the upper right quadrants. The least separation can be observed between the 13 – 19 year age group (females and males indicated by numbers 3 and 6 respectively) with both being situated close together in the lower left quadrant.

4.2.1 Ages 1 – 6

Figure 4.25 is the Relative Warp Analysis for all the juvenile males and females aged 1 – 6 years. Females are indicated by numbers 1 – 7 and males by numbers 8 – 15. Some separation can be seen between the two sexes. The females are mostly distributed in the upper and lower right (three individuals each), as well as the lower left quadrants (one individual). The males are dispersed in the upper and lower left and lower right quadrants with two individuals in the lower left and right quadrants and four individuals in the upper left quadrant.

The reference for the consensus thin- plate splines is presented in Figure 4.26. Figures 4.27 and 4.28 represent the thin- plate splines for 1 – 6 year old female and male scapulae respectively. When these images are compared it can be seen that some differences exist between the sexes. The male scapula is more elongated than the female scapula, while the infraspinous fossa of the female scapula is broader than that of the

male. The differences between the two sexes can be seen more clearly when male and female scapular shapes are compared in vector mode (Figure 4.29). From this vector thin-plate spline it can be seen that the 1 – 6 year old males differ most from the females at landmarks 1, 2, 4 – 8, 13, 15, 18, 20 and 21. Landmarks 1 – 6 form part of the lateral border, which is longer and straighter in males. Landmarks 5, 7 and 8 form part of the medial border, which is longer in males and more curved in females. Landmarks 13 and 18 can be found along the superior border of the supraspinous fossa, while landmarks 15, 20 and 21 form part of the medial border of the supraspinous fossa. The superior border of the supraspinous fossa is narrower and higher in the males than in the females.

Figure 4.30 is a representation of the TwoGroup BC Superimposition plot for 1 – 6 year old males and females. Males are indicated by red squares and females by blue circles. Separation exists between the two sexes with the landmarks indicating the medial and superior borders being less tightly clustered than the landmarks indicating the lateral border. These results correspond with the results obtained from the thin-plate splines, although the differences along the lateral border were seen more clearly on the thin-plate splines than on the TwoGroup BC Superimposition plot.

In summary, scapular shape for 1 – 6 year old females is shorter and broader than that of males. The inferior angle is sharper in males than in females. The lateral as well as the medial borders seem to be longer and straighter in males than in females, while the superior border of the supraspinous fossa is convex for both sexes. The female shape is slightly more convex here. The medial border of the supraspinous fossa is slightly more curved for females.

No CVA analysis could be performed due to the small size of the sample (15 individuals). Goodall's F- test and Hotelling's T^2 - test were performed using the TwoGroup program. Goodall's F- test yielded a p- value of 0.014. No results were

obtained from Hotelling's T^2 - test. The p- value obtained from Goodall's F- test indicates that there is a statistically significant difference between the shapes of 1 – 6 year old male and female scapulae.

4.2.2 Ages 7 – 12

Figure 4.31 is the Relative Warp Analysis for all the juvenile males and females aged 7 – 12 years. Females are indicated by numbers 1 – 5 and males by numbers 6 – 8. Some separation exists with all the females (except one in the lower left quadrant and one in the upper left quadrant) situated in the upper right quadrant. Two of the male individuals are situated in the upper right quadrant and one in the lower left quadrant.

The reference for the consensus thin- plate splines is presented in Figure 4.32. Figures 4.33 and 4.34 represent the thin- plate splines for 7 – 12 year old female and male scapulae respectively. The male scapula is slightly more elongated than that of the female. The superior border of the supraspinous fossa is more convex in the males than in the females. The differences between the two sexes can be more clearly seen when the male and female scapular shapes are compared in vector mode (Figure 4.35). From this vector thin- plate spline it can be seen that 7 – 12 year old males differ most from females at landmarks 1 – 7 and 9 – 21. Landmarks 1 – 6 form part of the lateral border which is slightly more elongated and more curved in males than in females. The inferior angle is sharper in males than in females. Landmarks 5, 7 and 9 form part of the medial border which seems more curved in males than in females. Landmarks 10 – 21, along with landmark 7, form the outline of the supraspinous fossa. The male supraspinous fossa seems smaller in males than in females, with the medial border of the supraspinous fossa shorter in males than in females. The male scapula is narrower than that of the female.

Figure 4.36 is a representation of the TwoGroup BC Superimposition plot for 7 – 12 year old males and females. Males are indicated by red squares and females by blue circles. Some separation exists between the two sexes with the landmarks indicating the medial and superior borders being less tightly clustered than the landmarks indicating the lateral border. Most separation can be seen along the superior border. These results seem to correspond to some extent with the results obtained from the thin- plate splines, although the differences along the lateral border were seen more clearly on the thin- plate splines than on the TwoGroup BC Superimposition plot.

No CVA analysis could be performed due to the small number of individuals in this age group (8 individuals). Goodall's F- test was performed using the TwoGroup program. Goodall's F- test yielded a p- value of 0.609, which is not significant.

4.2.3 Ages 13 – 19

Figure 4.37 is the Relative Warp Analysis for all the juvenile males and females aged 13 – 19 years. Females are indicated by numbers 1 – 19 and males by numbers 20 – 58. No clear separation can be seen, with both sexes being widely distributed in all four quadrants.

The reference for the consensus thin- plate splines is presented in Figure 4.38. Figures 4.39 and 4.40 represent the thin- plate splines for 13 – 19 year old female and male scapulae respectively. The male scapula is slightly more elongated and narrow than that of the female. The superior border of the supraspinous fossa is concave for males and slightly more convex for females. The difference between the two sexes can be seen more clearly when the male and female shapes are compared in vector mode (Figure 4.41). From this vector thin- plate spline it can be seen that the male and female shapes differ at all landmarks, especially at landmarks 1 – 6, 9, 11, 13, 17 and 18. Landmarks 1

– 6 form the outline of the lateral border, which is straighter for males. Landmark 1 is lower in the males, indicating that the glenoid fossa is relatively lower in males than in females. Landmarks 5 and 9 form part of the medial border, which is more curved for males. Landmarks 11, 13, 17 and 18 form part of the superior border of the supraspinous fossa, which is concave for males and slightly convex for females. The medial border of the supraspinous fossa is slightly straighter for females than for males.

Figure 4.42 is a representation of the TwoGroup BC Superimposition plot for 13 – 19 year old males and females. Males are indicated by red squares and females by blue circles. Separation exists between the two sexes with the landmarks indicating the medial and superior borders being less tightly clustered than the landmarks indicating the lateral border. More separation can be seen along the superior border. The landmarks indicating the superior border of males seem to be more concave than that of the females. The males are also more “outside” than of the females. This might be as a result of the fact that the males are almost twice as many male as female individuals in this age group (39 males and 19 females). These results seem to correspond to some extent with the results obtained from the thin- plate splines, although the differences along the lateral border were seen more clearly on the thin- plate splines than on the TwoGroup BC Superimposition plot.

Goodall’s F- test was performed using the TwoGroup program. Goodall’s F- test yielded a p- value of 0.003, indicating that there is a statistically significant difference between the shapes of 13 – 19 year old male and female scapulae.

Figure 4.43 is the CVA plot for juvenile females and males aged 13 – 19, with females indicated by black circles and males by blue crosses. Some separation can be seen between the two sexes, especially along the superior border of the supraspinous

fossa where the convex shape of the females and more concave shape of the males can clearly be seen.

Figure 4.44 is the mean of the CVA plot for juvenile females and males, with the females once again indicated by black circles and the males by blue crosses. The larger black circle and blue cross in the centre represent the mean shape of the females and males respectively. Clear separation can be seen between the sexes with almost no overlap present.

4.3 ONTOGENY OF THE SCAPULA

4.3.1 The complete scapula

In order to more effectively study the ontogeny of the scapula, the consensus thin- plate splines for each consecutive year were compared with each other (e.g., one and two year old juveniles). Relative Warp Analyses as well as vector thin- plate splines were drawn up for each consecutive age group. Once again the complete scapula was first studied, where after the three borders were studied separately.

Figure 4.45 is the Relative Warp Analysis (RWA) for the whole juvenile sample (1 – 19 years old). From this RWA it can be seen that the separation of the one and two year old juveniles from the rest of the groups is the most obvious. The younger juveniles (up to 12 years old) are all found in the two right hand quadrants, while the older juveniles (ages 13 and upwards) are scattered in all four quadrants with the majority in the two left hand quadrants. When the Relative Warp Analysis for the consensus of the juvenile age groups (Figure 4.46) is observed, the separation between the different age groups becomes clearer. The one and two year old juveniles show the most obvious separation from the rest of the juveniles by being positioned to the far right of the lower right quadrant. The 3 – 9 year old juveniles are situated closely together in the upper and

lower right quadrants with the 3, 6 and 7 year old juveniles situated closely together in the upper right quadrant and the 4, 8 and 9 year olds situated closely together in the upper and lower right quadrants. The single 10 year old juvenile is separated from the rest of the group by being situated at the top of the upper right quadrant. The 12, 13 and 16 year old juveniles are clustered together in the upper left quadrant, while the 14, 15 and 17 – 19 year olds are clustered together in the lower left quadrant with the 18 and 19 year olds situated closely together. From this we can deduce that although definite changes in the shape of the scapula take place during its growth process, some of these changes might be more gradual causing varying age groups to resemble one another, thus being clustered together on the Relative Warp Analysis.

4.3.1.1 One and two year old individuals

Figure 4.47 is the Relative Warp Analysis for the one and two year old juveniles. Numbers 1 – 6 represent the one year old juveniles, while 7 and 8 represent the two year old juveniles. Clear separation exists between the two age groups, with the one year old juveniles dispersed in the upper left (three individuals), upper right (two individuals) and lower right quadrants (one individual). The two year old juveniles are dispersed between the lower left and lower right quadrants.

When the consensus thin-plate splines for one and two year old juveniles (Figures 4.48 and 4.49) are observed, no obvious differences are visible. The two year old scapula is somewhat more stretched out toward the medial border, while the one year old scapula seems to have a straighter lateral border than the two year old. The superior border of the supraspinous fossa is concave for one and two year old juveniles, while the medial border of the supraspinous fossa is more rounded and relatively shorter for two year old juveniles.

The differences between one and two year old juveniles can be seen more clearly when viewed in vector mode (Figure 4.50). From this vector thin- plate spline it can be seen that one and two year old juveniles differ most from each other at landmarks 2, 4 – 6, 7, 8, 10, 11, 14, 15, 18, 20 and 21. Landmarks 2 – 6 are situated on the lateral border of the scapula, which is more elongated for two year old juveniles. The inferior angle of two year old juveniles seems slightly sharper than that of one year olds. Landmarks 5, 7 and 8 are situated on the medial border of the scapula, which is more stretched out for two year olds. Landmarks 10, 18 and 11 form part of the superior border of the supraspinous fossa, while landmarks 7, 14, 15, 20 and 21 form part of the medial border of the supraspinous fossa. The superior border of the supraspinous fossa of two year old juveniles is slightly more concave than that of one year old juveniles, while the medial border of the supraspinous fossa becomes more straightened, but shorter for two year old juveniles. The scapula is thus rounder in the younger group, becoming more elongated in the two year olds.

4.3.1.2 Two and three year old juveniles

Figure 4.51 is the Relative Warp Analysis for two and three year old juveniles. Numbers 1 and 2 represent the two year old juveniles, while 3 – 5 represent the three year old juveniles. Separation exists between the two and three year old juveniles, with the two year old juveniles situated in the upper and lower left quadrants and the three year old juveniles situated in the lower left, upper and lower right quadrants.

When the consensus thin- plate splines for two and three year old juveniles (Figures 4.49 and 4.52) are compared, it can be seen that the scapula as a whole is more elongated for three year olds. The lateral border of three year olds is longer, with less distance between landmarks 2 and 5. The medial border of three year olds is slightly

straighter. The superior border of the supraspinous fossa is slightly less concave for three year olds than for two year olds, while the medial border of the supraspinous fossa is straighter for three year olds.

The differences between the two age groups can be seen more clearly when viewed in vector mode (Figure 4.53). From this vector thin- plate spline it can be seen that two and three year old juveniles differ most at landmarks 1, 2, 6 – 8, 11 – 13, 15, 18, and 21. Landmarks 1, 2 and 6 are situated on the lateral border of the scapula, which is elongated and less curved in three year olds than in two year olds. Landmarks 7 and 8 are situated on the medial border, which is straighter and somewhat shorter in three year olds than in two year olds. Landmarks 11 – 13 and 18 are situated along the superior border of the supraspinous fossa, while landmarks 7, 15 and 21 are situated on the medial border of the supraspinous fossa. The superior border of the supraspinous fossa is less concave, but longer in three year old juveniles than in two year olds. The medial border of the supraspinous fossa is straighter for three year olds than that of two year old juveniles. It also seems to move more towards lateral for three year old juveniles.

4.3.1.3 Three and four year old juveniles

Figure 4.54 is a representation of the Relative Warp Analysis for three and four year old juveniles. Numbers 1 – 3 represent three year old juveniles, while 4 – 6 represent four year old juveniles. All the individuals are scattered in all four quadrants, with the three year old juveniles situated in the upper and lower left, as well as the upper right quadrants. The four year old juveniles are situated in the lower right (two individuals) and lower left quadrants.

When the consensus thin- plate splines for three and four year old juveniles are compared (Figures 4.52 and 4.55), it is found that the lateral border is slightly straighter

for four year old juveniles, while the medial border seems less narrow and somewhat more stretched out. The superior border of the supraspinous fossa is less concave in four year olds, while the medial border of the supraspinous fossa is straighter for three year old juveniles.

The differences between three and four year old juveniles become clearer when the two age groups are viewed in vector mode (Figure 4.56). From this vector thin-plate spline, it can be seen that three and four year old juveniles differ most at landmarks 1, 2, 3, 8 – 11, 13, 14 and 19. Landmarks 1 – 3 form part of the lateral border of the scapula, which is straighter and more laterally situated for four year old juveniles than for three year olds. This seems to indicate a trend in the younger juveniles with the lateral border becoming more elongated and straighter in each consecutive year. Landmarks 8 and 9 form part of the medial border of the scapula, which is slightly rounded and more medially situated for four year olds than for three year olds. These differences, although small, in the lateral and medial borders create the impression that the body of the scapula is broader in four year old juveniles than in three year old juveniles. Landmarks 10, 11 and 13 form part of the superior border of the supraspinous fossa, while landmarks 11, 14 and 19 form part of the medial border of the supraspinous fossa. The superior border of the supraspinous fossa is less concave in four year olds than in three year olds, while the medial border of the supraspinous fossa is straighter for four year olds than in three year olds. This indicates a trend in the younger juveniles with the superior border of the supraspinous fossa seemingly becoming less concave with each consecutive year, while the medial border of the supraspinous fossa becomes straighter with each consecutive year.

4.3.1.4 Four and six year old juveniles

As no five year old samples could be found, the four and six year old juveniles were compared with each other. Figure 4.57 is the Relative Warp Analysis for four and six year old juveniles. Numbers 1 – 3 represent the four year old juveniles, while 4 represents the only six year old juvenile. The four year old juveniles are situated in the upper and lower right, as well as the lower left quadrants, while the six year old juvenile is situated in the upper right quadrant. Due to the small sample size it is not possible to determine whether separation exists.

When the consensus thin- plate splines for four and six year old juveniles are compared (Figures 4.55 and 4.58), it can be seen that the scapular body is narrower in the six year old than in four year olds. The lateral border is more concavely rounded for the six year old, while that of four year olds is straighter. The inferior angle seems slightly sharper for the six year old. The medial border is straighter and situated more laterally for the six year old. The superior border of the supraspinous fossa is more concave for the six year old, while the medial border of the supraspinous fossa is more rounded for the six year old juvenile.

The differences between four and six year old juveniles can be seen more clearly when viewed in vector mode (Figure 4.59). From this vector thin- plate spline, it can be seen that four and six year old juveniles differ most at landmarks 2 – 5, 7 – 9, 13, 15, 16 and 20. Landmarks 2 – 5 form part of the lateral border of the scapula, which is more rounded in the six year old than in four year olds. This contrasts with the trend that has been observed in the younger age groups, where the lateral border became straighter and more elongated with each consecutive year, but it should be kept in mind that there is only one six year old. Landmarks 5 – 9 form the outline of the medial border of the scapula, which is longer and straighter for the six year old than for four year olds. These

differences between the lateral and medial borders of four and six year old juveniles create the impression that the scapular body is narrower for the six year old than for four year old juveniles. This also indicates a trend in the younger juveniles with the scapular body seemingly becoming narrower for each consecutive year. Landmarks 13 and 16 form part of the superior border of the supraspinous fossa, while landmarks 7, 15 and 20 form part of the medial border of the scapula. The superior border of the supraspinous fossa is more concave in six year old juveniles than in four year olds, while the medial border of the supraspinous fossa is more rounded in six year old juveniles.

4.3.1.5 Six and seven year old juveniles

Figure 4.60 is the Relative Warp Analysis for six and seven year old juveniles. Number 1 represents the only six year old juvenile, while 2 and 3 represent the two seven year old juveniles. Separation can be seen with the six year old juvenile in the lower left quadrant and the seven year old juveniles in the upper left and right quadrants, although it should be kept in mind that the sample size is small.

When the consensus thin- plate splines for six and seven year old juveniles are compared (Figures 4.58 and 4.61), it can be seen that the scapular body is broader for seven year old juveniles than for the six year old. The lateral border is straighter for seven year olds, while the medial border is slightly more rounded for seven year olds. The superior border of the supraspinous fossa is slightly more concave for seven year old juveniles, while the medial border of the supraspinous fossa is more rounded for seven year olds.

The differences between the scapulae of six and seven year old juveniles can be seen more clearly when viewed in vector mode (Figure 4.62). From this vector thin- plate spline it can be seen that six and seven year old juveniles differ most at landmarks

1, 3 – 7, 10, 13, 15, 16, 20 and 21. Landmarks 1 and 3 – 6 form part of the lateral border of the scapula, which is straighter for seven year old juveniles, with the inferior angle being slightly sharper for seven year olds. Landmarks 5 and 7 form part of the medial border of the scapula, which is longer and slightly straighter for seven year old juveniles than for the six year old. These differences between the lateral and medial borders of six and seven year old juveniles make the scapular body seem broader for seven year old juveniles. This seems to contrast with the trend seen in younger individuals with the scapular body seemingly becoming narrower with each consecutive year. Landmarks 10, 13 and 16 form part of the superior border of the supraspinous fossa, while landmarks 7, 15, 20 and 21 form part of the medial border of the supraspinous fossa. The superior border of the supraspinous fossa is somewhat more concave for seven year old juveniles than for the six year old, while the medial border of the supraspinous fossa is more rounded for seven year old juveniles. This seems to contrast once again with the trend previously seen where the superior border of the supraspinous fossa became less concave, while the medial border of the supraspinous fossa became straighter with advancing age. It should be kept in mind that the sample is small.

4.3.1.6 Seven and eight year old juveniles

Figure 4.63 is the Relative Warp Analysis for the seven and eight year old juveniles. Numbers 1 and 2 represent the seven year old juveniles, while 3 represents the only eight year old juvenile. Separation can be seen with the seven year old juveniles situated in the lower left and right quadrants and the eight year old situated in the upper left quadrant, although it should be kept in mind that the sample size is small.

When the consensus thin-plate splines for the scapulae of seven and eight year old juveniles are compared (Figures 4.61 and 4.64), it can be seen that the scapular body

is wider in the eight year old juvenile. The lateral border of the eight year old juvenile is straighter than that of seven year olds. The inferior angle of the eight year old juvenile is slightly sharper than that of seven year olds. This indicates a trend with the inferior angle becoming sharper for each consecutive age group. The medial border is straighter for the eight year old juvenile than for seven year olds. The superior border of the supraspinous fossa is slightly more concave for the eight year old than for seven year olds, while the medial border of the supraspinous fossa is straighter for the eight year old juvenile than for seven year olds.

The differences between the scapulae of seven and eight year old juveniles can be seen more clearly when viewed in vector mode (Figure 4.65). From this vector thin-plate spline it can be seen that seven and eight year old juveniles differ most at landmarks 1, 3 – 7, 10, 11, 13 – 15, 17, 20, and 21. All the landmarks seem to rotate clockwise in the eight year old juvenile. Landmarks 1 and 3 – 6 form part of the lateral border of the scapula, with all the landmarks seemingly moving upwards and lateral in the eight year old. This makes the lateral border of the eight year old seem straighter than that of the seven year old juveniles. The inferior angle is also sharper for the eight year old juvenile. Landmarks 5 and 7 form part of the medial border of the scapula, which is straighter for the eight year old juvenile. Landmarks 10, 11, 17 and 13 form part of the superior border of the supraspinous fossa, while landmarks 7, 11, 14, 15, 20 and 21 form part of the medial border of the supraspinous fossa. The superior border of the supraspinous fossa is somewhat more concave for the eight year old juvenile, while the medial border of the supraspinous fossa is straighter for the eight year old juvenile than for seven year olds.

4.3.1.7 Eight and nine year old juveniles

No Relative Warp Analysis could be conducted for the eight and nine year old juveniles, due to the small number of individuals in each age group (one eight year old and one nine year old).

When the consensus thin-plate splines for the scapulae of the eight and nine year old juveniles are compared (Figures 4.64 and 4.66), it can be seen that the scapular body of nine year old juveniles is narrower than that of eight year olds. The lateral border is straighter for the nine year old juvenile, while the medial border is also straighter for the nine year old. The superior border of the supraspinous fossa is more concave for the nine year old juvenile, while the medial border of the supraspinous fossa is slightly more rounded for the nine year old juvenile.

The differences between the scapulae of the eight and nine year old juveniles can be seen more clearly when viewed in vector mode (Figure 4.67). From this vector thin-plate spline, it can be seen that the scapulae of eight and nine year old juveniles differ most at landmarks 2 – 6, 8 – 12, 14 and 16 – 20. Landmarks 2 – 6 form part of the lateral border of the scapula, which is straighter for the nine year old juvenile. All the landmarks of the lateral border are situated more medially for the nine year old juvenile, while the inferior angle seems slightly more rounded than that of the eight year old juvenile. This seems to contrast with the previously observed trend where the inferior angle became sharper with each consecutive year. Landmarks 5, 8 and 9 form part of the medial border of the scapula, which seems more rounded for the nine year old juvenile, with all the landmarks, except landmark 7 seeming to be more medially situated than in the eight year old. These changes in the lateral and medial borders of eight and nine year old juveniles indicate that the scapular body expands medially and downwards. Landmarks 10 – 12, 16 and 17 form part of the superior border of the supraspinous

fossa, while landmarks 11, 14 and 18 – 20 form part of the medial border of the supraspinous fossa. The superior border of the supraspinous fossa is more concave for the nine year old juvenile than for the eight year old, with all the landmarks seeming to be more laterally situated than for the eight year old. The medial border of the supraspinous fossa is much the same for the eight and nine year old juveniles. Landmarks 7, 15, 20 and 21 seem to be more rounded for the nine year old, while landmarks 11, 14 and 19 seem to be more laterally situated than in the eight year old juvenile.

4.3.1.8 Nine and 10 year old juveniles

No Relative Warp Analysis could be conducted for nine and 10 year old juveniles, due to the small sample size (only one individual in each group). When the consensus thin- plate splines for nine and 10 year old juveniles are compared (Figures 4.66 and 4.68), it can be seen that the scapular body is slightly narrower for the 10 year old juvenile than for the nine year old. The lateral border is more curved for the 10 year old juvenile than for the nine year old, while the inferior angle is slightly sharper than in the nine year old. The medial border is straighter for the 10 year old juvenile than for the nine year old. The superior border of the supraspinous fossa is more concave for the 10 year old juvenile, while the medial border of the supraspinous fossa is less curved than for the nine year old.

The differences between the scapulae of the nine and 10 year old juveniles can be seen more clearly when viewed in vector mode (Figure 4.69). From this vector thin-plate spline it can be seen that the two nine and 10 year old juveniles differ most at landmarks 1 – 3, 5 – 10, 12, 15 – 17, 19 and 21. Most of the landmarks rotate anticlockwise in the 10 year old juvenile. This contrasts with the results seen for the

seven and eight year old juveniles, where the landmarks rotated clockwise in the eight year old. Landmarks 1 – 3, 5 and 6 form part of the lateral border of the scapula, which is more curved in the 10 year old juvenile and not as elongated as in the nine year old. Landmarks 1 and 3 are situated lower in the 10 year old, while landmarks 2 and 4 seem to be situated more laterally, contrasting with the trend observed in younger individuals where the lateral border became straighter and more elongated for each consecutive age group. The inferior angle also seems slightly sharper for the 10 year old juvenile, continuing the trend observed in the younger individuals, up to eight years, where the inferior angle became sharper for each consecutive year. Landmarks 5 and 7 – 9 form the outline of the medial border of the scapula, which is straighter in the 10 year old juvenile. Landmarks 7 – 9 seem to be situated more laterally and superiorly, while landmark 5 is situated more laterally in the 10 year old juvenile. These differences between the lateral and medial borders make the scapular body seem narrower for the 10 year old juvenile than that of the nine year old. Landmarks 10, 12, 16 and 17 form part of the superior border of the supraspinous fossa, while landmarks 7, 15, 19 and 21 form part of the medial border of the supraspinous fossa. The superior border of the supraspinous fossa shows little change from the nine to 10 year old juveniles with the concave curve staying the same. The medial border of the supraspinous fossa is slightly straighter for the 10 year old juvenile. The trend seen in the younger juveniles seems to continue, with the superior border of the supraspinous fossa seemingly becoming less concave in each consecutive year, while the medial border of the supraspinous fossa becomes straighter in each consecutive year.

4.3.1.9 Ten and 12 year old juveniles

As no 11 year old samples could be found, the 10 and 12 year old juveniles were compared with each other. Figure 4.70 is the Relative Warp Analysis for 10 and 12 year old juveniles. Number 1 represents the only 10 year old juvenile, while 2 – 4 represent the 12 year old juveniles. Separation exists, with the 10 year old juvenile situated in the lower right quadrant and the 12 year old juveniles situated in the upper and lower left, as well as the upper right quadrants.

When the consensus thin- plate splines for the scapulae of 10 and 12 year old juveniles are compared (Figures 4.68 and 4.71), it can be seen that the scapula is larger and broader in 12 year old juveniles than in the 10 year old juvenile. The lateral border of 12 year old juveniles is longer and slightly straighter than that of the 10 year old. The medial border is more rounded for 12 year old juveniles than for the 10 year old. The superior border of the supraspinous fossa is less concave or almost straight for 12 year olds, while the medial border of the supraspinous fossa is almost straight for 12 year old juveniles.

The differences between the scapulae of 10 and 12 year old juveniles can be seen more clearly when viewed in vector mode (Figure 4.72). From this vector thin- plate spline it can be seen that the scapulae of 10 and 12 year old juveniles differ most at landmarks 1, 3, 4, 7, 8, 10, 11, 12, 14 – 16 and 18 – 21. Landmarks 1, 3 and 4 form part of the lateral border of the scapula, which is longer and straighter in 12 year old juveniles. Landmarks 7 and 8 form part of the medial border of the scapula, which is more rounded and broader for 12 year olds. The lateral border of 12 year old juveniles moves towards superior, while the medial border elongates. Landmarks 10 – 12, 16 and 18 form part of the superior border of the supraspinous fossa, while landmarks 7, 11, 14, 15 and 19 – 21 form the outline of the medial border of the supraspinous fossa. The

superior border of the supraspinous fossa is much less concave in 12 year old juveniles, being almost straight, while the medial border of the supraspinous fossa is straighter in 12 year old juveniles than in the 10 year old.

4.3.1.10 Twelve and 13 year old juveniles

Figure 4.73 is the Relative Warp Analysis for 12 and 13 year old juveniles. Numbers 1 – 3 represent the 12 year old juveniles, while 4 – 10 represent the 13 year olds. Some separation exists with the 12 year olds situated in the upper and lower left, as well as the upper right quadrants (one individual each). The 13 year olds are evenly situated in the upper right (three individuals), lower right (two individuals) and lower left (two individuals) quadrants. Some overlap can, however, be seen with number 10 situated at the top of the upper right quadrant, separated from the other 13 year olds by the 12 year old juveniles.

When the consensus thin- plate splines for 12 and 13 year old juveniles are compared (Figures 4.71 and 4.74), the lateral border is longer and somewhat more curved for 13 year old juveniles. The inferior angle also seems slightly sharper in 13 year olds, while the medial border is narrower and slightly straighter. The superior border of the supraspinous fossa is almost straight in 13 year old juveniles, while the medial border of the supraspinous fossa is straighter for 13 year old juveniles than for 12 year olds.

When the 12 and 13 year old scapulae are viewed in vector mode (Figure 4.75), there is little difference between the two age groups.

4.3.1.11 Thirteen and 14 year old juveniles

Figure 4.76 is the Relative Warp Analysis for 13 and 14 year old juveniles. Numbers 1 – 7 represent the 13 year old juveniles, while 8 – 10 represent the 14 year old juveniles. The 13 year old juveniles seem to be grouped together to the right, while the 14 year olds are mainly situated to the left, but with one outlier. Thus, no clear separation can be seen.

When the consensus thin- plate splines for the scapulae of 13 and 14 year old individuals are compared (Figures 4.74 and 4.77), it can be seen that the scapular shape of 14 year old juveniles is more elongated and slightly broader than that of 13 year olds. The lateral border is longer and more curved for 14 year old juveniles, while the inferior angle is more rounded than that of 13 year olds. The medial border of 14 year old juveniles is longer and straighter than that of 13 year olds. The superior border of the supraspinous fossa is more convex for 14 year old juveniles, while the medial border of the supraspinous fossa is more rounded for 14 year old juveniles than for 13 year olds. This contrasts with the trends observed in the younger individuals, where the lateral border was found to become straighter and more elongated for each consecutive age group. The superior border of the supraspinous fossa was also found to be concave in the younger juveniles, while the medial border of the supraspinous fossa was found to become straighter for each consecutive age group in the younger juveniles.

When the 13 and 14 year old scapulae are compared in vector mode (Figure 4.78), there is little difference between the two age groups. The biggest difference can be seen in the lateral border, where the landmarks move upwards and laterally for 14 year old juveniles (once again creating the effect of rotation), while the inferior angle seems to move more medially for 14 year old juveniles. During early adolescence there is little change in scapular shape.

4.3.1.12 Fourteen and 15 year old juveniles

Figure 4.79 is the Relative Warp Analysis for 14 and 15 year old juveniles. Numbers 1 – 3 represent the 14 year old juveniles, while 4 – 11 represent the 15 year old juveniles. No clear separation can be seen between the two age groups.

When the consensus thin- plate splines for the scapulae of 14 and 15 year old juveniles, as well as the vector diagram for the two age groups are compared (Figures 4.77, 4.80 and 4.81), little difference can be seen between the two age groups. The only clearly distinguishable differences can be seen in the lateral border which becomes less straight in the 15 year old juveniles, as well as the inferior angle which moves more laterally in the same group

4.3.1.13 Fifteen and 16 year old juveniles

Figure 4.82 is the Relative Warp Analysis for 15 and 16 year old juveniles. Numbers 1 – 8 represent the 15 year old juveniles, while 9 – 16 represent the 16 year old juveniles. No clear separation can be seen between the two age groups. It has to be kept in mind that differences between the sexes can also start to influence the results along with the age differences, however there are more males than females in this sample (3 females in the 15 year old sample and 1 in the 16 year old sample). Numbers 1, 3, 6 and 10 represent the females in the two age groups. No clear separation can be seen between the two sexes, although the females tend to group more to the right side.

Once again little difference can be seen the consensus thin- plate spline for the 15 and 16 year old juveniles, as well as the vector diagram for the two age groups (Figures 4.80, 4.83 and 4.84). The only clearly visible difference can be seen in the supraspinous fossa of the 16 year old juveniles which enlarges slightly towards superior.

4.3.1.14 Sixteen and 17 year old juveniles

Figure 4.85 is the Relative Warp Analysis for 16 and 17 year old juveniles. Numbers 1 – 8 represent the 16 year old juveniles, while 9 – 18 represent the 17 year olds. Separation exists with the 16 year old juveniles situated mostly to the left and the 17 year olds mostly to the right with two outliers present (numbers 13 and 14). The individuals in the two age groups consist mainly of males with only one female present in each age group (number 2 for the 16 year olds and 18 for the 17 year olds).

When the consensus thin- plate splines for the scapulae of 16 and 17 year old juveniles are compared (Figures 4.83 and 4.86), it can be seen that scapular shape for 17 year old juveniles is slightly narrower than for 16 year olds. The lateral border is less curved for 17 year old juveniles, while the inferior angle is more rounded. The medial border is longer and straighter for 17 year old juveniles. The superior border of the supraspinous fossa is slightly less convex for 17 year old juveniles, while the medial border of the supraspinous fossa is more rounded than for 16 year old juveniles.

The differences between the scapulae of 16 and 17 year old juveniles can be more clearly seen when viewed in vector mode (Figure 4.87). From this vector thin-plate spline it seems that there is a clear difference between 16 and 17 year old juveniles at all the landmarks, especially landmarks 1 – 7, 9 – 14 and 16 – 19. Landmarks 1 – 6 form the outline of the lateral border of the scapula, which is longer and straighter for 17 year old juveniles, while the inferior angle is rounder than that of 16 year olds. Once again the landmarks of the lateral border seem to rotate clockwise for the 17 year old juveniles, with landmark 1 situated higher than the superior border. Landmarks 5, 7 and 9 form part of the medial border of the scapula, which is longer and straighter for 17 year old juveniles. Landmarks 10 – 13 and 16 – 18 form the outline of the superior border of the supraspinous fossa, while landmarks 7, 11, 14 and 19 form part of the

medial border of the supraspinous fossa. The superior border of the supraspinous fossa is less convex for 17 year old juveniles, while the medial border of the supraspinous fossa is more rounded than that of 16 year olds.

4.3.1.15 Seventeen and 18 year old juveniles

Figure 4.88 is the Relative Warp Analysis for 17 and 18 year old juveniles. Numbers 1 – 10 represent the 17 year old juveniles, while 11 – 21 represent the 18 year olds. This RWA shows almost complete overlap and no separation can be seen. Once again the sample consists mainly of males with only one female present in the 17 year old group (number 10) and two females present in the 18 year old group (numbers 13 and 18).

When the consensus thin- plate splines for the scapulae of 17 and 18 year old juveniles, as well as the vector diagram for the two age groups are compared (Figures 4.86, 4.89 and 4.90), little difference can be seen between the two age groups. Once again, landmark 1 is situated higher than the superior border of the supraspinous fossa.

4.3.1.16 Eighteen and 19 year old juveniles

Figure 4.91 is the Relative Warp Analysis for 18 and 19 year old juveniles. Numbers 1 – 11 represent the 18 year old juveniles, while 12 – 22 represent the 19 year olds. Once again this RWA shows almost complete overlap and no clear separation can be seen. The 18 year old sample consists mostly of males with only two females present (numbers 3 and 8), while the 19 year old sample consists mainly of females with only three males present (numbers 13, 14 and 18).

Once again little difference can be seen the consensus thin- plate spline for the 18 and 19 year old juveniles, as well as the vector diagram for the two age groups (Figures

4.89, 4.92 and 4.93). The biggest differences can be seen in the lateral border with landmark 1 once again situated higher for 19 year old juveniles, while the inferior angle is situated more laterally for 19 year olds.

4.3.1.17 Results obtained from grouped juveniles

From the results obtained from one to 19 year old juveniles, as described above, it seemed that the shape of the superior border of the supraspinous fossa changed after 10 years of age from concave to convex. As a result of this shape change, the consensus thin-plate splines of the younger individuals (1 – 10 years) and the older individuals (12 – 19 years) were compared. Vector thin-plate splines, as well as a Relative Warp Analysis were constructed for these two groups. Sheets' Integrated Morphometric Package (IMP) TwoGroup-program and Canonical Variates Analysis-program (CVAGen6) were used for calculation of significance levels.

Figure 4.94 is the Relative Warp Analysis for 1 – 10 and 12 – 19 year old juveniles. Numbers 1 – 20 represent the 1 – 10 year old juveniles, while 21 – 81 represent the 12 – 19 year olds. Clear separation exists with the younger juveniles situated towards the right and the older individuals to the left.

When the consensus thin-plate splines for the younger and older juveniles, as well as the vector diagram for the two age groups are compared (Figures 4.95, 4.96 and 4.97), it is clear that the scapular body is shorter and broader for younger juveniles, while being more elongated and narrower for the older juveniles. The lateral border is more curved for younger juveniles than for older juveniles, while the inferior angle is sharper in older juveniles. The medial border is straighter and longer and the body of the scapula is narrower in older juveniles. The superior border of the supraspinous fossa is

concave in the younger juveniles and convex in the older juveniles, while the medial border of the supraspinous fossa is straighter in older juveniles.

Figure 4.98 represents the TwoGroup BC Superimposition plot for the younger and older individuals. The younger individuals are indicated by blue circles and older individuals by red squares. Landmarks 1 and 2 are fixed at (0,0) and (1,0) respectively. Some separation exist along the medial border, but the greatest separation can be seen along the superior border with the landmarks indicating this border being less tightly clustered than those along the lateral border. The superior border of the younger individuals is situated relatively higher than landmark 1, while in the older group the superior border is situated on the same level, or lower than landmark 1. These results seem to correspond with the results obtained from the thin- plate splines, although the differences along the lateral border were seen more clearly on the thin- plate splines than on the TwoGroup BC Superimposition plot.

Goodall's F- test and Hotelling's T^2 - test were performed using the TwoGroup program. Goodall's F- test yielded a p- value of 0.0, and Hotelling's T^2 - test, however, yielded a p-value of 2.15. These values indicate that there is a statistically significant difference between the scapular shapes of the younger (1 – 10 year old) and older (12 – 19 year old) juveniles.

Figure 4.99 is a representation of the CVA plot for the two population groups, with older and younger juveniles indicated by blue crosses and black dots respectively. Separation can be seen along all the borders with the concave shape of the superior border of younger juveniles, and the convex shape of the superior border of older juveniles clearly visible. The inferior and lateral angles also separate between the younger and older juveniles with the inferior angle moving lower in older juveniles and

the lateral angle moving upwards in older juveniles. The infraspinous body of the scapula is narrower in older than in younger juveniles.

Figure 4.100 is the mean of the CVA plot for the two juvenile population groups, with the younger juveniles once again indicated by black circles and the older juveniles by blue crosses. The larger black circle and blue cross in the centre represent the mean scapular shape for the younger and older juveniles respectively. Clear separation can be seen between the two age groups and no overlap is present.

Based on the above mentioned results (obtained from the TwoGroup analysis, as well as the TwoGroup BC Superimposition plot and the two CVA plots) a CVA analysis was carried out to test the accuracy with which a scapula can be categorised within the younger (less than 10 years) or older group (older than 12 years). Table 4.2 represents the accuracies obtained from this analysis. All 20 of the younger individuals (1 – 10 years) were correctly assigned to the younger group, while 60 of the 61 older individuals (12 – 19 years) were correctly assigned to the older group (98.36%). This gives an indication of the degree to which these two groups differ.

4.3.2 The lateral border of juveniles (landmarks 1 – 6)

In order to determine where the largest amount of change takes place during growth, the three borders of the scapula were studied separately. The consensus thin-plate splines for the lateral borders of each consecutive year were compared with each other (e.g. one and two year old juveniles). Relative Warp Analyses as well as vector thin-plate splines were also drawn up for the lateral border of each consecutive age group.

Figure 4.101 is the Relative Warp Analysis for the lateral border of the whole juvenile sample. From this RWA it can be seen that some separation may exist between

the various age groups, although no clear pattern can be distinguished. When the Relative Warp Analysis for the consensus of the juvenile age groups (Figure 4.102) is observed, the separation between the different age groups becomes clearer.

4.3.2.1 Lateral border: One and two year old individuals

Figure 4.103 is the Relative Warp Analysis for the lateral border of one and two year old juveniles. Numbers 1 – 6 represent the one year old juveniles, while 7 and 8 represent the two year olds. Little separation can be seen between these two age groups.

Figure 4.104 is the consensus thin- plate spline (in vector mode) to indicate the separation between the lateral borders of one and two year old juveniles. From this vector thin- plate spline it can be seen that the lateral borders of one and two year old juveniles differ most at landmarks 2 and 5. The lateral border of two year old juveniles is longer and slightly straighter than for one year olds.

4.3.2.2 Lateral border: Two and three year old juveniles

Figure 4.105 is the Relative Warp Analysis for the lateral border of two and three year old juveniles. Numbers 1 and 2 represent the two year old juveniles, while 3 – 5 represent the three year old juveniles. Some separation exists with the two year old juveniles situated in the lower left and right quadrants, while the three year olds are evenly dispersed in the upper left, as well as the lower left and right quadrants.

Figure 4.106 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of two and three year old juveniles. From this vector thin- plate spline, it can be seen that the lateral border of three year old juveniles is longer and straighter than that of two year olds.

4.3.2.3 Lateral border: Three and four year old juveniles

Figure 4.107 is the Relative Warp Analysis for the lateral border of three and four year old juveniles. Numbers 1 – 3 represent the three year old juveniles, while 4 – 6 represent the four year old juveniles. Separation exists with three year old juveniles situated more to the right and four year old juveniles situated to the left.

Figure 4.108 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of three and four year old juveniles. From this vector thin- plate spline it can be seen that the lateral border of four year old juveniles is longer and straighter for four year old juveniles than for three year olds.

4.3.2.4 Lateral border: Four and six year old juveniles

Figure 4.109 is the Relative Warp Analysis for the lateral border of four and six year old juveniles. Numbers 1 – 3 represent the four year old juveniles, while 4 represent the only six year old juvenile. Separation exists with the four year old juveniles situated to the left and the six year old situated to the right. It should be kept in mind, however that the sample size is small.

Figure 4.110 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of four and six year old juveniles. From this vector thin- plate spline it seems that the lateral border is longer and straighter in the six year old juvenile.

4.3.2.5 Lateral border: Six and seven year old juveniles

Figure 4.111 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of six and seven year old juveniles. From this vector diagram it seems that the lateral border of seven year old juveniles is longer and

straighter than that of the six year old. A trend can be observed with the lateral border seemingly becoming longer and straighter for each consecutive age group.

4.3.2.6 Lateral border: Seven and eight year old juveniles

Figure 4.112 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of seven and eight year old juveniles. From this vector diagram it can be seen that the lateral border of the eight year old juvenile is longer and straighter than that of seven year olds.

4.3.2.7 Lateral border: Eight and nine year old juveniles

Figure 4.113 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of the eight and nine year old juveniles. From this vector diagram it can be seen that the lateral border of nine year old juveniles is more curved than that of eight year olds. This seems to contrast with the trend observed thus far, where the lateral border became straighter for each consecutive age group.

4.3.2.8 Lateral border: Nine and ten year old juveniles

Figure 4.114 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of the nine and ten year old juveniles. From this vector diagram it can be seen that the two age groups are very similar, but the lateral border of the 10 year old juvenile is longer and more curved than that of the nine year old.

4.3.2.9 Lateral border: 10 and 12 year old juveniles

Figure 4.115 is the Relative Warp Analysis for the lateral border of 10 and 12 year old juveniles. Number 1 represents the 10 year old juvenile, while 2 – 4 represent the 12 year old juveniles. Separation exists with the 10 year old juvenile situated in the upper left quadrant and the 12 year old juveniles situated in the upper and lower right, as well as the lower left quadrants.

Figure 4.116 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of 10 and 12 year old juveniles. From this vector diagram little difference can be seen between the two age groups. The lateral border of 12 year old juveniles seems longer and slightly straighter than that of the 10 year old.

4.3.2.10 Lateral border: 12 and 13 year old juveniles

Figure 4.117 is the Relative Warp Analysis for the lateral border of 12 and 13 year old juveniles. Numbers 1 – 3 represent the 12 year old juveniles, while 4 – 10 represent the 13 year old juveniles. Overlap is present and no clear separation can be seen between the two age groups.

Figure 4.118 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of 12 and 13 year old juveniles. From this vector diagram no clear difference can be seen between the two age groups.

4.3.2.11 Lateral border: 13 and 14 year old juveniles

Figure 4.119 is the Relative Warp Analysis for the lateral border of 13 and 14 year old juveniles. Numbers 1 – 7 represent the 13 year old juveniles, while 8 – 10 represent the 14 year olds. Some separation exists with the 13 year old juveniles situated in all four quadrants (one individual each in the upper and lower left, as well as the

upper right quadrant and four in the lower right quadrant). The 14 year olds are situated in the upper and lower left quadrants (one individual in the lower left quadrant and two in the upper left quadrant). Overlap is, however, present.

Figure 4.120 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of 13 and 14 year old juveniles. From this vector diagram little difference can be seen between the two age groups. The lateral border of 14 year old juveniles is slightly straighter than that of 13 year old juveniles. The inferior angle is situated more medially for 14 year old juveniles than for 13 year olds.

4.3.2.12 Lateral border: 14 and 15 year old juveniles

Figure 4.121 is the Relative Warp Analysis for the lateral border of 14 and 15 year old juveniles. Numbers 1 – 3 represent the 14 year old juveniles, while 4 – 11 represent the 15 year old juveniles. No clear separation can be seen between the two age groups.

Figure 4.122 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of 14 and 15 year old juveniles. Little difference can be seen between the two age groups.

4.3.2.13 Lateral border: 15 and 16 year old juveniles

Figure 4.123 is the Relative Warp Analysis for the lateral border of 15 and 16 year old juveniles. Numbers 1 – 8 represent the 15 year old juveniles, while 9 – 16 represent the 16 year old juveniles. The landmarks indicating the two age groups overlap totally and no separation can be seen.

Figure 4.124 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of 15 and 16 year old juveniles. No clear difference can be observed between the two age groups.

4.3.2.14 Lateral border: 16 and 17 year old juveniles

Figure 4.125 is the Relative Warp Analysis for the lateral border of 16 and 17 year old juveniles. Numbers 1 – 8 represent the 16 year old juveniles, while 9 – 18 represent the 17 year olds. The two age groups overlap each other totally and no separation can be seen.

Figure 4.126 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of 16 and 17 year old juveniles. Little difference can be seen between these two age groups.

4.3.2.15 Lateral border: 17 and 18 year old juveniles

Figure 4.127 is the Relative Warp Analysis for the lateral border of 17 and 18 year old juveniles. Numbers 1 – 10 represent the 17 year old juveniles, while 11 – 21 represent the 18 year old juveniles. The two age groups overlap each other and no separation can be seen.

Figure 4.128 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of 17 and 18 year old juveniles. Once again, no clear difference can be observed between the two age groups.

4.3.2.16 Lateral border: 18 and 19 year old juveniles

Figure 4.129 is the Relative Warp Analysis for the lateral border of 18 and 19 year old juveniles. Numbers 1 – 11 represent the 18 year old juveniles, while 12 – 22 represent the 19 year olds. No separation can be seen between the two age groups.

Figure 4.130 is the consensus thin- plate spline (in vector mode) to show the separation between the lateral borders of 18 and 19 year old juveniles. Little difference can be seen between the two age groups. The lateral border of 19 year old juveniles is straighter and longer than that of 18 year olds.

4.3.2.17 Summary: Lateral border of juveniles

The lateral border was found to remain constant with advancing age. It became slightly straighter and more elongated with progressing age in the younger juveniles, but after 12 years of age the lateral border shows little change.

4.3.3 The medial border of juveniles (landmarks 5, 7 – 9)

The consensus thin- plate splines for the medial borders of each consecutive year were compared with each other (e.g., one and two year old juveniles). Relative Warp Analyses as well as vector thin- plate splines were drawn up for the medial border of each consecutive age group.

Figure 4.131 is the Relative Warp Analysis for the medial border of the whole juvenile sample. From this RWA it can be seen that separation exists between the various age groups, although no clear pattern can be distinguished. The younger individuals seem to be situated to the left and more to the top than the older individuals. When the Relative Warp Analysis for the consensus of the juvenile age groups (Figure 4.132) is observed, the separation between the different age groups becomes clearer.

4.3.3.1 Medial border: One and two year old individuals

Figure 4.133 is the Relative Warp Analysis for the medial border of one and two year old juveniles. Numbers 1 – 6 represent the one year old juveniles, while 7 and 8 represent the two year olds. Some separation exists, although not clearly visible, with the one year old juveniles situated in the upper and lower left, as well as the upper right quadrants (one individual in the upper right quadrant, two in the upper left quadrant and three in the lower left quadrant). The two year old juveniles are situated in the lower left and right quadrants.

Figure 4.134 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of one and two year old juveniles. From this vector thin- plate spline it can be seen that the medial border of two year old juveniles expands inferiorly.

4.3.3.2 Medial border: Two and three year old juveniles

Figure 4.135 is the Relative Warp Analysis for the medial border of two and three year old juveniles. Numbers 1 and 2 represent the two year old juveniles, while 3 – 5 represent the three year olds. Separation exists with the two year old juveniles situated to the left and the three year old juveniles situated lower.

Figure 4.136 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of two and three year old juveniles. From this vector diagram it can be seen that the medial border of three year old juveniles expands from superior- medial to inferio-lateral.

4.3.3.3 Medial border: Three and four year old juveniles

Figure 4.137 is the Relative Warp Analysis for the medial border of three and four year old juveniles. Numbers 1 – 3 represent the three year old juveniles, while 4 – 6 represent the four year olds. No clear separation can be seen as the two age groups overlap one another.

Figure 4.138 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of three and four year old juveniles. From this vector thin- plate spline it was found that the two age groups are very similar.

4.3.3.4 Medial border: Four and six year old juveniles

Figure 4.139 is the Relative Warp Analysis for the medial border of four and six year old juveniles. Numbers 1 – 3 represent the four year old juveniles, while 4 represents the single six year old. Separation exists with the four year old juveniles situated in the upper and lower left, as well as the lower right quadrants. The six year old is situated in the upper left quadrant.

Figure 4.140 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the four and six year old juveniles. Little difference can be seen between the two age groups.

4.3.3.5 Medial border: Six and seven year old juveniles

Figure 4.141 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the six and seven year old juveniles. From this vector thin- plate spline it can be seen that the medial borders of six and seven year old juveniles differ most at landmarks 5 and 7.

The medial border of seven year old juveniles is slightly longer and straighter than that of six year olds. The most inferior point of the medial border of seven year old juveniles seems to move in the direction of the upper most medially situated point.

4.3.3.6 Medial border: Seven and eight year old juveniles

Figure 4.142 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the seven and eight year old juveniles. The medial border of the eight year old juvenile is longer and more curved than that of seven year olds. This seems to contrast with the results seen in the six and seven year old juveniles where the medial border became longer and straighter.

4.3.3.7 Medial border: Eight and nine year old juveniles

Figure 4.143 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the eight and nine year old juveniles. The medial border of the nine year old juvenile is longer and more curved than that of the eight year old. The differences between the eight and nine year old juveniles are similar to the results seen in the six and seven year old juveniles. The medial border of the nine year old is broader than that of the eight year old with landmark 5 once again seeming to move underneath landmark 7.

4.3.3.8 Medial border: Nine and 10 year old juveniles

Figure 4.144 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the nine and 10 year old juveniles. Little difference can be seen between the two age groups. The medial border of the 10 year old

juvenile is slightly longer and more concavely curved than that of the nine year old juvenile.

4.3.3.9 Medial border: 10 and 12 year old juveniles

Figure 4.145 is the Relative Warp Analysis for the medial border of 10 and 12 year old juveniles. Number 1 represents the 10 year old juvenile, while 2 – 4 represent the 12 year olds. Separation exists with the 10 year old juvenile situated in the upper left quadrant, while the 12 year old juveniles are situated in the upper and lower right, as well as the lower left quadrants.

Figure 4.146 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the 10 and 12 year old juveniles. The medial border of 12 year old juveniles is straighter than that of the 10 year old. No clear trends can, however, be distinguished.

4.3.3.10 Medial border: 12 and 13 year old juveniles

Figure 4.147 is the Relative Warp Analysis for the medial border of 12 and 13 year old juveniles. Numbers 1 – 3 represent the 12 year old juveniles, while 4 – 10 represent the 13 year olds. No clear separation can be seen as the two age groups overlap one another.

Figure 4.148 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the 12 and 13 year old juveniles. The medial border of 13 year old juveniles is longer and more curved than that of 12 year olds. This once again resembles the trend seen in the six to seven and eight to nine age groups, where landmark 5 seemed to move medially to be situated more underneath landmark 7.

4.3.3.11 Medial border: 13 and 14 year old juveniles

Figure 4.149 is the Relative Warp Analysis for the medial border of 13 and 14 year old juveniles. Numbers 1 – 7 represent the 13 year old juveniles, while 8 – 10 represent the 14 year olds. Some separation exists with the 13 year old juveniles situated in the upper and lower right, as well as the upper left quadrants (one individual in the lower right quadrant, two in the upper left quadrant and four in the upper right quadrant). The 14 year old juveniles are situated in the upper and lower left, as well as the lower right quadrants.

Figure 4.150 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the 13 and 14 year old juveniles. The medial border of 14 year old juveniles is straighter than that of 13 year olds. This contrasts once again with the trend observed in the 6 – 7, 8 – 9 and 12 – 13 year old age groups, where the medial border became longer and more curved.

4.3.3.12 Medial border: 14 and 15 year old juveniles

Figure 4.151 is the Relative Warp Analysis for the medial border of 14 and 15 year old juveniles. Numbers 1 – 3 represent the 14 year old juveniles, while 4 – 11 represent the 15 year olds. Separation exists with the 14 year old juveniles situated in the lower left and right quadrants and the 15 year olds more to the upper parts.

Figure 4.152 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the 14 and 15 year old juveniles. Little difference can be seen between the two age groups, with the medial border of 15 year old juveniles slightly shorter than that of 14 year olds.

4.3.3.13 Medial border: 15 and 16 year old juveniles

Figure 4.153 is the Relative Warp Analysis for the medial border of 15 and 16 year old juveniles. Numbers 1 – 8 represent the 15 year old juveniles, while 9 – 16 represent the 16 year olds. No clear separation can be seen as overlap is present between the two age groups.

Figure 4.154 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the 15 and 16 year old juveniles. No clear difference can be seen between the two age groups.

4.3.3.14 Medial border: 16 and 17 year old juveniles

Figure 4.155 is the Relative Warp Analysis for the medial border of 16 and 17 year old juveniles. Numbers 1 – 8 represent the 16 year old juveniles, while 9 – 18 represent the 17 year olds. Some separation can be seen, but the two age groups overlap each other.

Figure 4.156 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the 16 and 17 year old juveniles. Once again, no clear difference can be seen between the two age groups.

4.3.3.15 Medial border: 17 and 18 year old juveniles

Figure 4.157 is the Relative Warp Analysis for the medial border of 17 and 18 year old juveniles. Numbers 1 – 10 represent the 17 year old juveniles, while 11 – 21 represent the 18 year old juveniles. No clear separation can be seen as the two age groups overlap one another totally.

Figure 4.158 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the 17 and 18 year old juveniles. The two age groups seem to be more or less identical.

4.3.3.16 Medial border: 18 and 19 year old juveniles

Figure 4.159 is the Relative Warp Analysis for the medial border of 18 and 19 year old juveniles. Numbers 1 – 11 represent the 18 year old juveniles, while 12 – 22 represent the 19 year old juveniles. The two age groups overlap one another and no separation can be seen.

Figure 4.160 is the consensus thin- plate spline (in vector mode) to show the separation between the medial borders of the 18 and 19 year old juveniles. Little difference can be seen between the two age groups.

4.3.3.17 Summary: Medial border of juveniles

The medial border of the juvenile scapula remained constant during early childhood up to the age of six. During older childhood and early adolescence (seven to 15 years old) the medial border became longer and varied between straight and curved, with no clear directional pattern. In the older adolescents (15 – 19 years old) the shape of the medial border remained constant showing little change.

4.3.4 The supraspinous fossa of juveniles (landmarks 7, 10 – 21)

The consensus thin- plate splines for the supraspinous borders of each consecutive year were compared with each other (e.g., one and two year old juveniles). Relative Warp Analyses as well as vector thin- plate splines were drawn up for the supraspinous border of each consecutive age group.

Figure 4.161 is the Relative Warp Analysis for the supraspinous border of the whole juvenile sample. From this RWA it can be seen that separation exists between the various age groups, although no clear pattern can be distinguished. When the Relative Warp Analysis for the consensus of the juvenile age groups (Figure 4.162) is observed, the separation between the different age groups becomes clearer. The younger juveniles (up to 10 years of age) are situated to the right, with the exception of two outliers. The older juveniles (ages 12 and up) are situated to the left.

4.3.4.1 Supraspinous fossa: One and two year old individuals

Figure 4.163 is the Relative Warp Analysis for the supraspinous border of one and two year old juveniles. Numbers 1 – 6 represent the one year old juveniles, while 7 and 8 represent the two year olds. Separation exists with the one year old juveniles situated more to the left and the two year old juveniles to the right.

Figure 4.164 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the one and two year old juveniles. From this vector thin- plate spline it can be seen that the supraspinous fossae of one and two year old juveniles differ most at landmarks 7, 10 – 13, 18, 20 and 21. Landmarks 10 – 13 and 18 form part of the superior border, while landmarks 7, 11, 20 and 21 form part of the medial border. The superior border of the supraspinous fossa is slightly more concave for one year old juveniles than for two year olds, forming more of an angle at landmark 18, while the medial border is rounded for both age groups, but slightly more for the two year old juveniles.

4.3.4.2 Supraspinous fossa: Two and three year old juveniles

Figure 4.165 is the Relative Warp Analysis for the supraspinous border of two and three year old juveniles. Numbers 1 and 2 represent the two year old juveniles, while 3 – 5 represent the three year old juveniles. Separation exists with the two year old juveniles situated toward the left and the three year olds situated to the right.

Figure 4.166 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the two and three year old juveniles. From this vector thin- plate spline it can be seen that the superior border of the supraspinous fossa of two year old juveniles is slightly more concave than that of the three year olds, while the medial border is straighter for three year olds. The supraspinous fossa decreases in size from the medial border in three year olds.

4.3.4.3 Supraspinous fossa: Three and four year old juveniles

Figure 4.167 is the Relative Warp Analysis for the supraspinous border of three and four year old juveniles. Numbers 1 – 3 represent the three year old juveniles, while 4 – 6 represent the four year olds. Some separation can be seen with the three year old juveniles situated to the left and the four year olds situated to the right. There is, however, some overlap.

Figure 4.168 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the three and four year old juveniles. From this vector diagram it can be seen that the superior border of the supraspinous fossa of four year old juveniles is straighter than that of three year olds, moving up towards the superior angle of the scapula. The supraspinous fossa decreases in size from the medial border of four year old juveniles.

4.3.4.4 Supraspinous fossa: Four and six year old juveniles

Figure 4.169 is the Relative Warp Analysis for the supraspinous border of four and six year old juveniles. Numbers 1 – 3 represent the four year old juveniles, while 4 represents the six year old juvenile. The two age groups overlap one another and no clear separation can be seen.

Figure 4.170 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the four and six year old juveniles. From this vector thin- plate spline it can be seen that there is little difference between the two age groups. The superior border of the supraspinous fossa of the six year old juveniles is slightly more concave than that of four year olds, while the medial border seems slightly more rounded for the six year old.

4.3.4.5 Supraspinous fossa: Six and seven year old juveniles

Figure 4.171 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the six and seven year old juveniles. The superior border of the supraspinous fossa of seven year old juveniles is slightly more concave than that of the six year old, while the medial border of seven year olds is slightly more curved and seems to expand more medially.

4.3.4.6 Supraspinous fossa: Seven and eight year old juveniles

Figure 4.172 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the seven and eight year old juveniles. The superior border of the supraspinous fossa of the eight year old juvenile is more concave than that of seven year olds, while the medial border is slightly straighter for the

eight year old. The supraspinous fossa of the eight year old juvenile becomes narrower and higher than that of the seven year olds.

4.3.4.7 Supraspinous fossa: Eight and nine year old juveniles

Figure 4.173 is the consensus thin-plate spline (in vector mode) to show the separation between the supraspinous fossae of the eight and nine year old juveniles. The superior border of the supraspinous fossa of the nine year old juvenile is less concave than that of the eight year old, with the superior border moving slightly lower in the nine year old. The medial border seems more curved for the nine year old, with the landmarks moving laterally upwards.

4.3.4.8 Supraspinous fossa: Nine and 10 year old juveniles

Figure 4.174 is the consensus thin-plate spline (in vector mode) to show the separation between the supraspinous fossae of the nine and 10 year old juveniles. From this vector thin-plate spline it seems as if the shape of the supraspinous fossa changes in the 10 year old. Along the superior border landmark 10 is situated lower in the 10 year old than in the nine year old. The superior border forms a slight curve upwards from landmarks 10 to 18. The medial border shows little difference between the nine and 10 year old juveniles.

4.3.4.9 Supraspinous fossa: 10 and 12 year old juveniles

Figure 4.175 is the Relative Warp Analysis for the supraspinous border of 10 and 12 year old juveniles. Number 1 represents the 10 year old juvenile, while 2 – 4 represent the 12 year old juveniles. Separation exists with the 10 year old juvenile situated to the far right and the 12 year olds situated to the left.

Figure 4.176 is the consensus thin-plate spline (in vector mode) to show the separation between the supraspinous fossae of the 10 and 12 year old juveniles. From this vector thin-plate spline the differences between the supraspinous fossae of 10 and 12 year old juveniles can clearly be seen. The superior border of the 12 year old juveniles seems straight, but becomes higher than that of the 10 year old, with landmark 10 situated much higher than landmark 18. The landmarks of the medial border move downwards and more medially in the 12 year olds.

4.3.4.10 Supraspinous fossa: 12 and 13 year old juveniles

Figure 4.177 is the Relative Warp Analysis for the supraspinous border of 12 and 13 year old juveniles. Numbers 1 – 3 represent the 12 year old juveniles, while 4 – 10 represent the 13 year olds. Some separation exists with the 12 year old juveniles situated in the upper left and right quadrants (one individual in the upper right quadrant and two in the upper left quadrant). The 13 year olds are situated in all four quadrants, but are mostly concentrated in the lower parts. There doesn't seem to be any sexual dimorphism between the two age groups. All three of the 12 year old juveniles are female while two of the 13 year olds (numbers 5 and 6) are female. From the RWA little separation can be seen between males and females in the two age groups with the 12 year old females situated in the upper left and right quadrants, while the two 13 year old females are situated in the bottom right quadrant. Overlap is present.

Figure 4.178 is the consensus thin-plate spline (in vector mode) to show the separation between the supraspinous fossae of the 12 and 13 year old juveniles. From this vector diagram little difference can be seen between the two age groups. The superior border of the supraspinous fossa of 13 year old juveniles is straighter than that of 12 year olds, with landmark 10 once again situated higher than landmark 18 in the 13

year olds. The medial border is straighter for 13 year olds, with the landmarks once again moving down and inwards (medially). The supraspinous fossa shows the same trend as observed in the 10 – 12 year group, but to a lesser degree.

4.3.4.11 Supraspinous fossa: 13 and 14 year old juveniles

Figure 4.179 is the Relative Warp Analysis for the supraspinous border of 13 and 14 year old juveniles. Numbers 1 – 7 represent the 13 year old juveniles, while 8 – 10 represent the 14 year olds. Separation exists with the 13 year old juveniles situated more in the lower parts and the 14 year olds more in the upper parts of the graph. As far as sexual dimorphism is concerned, there are two 13 year old females (numbers 2 and 3) and two 14 year old females (numbers 9 and 10). Some separation can be seen between males and females of the two age groups with the 13 year old females situated in the upper left and right quadrants, while the 14 year old females are situated in the upper left and far upper right quadrants. Overlap is present.

Figure 4.180 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the 13 and 14 year old juveniles. The superior border of the supraspinous fossa of 14 year old juveniles is more convex than that of 13 year olds, with landmark 10 of the 14 year olds moving down to become lower than landmark 18. The medial border of 14 year olds seems to expand, with the landmarks moving more laterally.

4.3.4.12 Supraspinous fossa: 14 and 15 year old juveniles

Figure 4.181 is the Relative Warp Analysis for the supraspinous border of 14 and 15 year old juveniles. Numbers 1 – 3 represent the 14 year old juveniles, while 4 – 11 represent the 15 year olds. Some separation exists with the 14 year old juveniles situated

more to the left, with one individual in the right hand side of the graph. The 15 year olds are situated more to the right. The sample consists mostly of males with two 14 year old females (numbers 2 and 3) and three 15 year old females present (numbers 4, 6 and 9). Some separation can be seen with the 14 year old females situated in the upper left quadrant, while the 15 year old females are situated in the lower left and right quadrants. A considerable degree of overlap does, however, exist.

Figure 4.182 is the consensus thin-plate spline (in vector mode) to show the separation between the supraspinous fossae of the 14 and 15 year old juveniles. The same trend can be observed as in the 10 – 12 and 12 – 13 groups. The superior border of the 15 year old juveniles seems almost straight when compared to the 14 year olds, with landmark 10 situated at almost the same level as landmark 18. The medial border of the 15 year olds once again seems to move downwards and medially.

4.3.4.13 Supraspinous fossa: 15 and 16 year old juveniles

Figure 4.183 is the Relative Warp Analysis of the supraspinous border of 15 and 16 year old juveniles. Numbers 1 – 8 represent the 15 year old juveniles, while 9 – 16 represent the 16 year olds. Some separation exists with the 15 year old juveniles mostly situated in the upper and lower right, as well as the lower left quadrants. The medial border seems rounded for both age groups, but slightly more for two year old juveniles. The 16 year olds are situated in all four quadrants, but are more concentrated in the upper parts. A considerable degree of overlap exists. This sample once again consists mostly of males with three 15 year old females (numbers 1, 3 and 6) and one 16 year old female present (number 10). Little separation can be seen with the 15 year old females situated in the upper and lower right quadrants, while the 16 year old female is situated in the upper right quadrant. Overlap does, however, exist.

Figure 4.184 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the 15 and 16 year old juveniles. Little difference can be seen between the two age groups. The superior border of the 16 year olds becomes more curved, with landmark 10 moving lower. The medial border of the 16 year olds seems to expand, with the landmarks moving laterally in the lower part of the medial border.

4.3.4.14 Supraspinous fossa: 16 and 17 year old juveniles

Figure 4.185 is the Relative Warp Analysis for the supraspinous border of 16 and 17 year old juveniles. Numbers 1 – 8 represent the 16 year old juveniles, while 9 – 18 represent the 17 year olds. Some separation exists with the 16 year old juveniles situated mostly in the upper quadrants, while the 17 year olds are mostly situated lower. A considerable degree of overlap exists. This sample consists mostly of males with only one female present in each age group (number 2 for the 16 year olds and number 18 for the 17 year olds). The two females group together in the upper right quadrant, but the males are present in all four quadrants and no clear separation can be seen.

Figure 4.186 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the 16 and 17 year old juveniles. From this vector thin- plate spline the differences between the two age groups are clearly visible. The superior border of the 17 year olds moves higher and seems to slope downwards with landmark 10 situated much higher than landmark 18. The medial border of the 17 year olds moves inward with the landmarks moving downwards and medially.

4.3.4.15 Supraspinous fossa: 17 and 18 year old juveniles

Figure 4.187 is the Relative Warp Analysis for the supraspinous border of 17 and 18 year old juveniles. Numbers 1 – 10 represent the 17 year old juveniles, while 11 – 21 represent the 18 year olds. No clear separation can be seen with the two age groups overlapping one another almost completely. Once again the sample consists mostly of males with only one 16 year old female (number 10) and two 18 year old females present (numbers 13 and 18). No clear separation can be seen as the two sexes overlap one another completely.

Figure 4.188 is the consensus thin- plate spline (in vector mode) to show the separation between the supraspinous fossae of the 17 and 18 year old juveniles. The differences between the two age groups resemble those seen in the 16 – 17 year group, but to a lesser degree. The medial border of the 18 year olds once again seems to slope downwards with landmark 10 situated higher than landmark 18, while the landmarks of the medial border once again move downwards and medially.

4.3.4.16 Supraspinous fossa: 18 and 19 year old juveniles

Figure 4.189 is the Relative Warp Analysis for the supraspinous border of 18 and 19 year old juveniles. Numbers 1 – 11 represent the 18 year old juveniles, while 12 – 22 represent the 19 year olds. The two age groups show almost complete overlap and no separation can be seen. Two 18 year old females (numbers 3 and 8) and eight 19 year old females are present (numbers 12, 15 – 17 and 19 – 22). The females are mostly situated in the upper left and right quadrants (seven individuals) with three individuals situated in the lower left and right quadrants, while the males are mostly situated in the upper and lower right quadrants (eight individuals) with four individuals in the upper and lower left quadrants. The two sexes do, however, overlap one another.

Figure 4.190 is the consensus thin-plate spline (in vector mode) to show the separation between the supraspinous fossae of the 18 and 19 year old juveniles. Little difference can be seen between the two age groups. The superior border of the supraspinous fossa of 19 year old juveniles is slightly straighter than that of 18 year olds, with landmark 10 situated higher than landmark 18. The medial border seems to expand more for 19 year olds, with the landmarks moving more laterally.

4.3.4.17 Summary of the supraspinous fossa of juveniles

The superior border of the supraspinous fossa changes from concave in the younger juveniles to convex to straight in the older juveniles. The superior angle (landmark 18) also becomes lower than landmark 10 with progressing age. This change does not occur at a constant tempo.

The change from concave to more convex or straight is more constant, being seen most clearly at 10 – 12 years of age. More variation is seen in the supraspinous fossa of older juveniles, with the superior border varying between convex and straighter. Sexual dimorphism did not seem to influence the development of the supraspinous fossa with the supraspinous fossae of the older juveniles (ages 12 and upwards) showing no clear sexual dimorphism.

4.3.4.18 Supraspinous fossa: Results of grouped juveniles

From the results obtained from the supraspinous fossae of one to 19 year old juveniles, it seemed that the shape of the superior border of the supraspinous fossa changed after 10 years of age from concave to convex or straight. As a result of this shape change, the consensus thin-plate splines of the supraspinous fossae of the younger individuals (1-10 years) and the older individuals (12-19 years) were then compared.

Vector thin-plate splines, as well as a Relative Warp Analysis were also constructed for these two groups. Sheets' Integrated Morphometric Package (IMP) TwoGroup-program and Canonical Variates Analysis-program (CVAGen6) were used for calculation of significance levels.

Figure 4.191 is the Relative Warp Analysis for 1-10 and 12-19 year old juveniles. Numbers 1 to 20 represent the 1-10 year old juveniles, while 21 to 81 represent the 12-19 year olds. A fair degree of separation exists with the younger juveniles mostly dispersed towards the right and the older juveniles to the left. Some overlap exists.

When the consensus thin-plate splines and vector diagram for the younger and older juveniles are compared (Figures 4.192 – 4.194), it is clear that the superior border of the supraspinous fossa is concave for the younger juveniles and convex for the older juveniles, while the medial border of the supraspinous fossa is straighter and narrower for the older juveniles. The supraspinous fossa becomes longer and thinner in the older juveniles.

Figure 4.195 represents the TwoGroup BC Superimposition plot for the younger and older individuals. The younger individuals are indicated by blue circles and older individuals by red squares. The supraspinous fossa border has been rotated so that landmark 7 is represented by the point (0,0) and landmark 10 by the point (0,1). Some separation can be seen with the landmarks indicating the older juveniles less tightly clustered than those indicating the younger juveniles. Goodall's F- test and Hotelling's T^2 - test were performed using the TwoGroup program. Goodall's F- test yielded a p-value of 0.0, and Hotelling's T^2 - test, however, yielded a p-value of 5.27.

Figure 4.196 CVA plot for the superior border of 1 – 10 and 12 – 19 year old individuals. The younger juveniles (ages 1 – 10) are represented by black circles and the older juveniles (ages 12 – 19) by blue crosses. The supraspinous fossa border has been

rotated so that landmark 7 is closest to the vertical (y-) axis. From this CVA plot the differences between the superior borders of the supraspinous fossae of the younger and older juveniles can clearly be seen with the landmarks indicating the younger juveniles clearly separated from those indicating the older juveniles.

Figure 4.197 is the mean of the CVA plot for the superior border of the two juvenile groups, with the younger juveniles once again indicated by black circles and the older juveniles by blue crosses. The larger black circle and blue cross in the centre represent the mean superior border shape for the younger and older juveniles respectively. Separation can be seen between the two age groups, although some overlap is present.

Based on the above mentioned results (obtained from the TwoGroup analysis, as well as the TwoGroup BC Superimposition plot and the two CVA plots) a CVA analysis was carried out to test the accuracy with which the superior border of the scapula can be categorised within the younger (less than 10 years) or older group (older than 12 years). Table 4.3 represents the accuracies obtained from the CVA analysis of the supraspinous fossa of younger and older juveniles. Of the younger age group (1 – 10 years old), 90% were correctly assigned, while 88.5% of the supraspinous fossae from the older age group (12 – 19) were correctly assigned to the older age group.

Figure 4.1: Relative warp analysis for adult females (green) and adult males (blue)

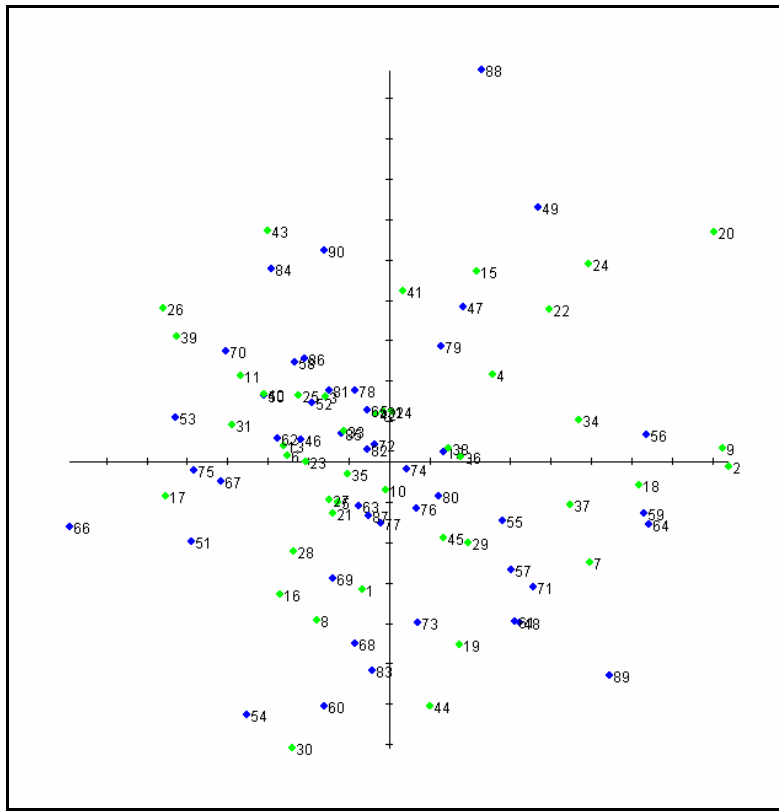


Figure 4.2: Reference for the consensus thin- plate splines of the adult males and females

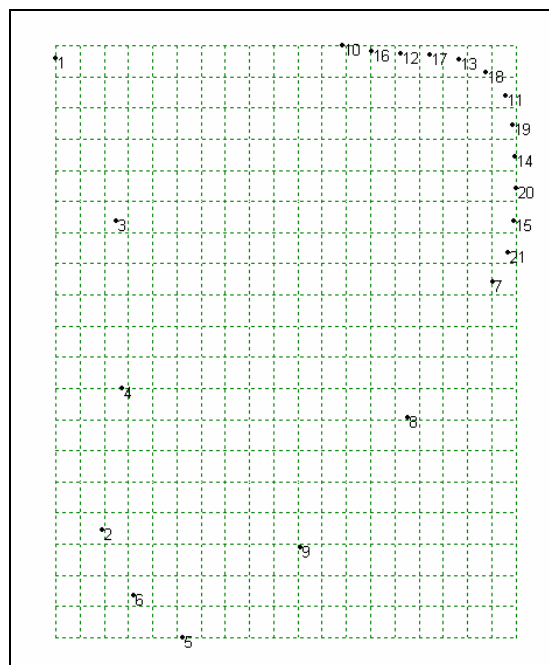


Figure 4.3: Consensus thin- plate spline for adult females

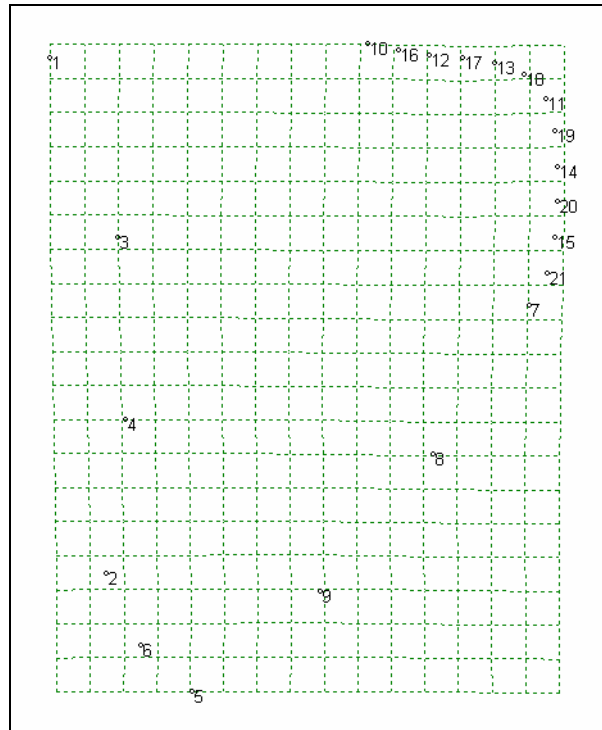


Figure 4.4: Consensus thin- plate spline for adult males

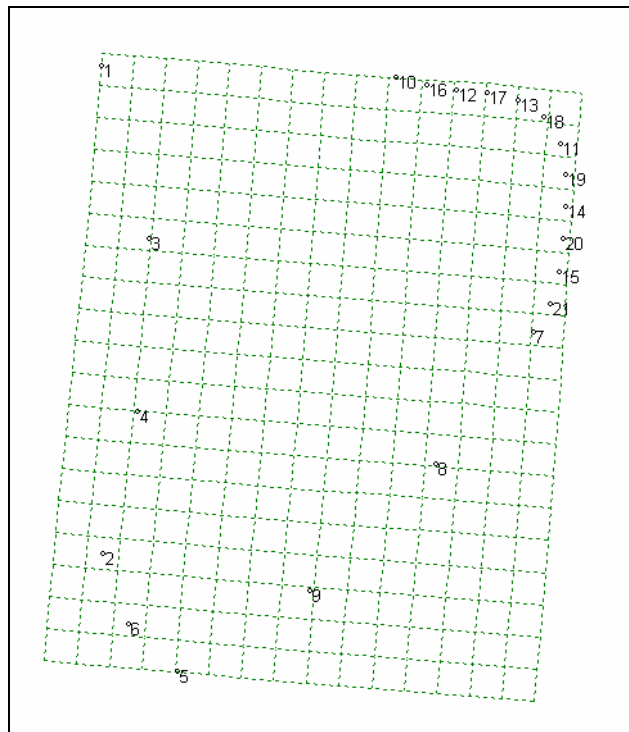


Figure 4.5: Consensus thin- plate spline (in vector mode) to show the separation of adult males (green arrow points) from adult females (black circles)

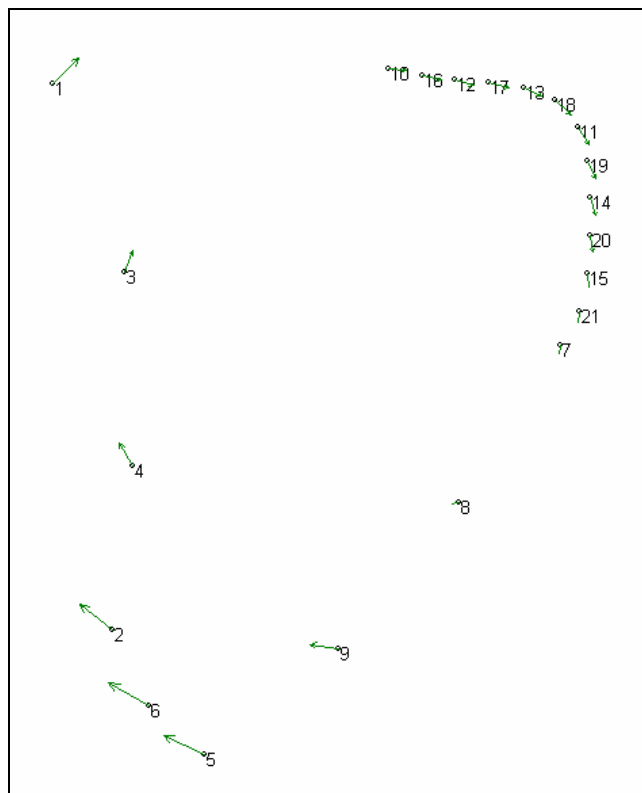


Figure 4.6: TwoGroup BC Superimposition plot for adult males and females (□ = males; ○ = females). The lateral border is on the horizontal (x-) axis. Landmark 1 is represented by the point (0,0) and landmark 2 by the point (0,1)

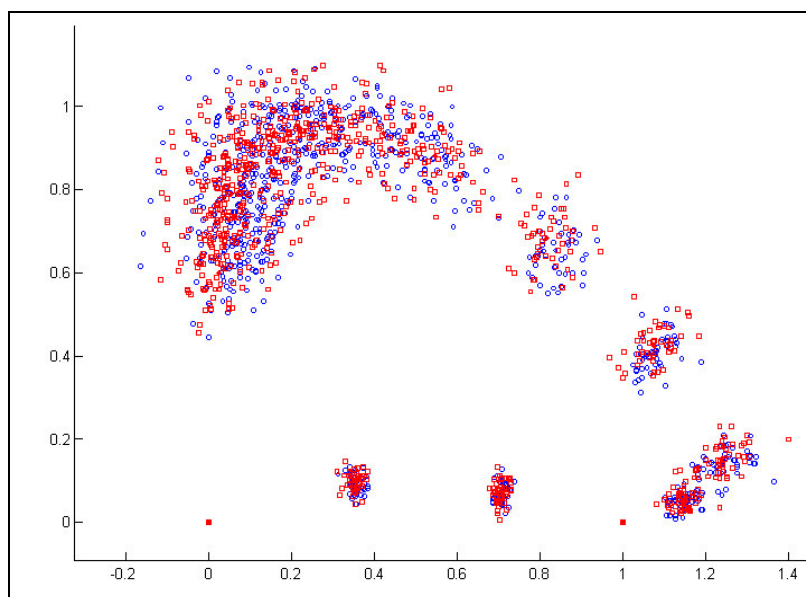


Figure 4.7 CVA plot for adult females and males (○ = adult females; x = adult males). The lateral border is situated on the horizontal (x-) axis

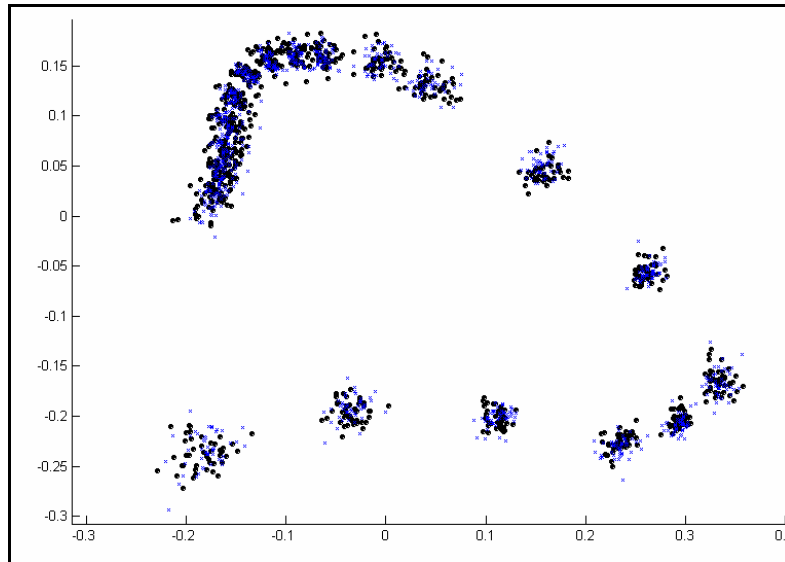


Figure 4.8: Mean of the CVA plot for adult females and males (○ = adult females; x = adult males). The larger black circle and blue cross represent the mean shape for adult females and males respectively

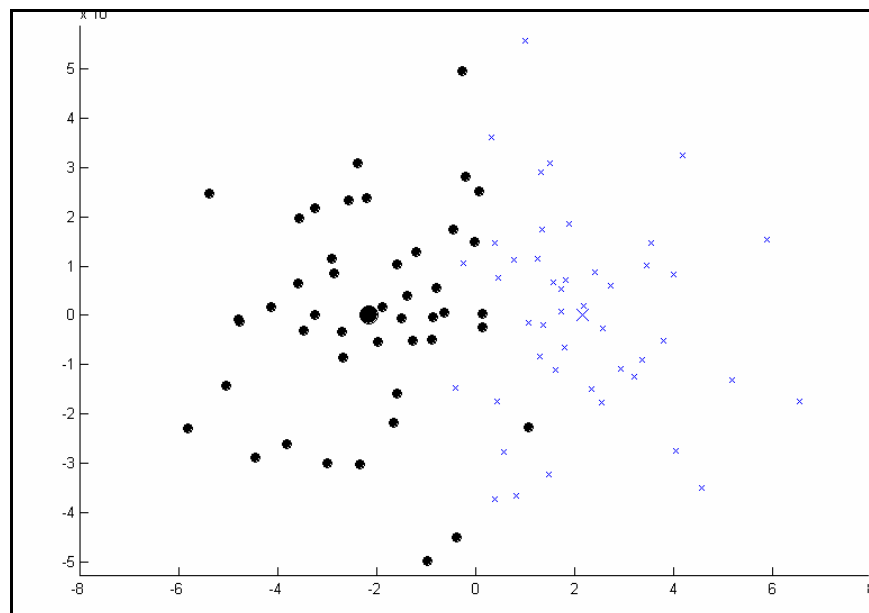


Figure 4.9: Relative warp analysis for the lateral border of adult females (green) and adult males (blue)

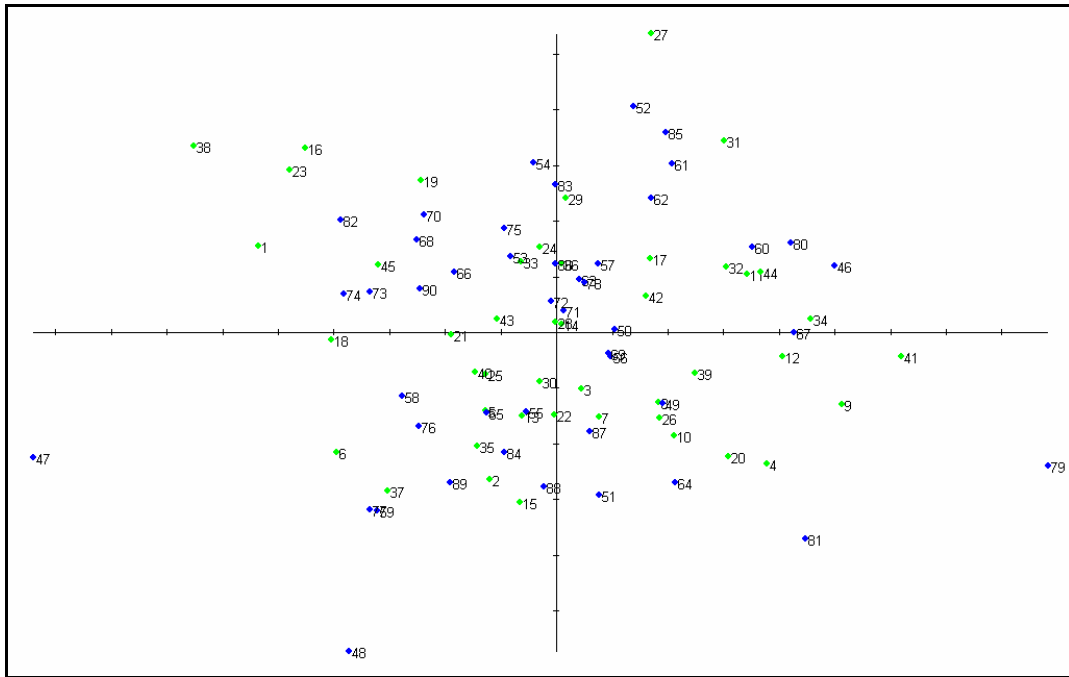


Figure 4.10: Reference for the consensus thin- plate splines of the lateral border of adult males and females

Figure 4.11: Consensus thin- plate spline (in vector mode) to show the separation of adult males (green arrow points) from adult females (black circles) along the lateral border

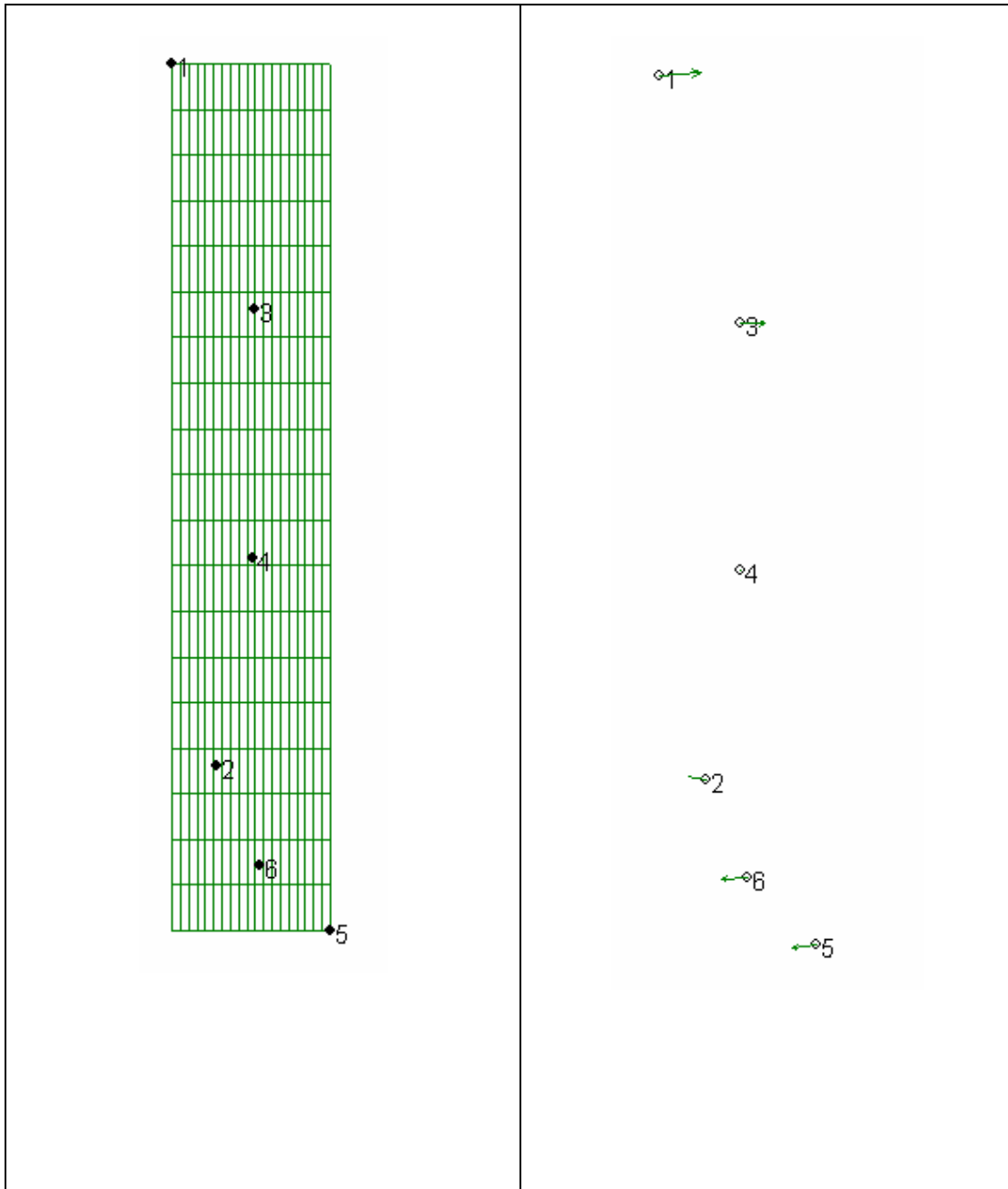


Figure 4.12: CVA plot for the lateral border of adult females and males (○ = adult females; x = adult males)

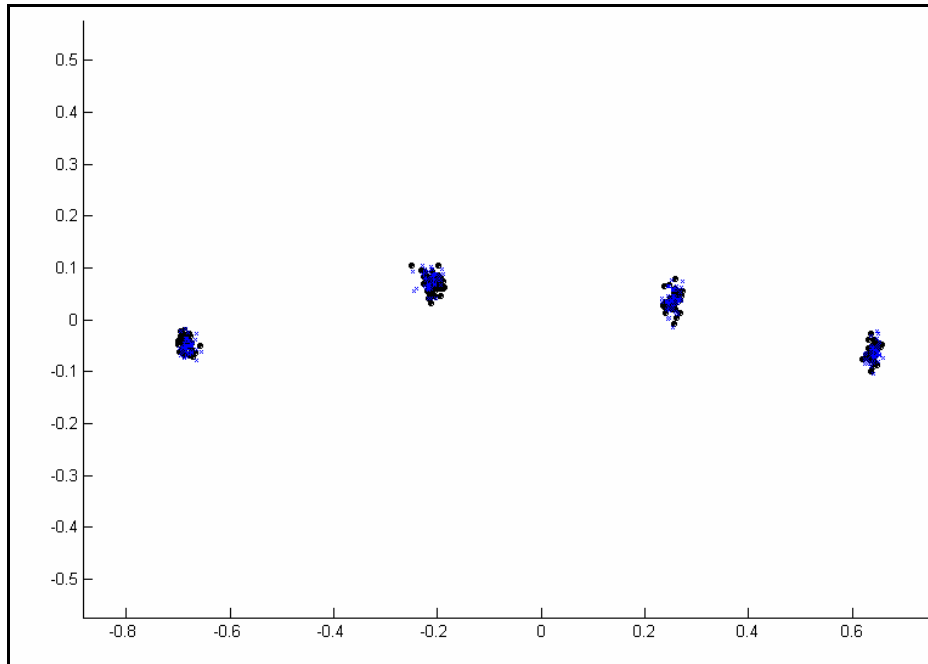


Figure 4.13: Mean CVA plot for adult females and males (○ = adult females; x = adult males). The larger black circle and blue cross represent the mean shape for adult females and males respectively

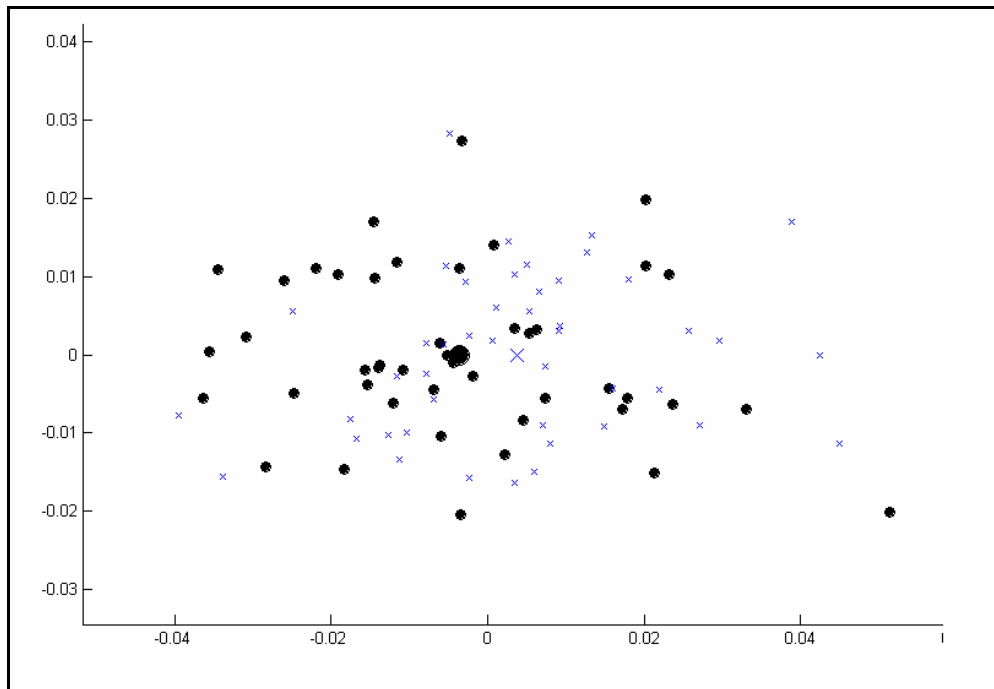


Figure 4.14: Relative warp analysis for the medial border of adult females (green) and adult males (blue)

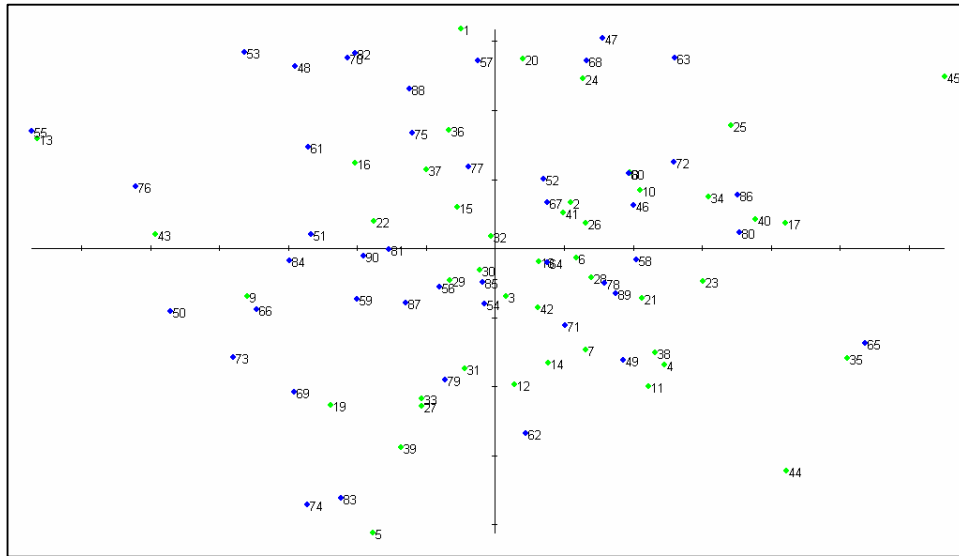


Figure 4.15: Reference for the consensus thin- plate splines of the medial border of adult males and females

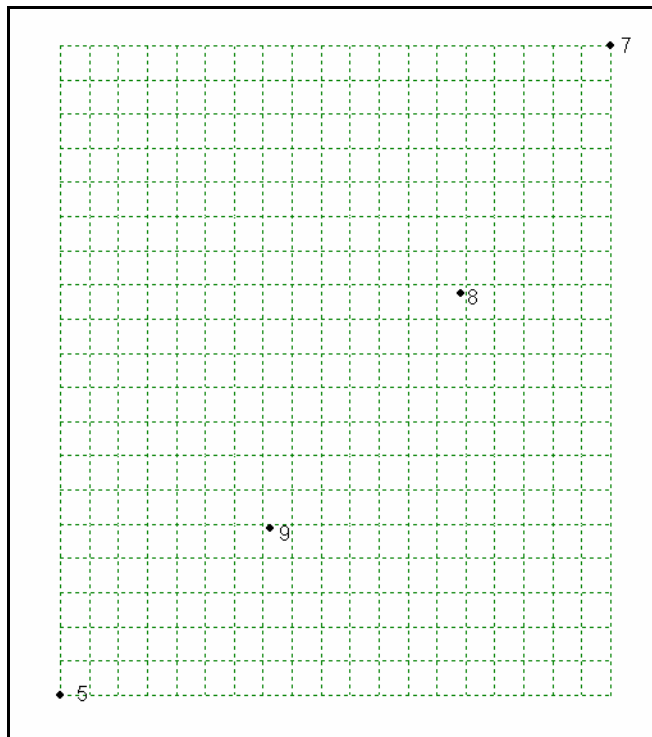


Figure 4.16: Consensus thin- plate spline (in vector mode) to show the separation of adult males (green arrow points) from adult females (black circles) along the medial border

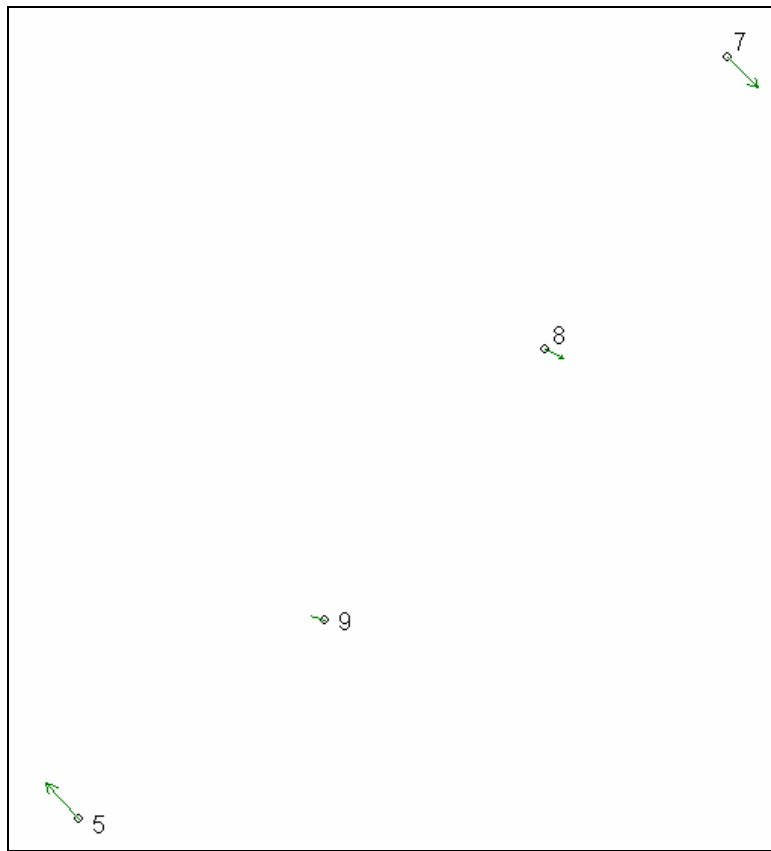


Figure 4.17: Relative warp analysis for the supraspinous border of adult females (green) and adult males (blue)

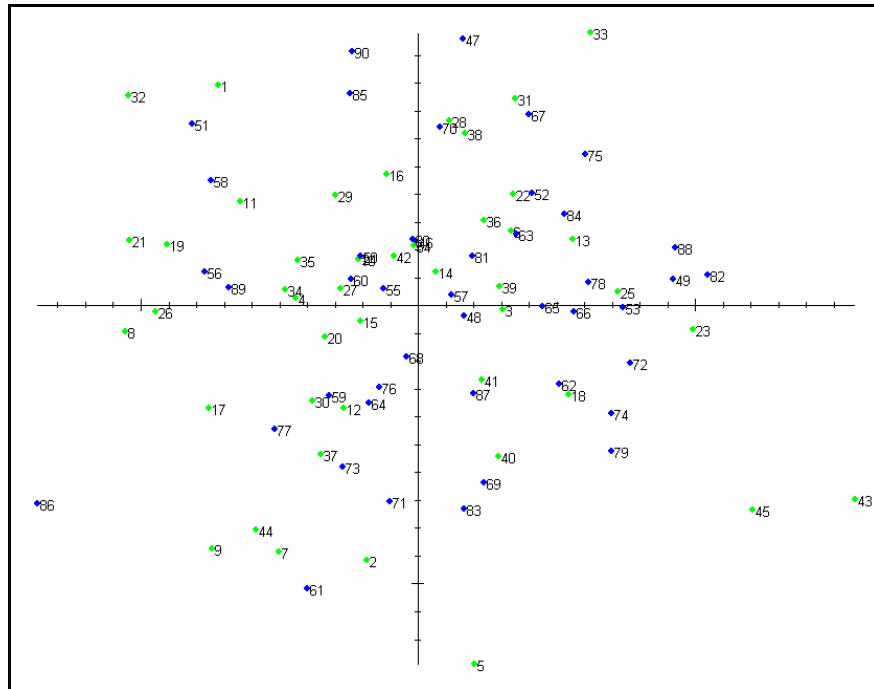


Figure 4.18: Reference for the consensus thin-plate splines of the supraspinous border of adult males and females

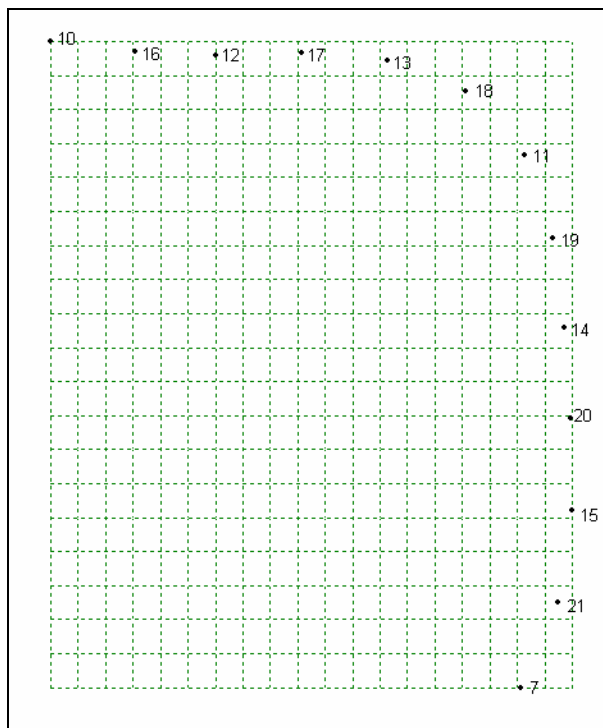


Figure 4.19: Consensus thin- plate spline (in vector mode) to show the separation of adult males (green arrow points) from adult females (black circles) along the supraspinous border

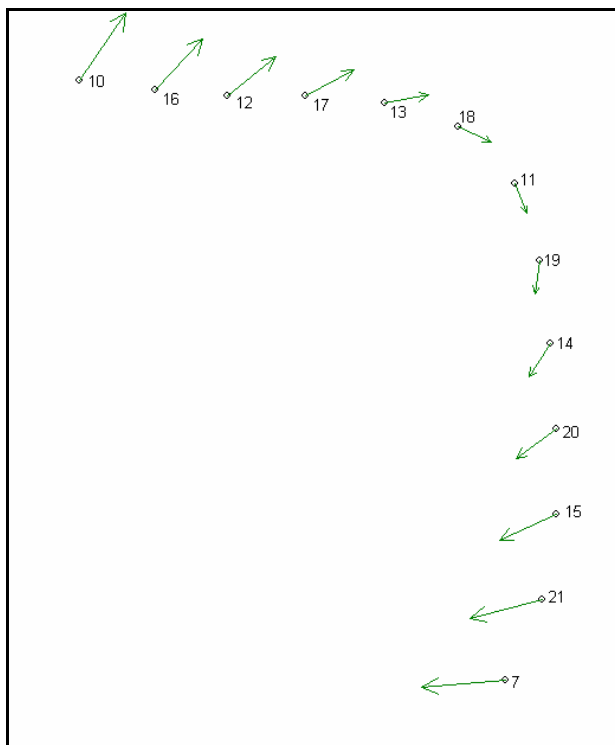


Figure 4.20: TwoGroup BC Superimposition plot for adult males and females along the supraspinous fossae (□ = males; ○ = females). The supraspinous fossa border has been rotated so that landmark 7 is represented by the point (0,0) and landmark 10 by the point (0,1)

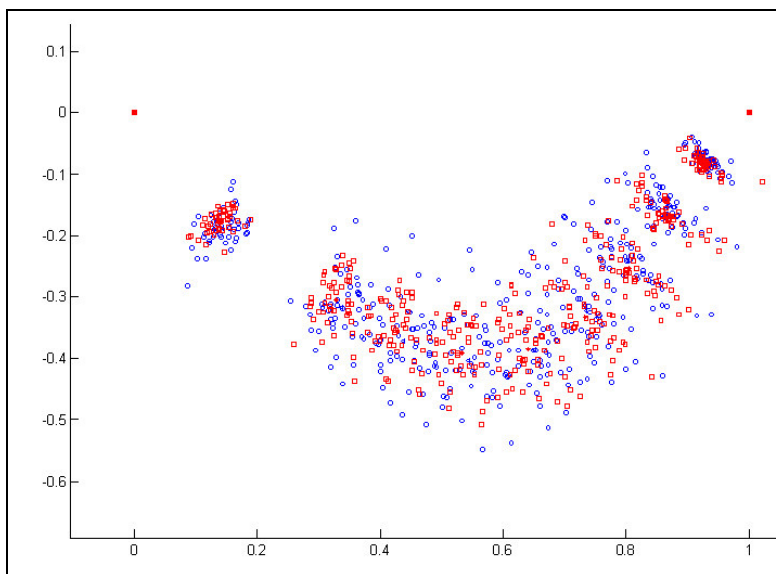


Figure 4.21: CVA plot for the superior border of adult females and males (○ = adult females; x = adult males). The supraspinous fossa border has been rotated so that landmark 7 is closest to the vertical (y-) axis

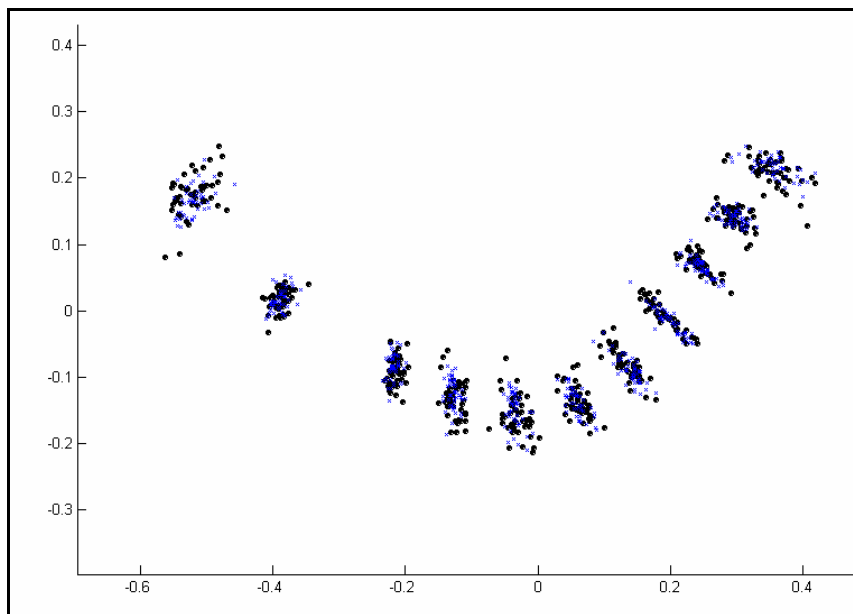


Figure 4.22: Mean of the CVA plot for the supraspinous fossa border of adult females and males (○ = adult females; x = adult males). The larger black circle and blue cross represent the mean shape for adult females and males respectively

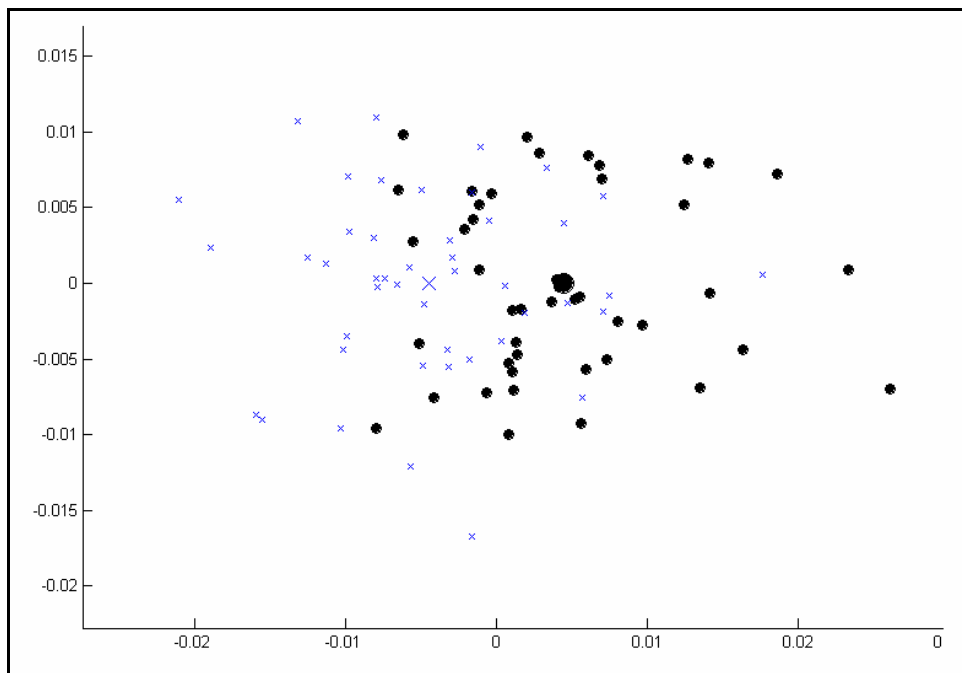


Figure 4.23: Relative warp analysis of juvenile females (green) and juvenile males (blue) of the whole juvenile sample

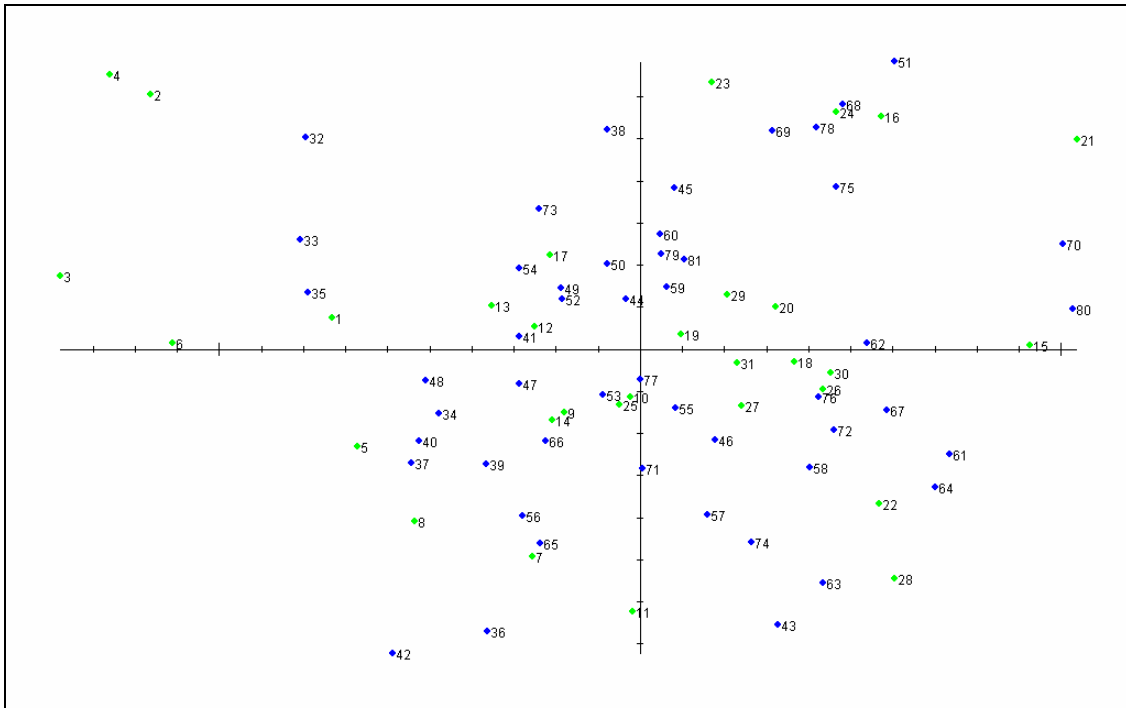


Figure 4.24: Relative warp analysis of the consensus of the juvenile females (green) and juvenile males (blue) in the three age groups (1 – 6 year old females indicated by 1; 7 – 12 year old females indicated by 2; 13 – 19 year old females indicated by 3; 1 – 6 year old males indicated by 4; 7 – 12 year old males indicated by 5; 13 – 19 year old males indicated by 6)

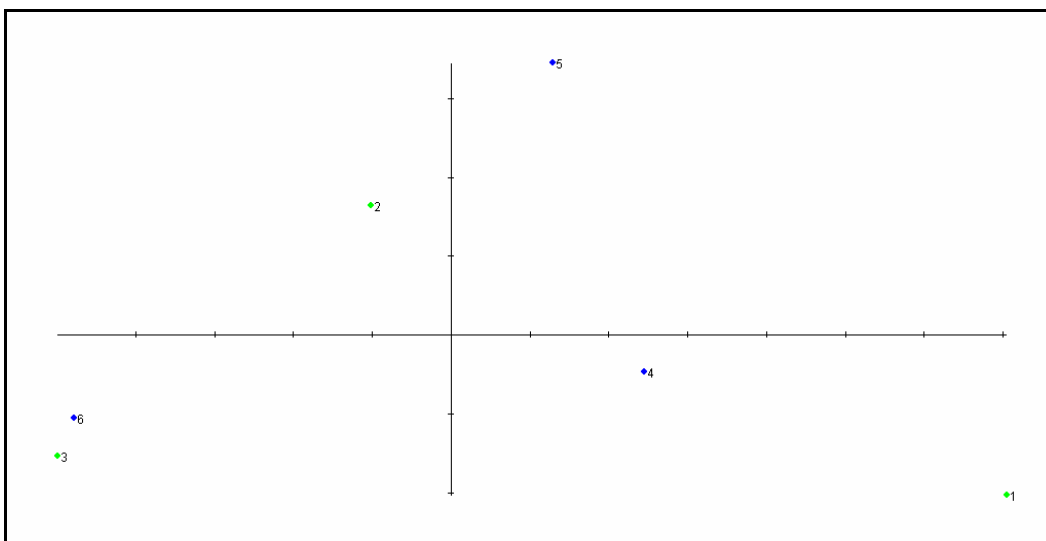


Figure 4.25: Relative warp analysis of the juvenile females (green) and juvenile males (blue) for ages 1 – 6

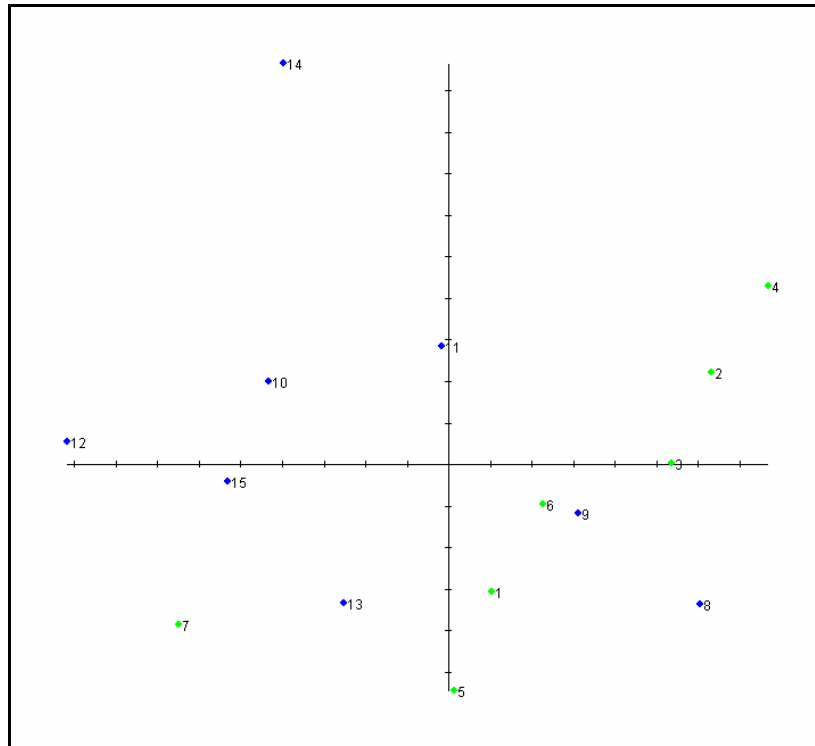


Figure 4.26: Reference for the consensus thin-plate splines of the juvenile males and females (ages 1 – 6)

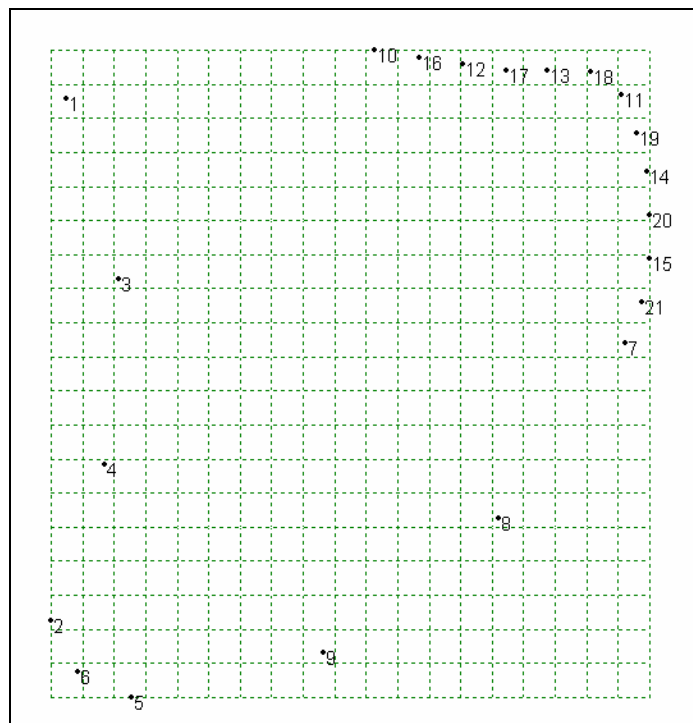


Figure 4.27: Consensus thin- plate spline for juvenile females (ages 1 – 6)

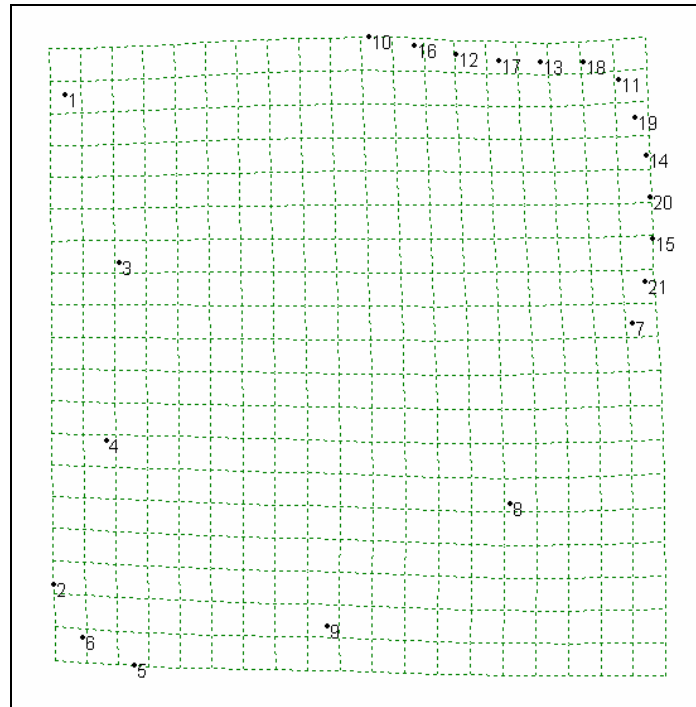


Figure 4.28: Consensus thin- plate spline for juvenile males (ages 1 – 6)

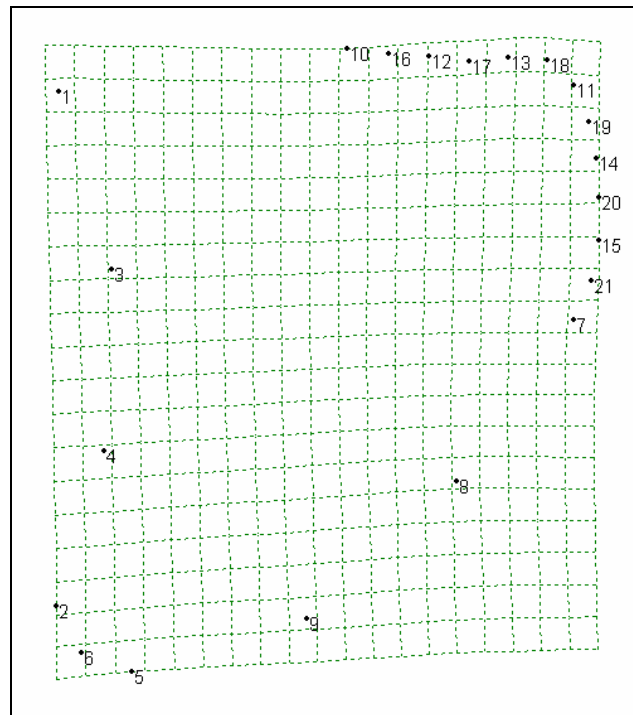


Figure 4.29: Consensus thin- plate spline (in vector mode) to show the separation of juvenile males (green arrow points) from juvenile females (black circles) (ages 1 – 6)

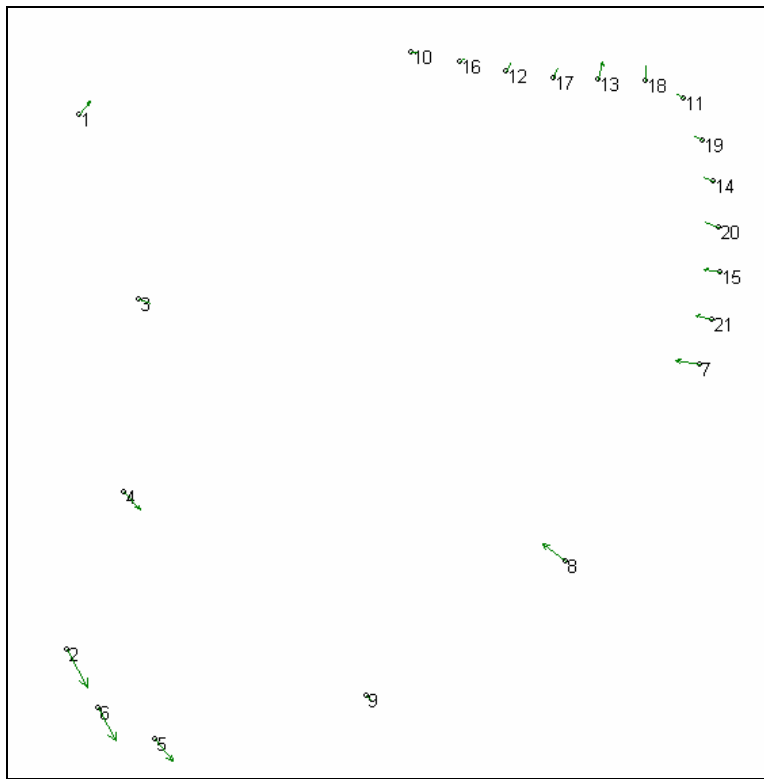


Figure 4.30: TwoGroup BC Superimposition plot for juvenile males and females ages 1 - 6 (□ = males; ○ = females). The lateral border is on the horizontal (x-) axis. Landmark 1 is represented by the point (0,0) and landmark 2 by the point (0,1)

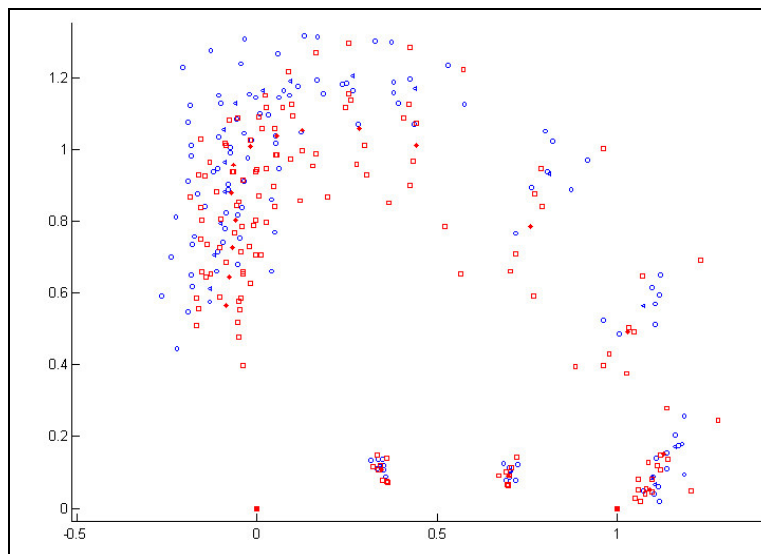


Figure 4.31: Relative warp analysis of the juvenile females (green) and juvenile males (blue) for ages 7 – 12

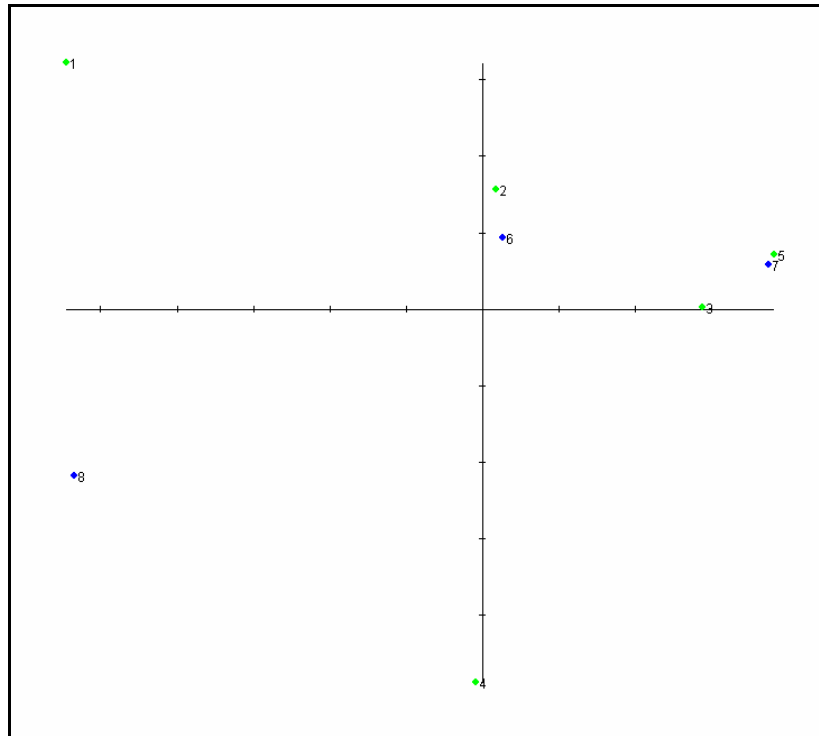


Figure 4.32: Reference for the consensus thin-plate splines of the juvenile males and females (ages 7 – 12)

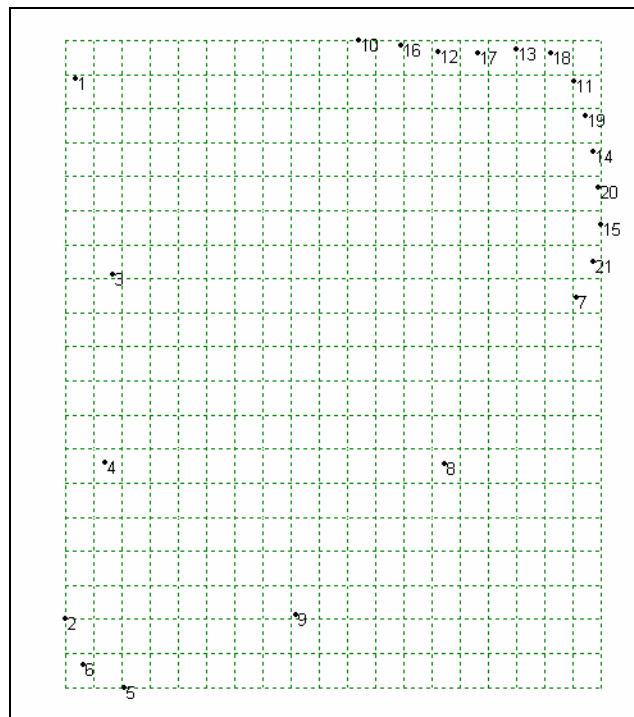


Figure 4.33: Consensus thin- plate spline for juvenile females (ages 7 – 12)

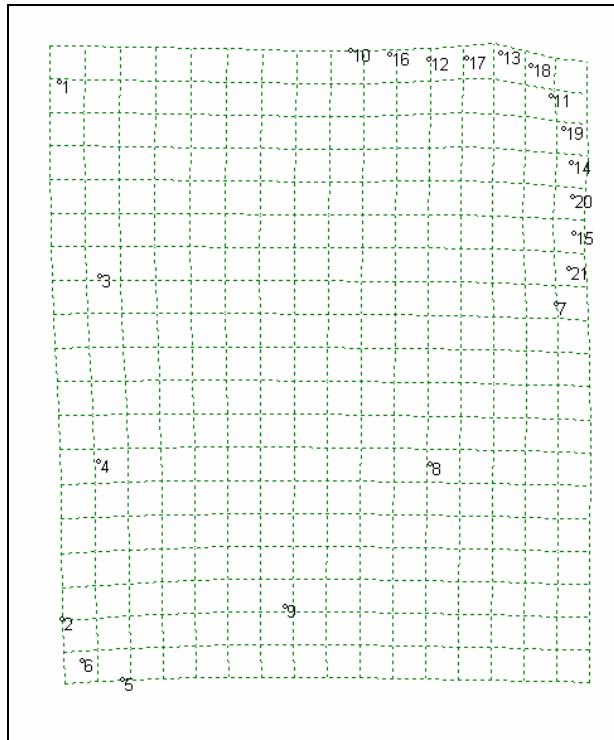


Figure 4.34: Consensus thin- plate spline for juvenile males (ages 7 – 12)

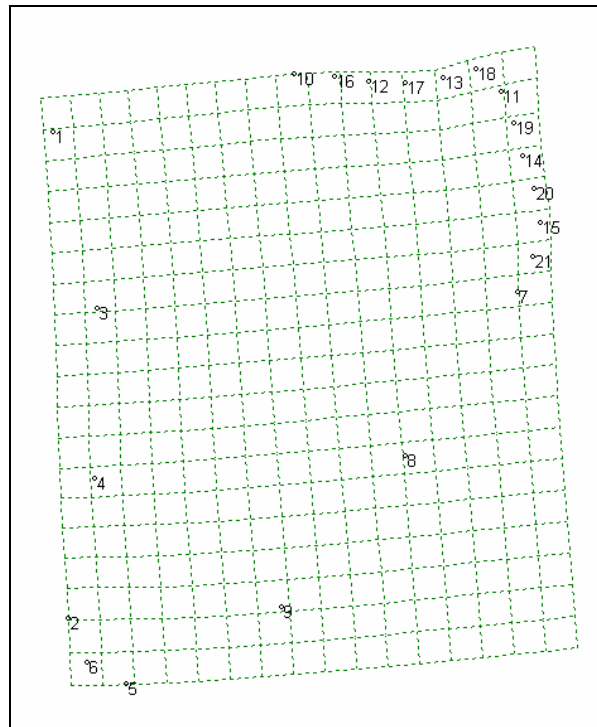


Figure 4.35: Consensus thin- plate spline (in vector mode) to show the separation of juvenile males (green arrow points) from juvenile females (black circles) (ages 7 – 12)

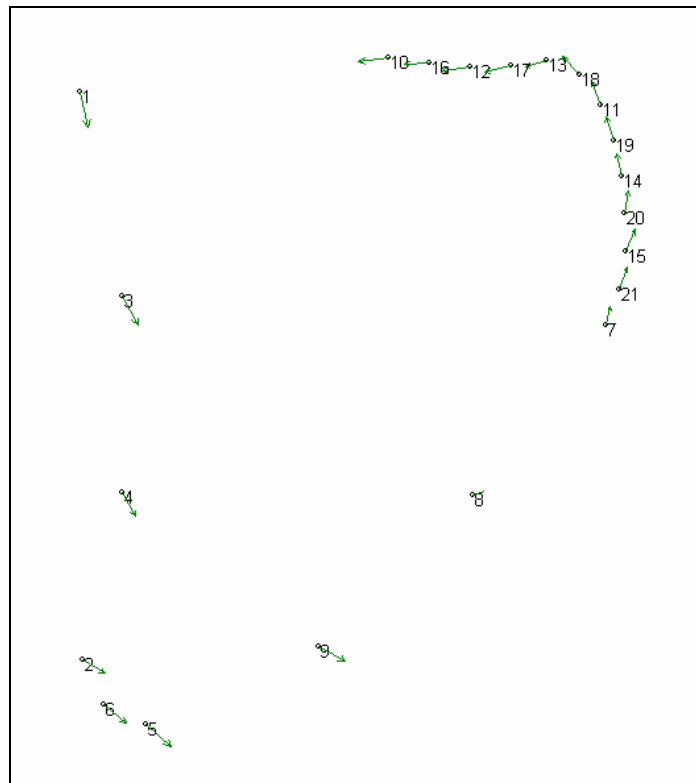


Figure 4.36: TwoGroup BC Superimposition plot for juvenile males and females ages 7 – 12 (□ = males; ○ = females). The lateral border is on the horizontal (x-) axis. Landmark 1 is represented by the point (0,0) and landmark 2 by the point (0,1)

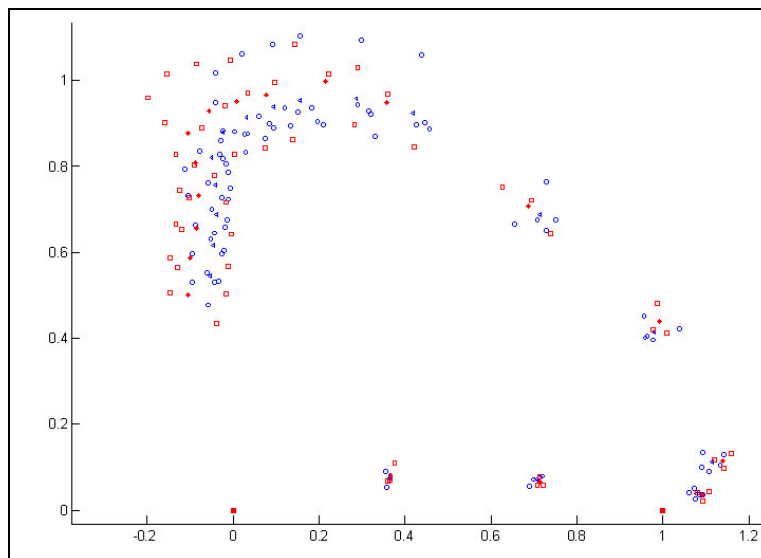


Figure 4.37: Relative warp analysis of the juvenile females (green) and juvenile males (blue) for ages 13 – 19

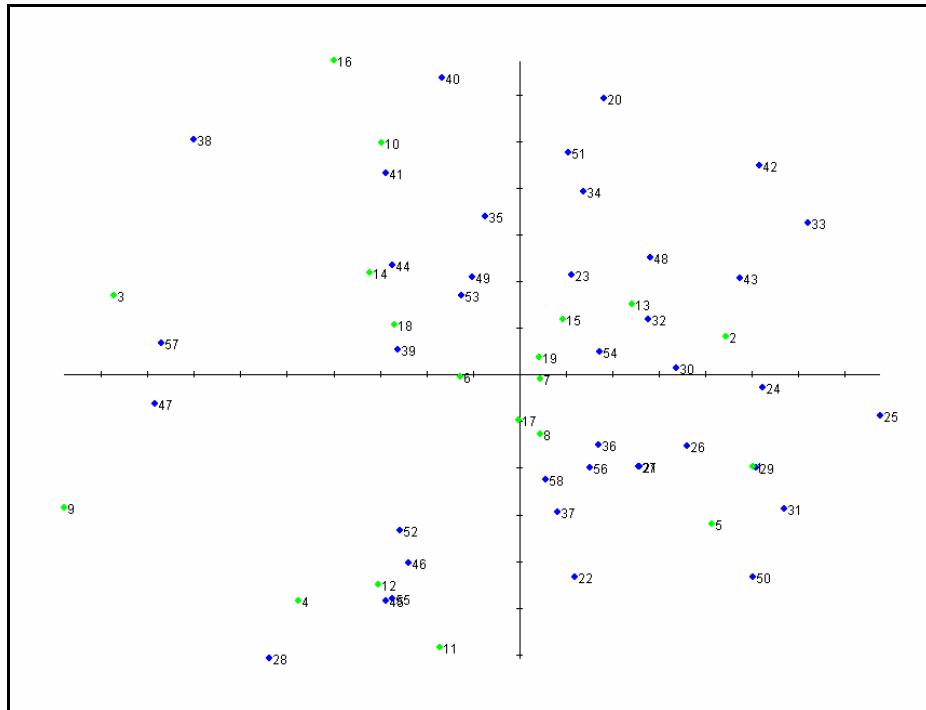


Figure 4.38: Reference for the consensus thin-plate splines of the juvenile males and females (ages 13 – 19)

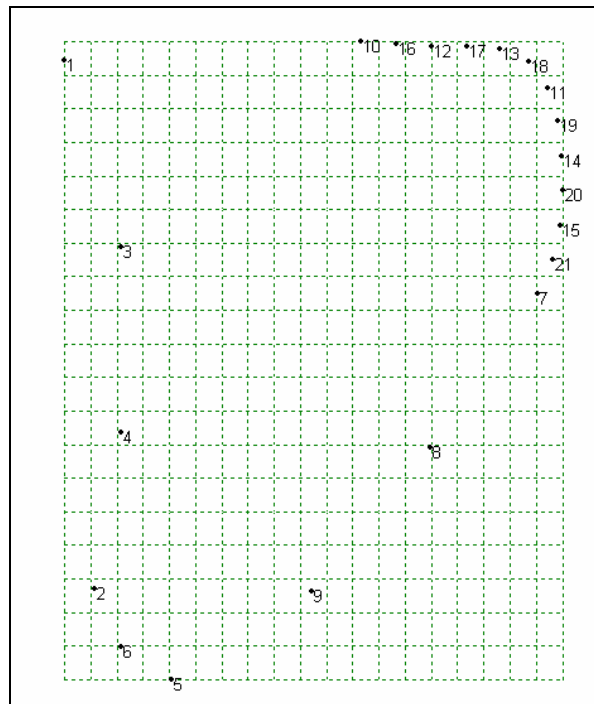


Figure 4.39: Consensus thin- plate spline for juvenile females (ages 13 – 19)

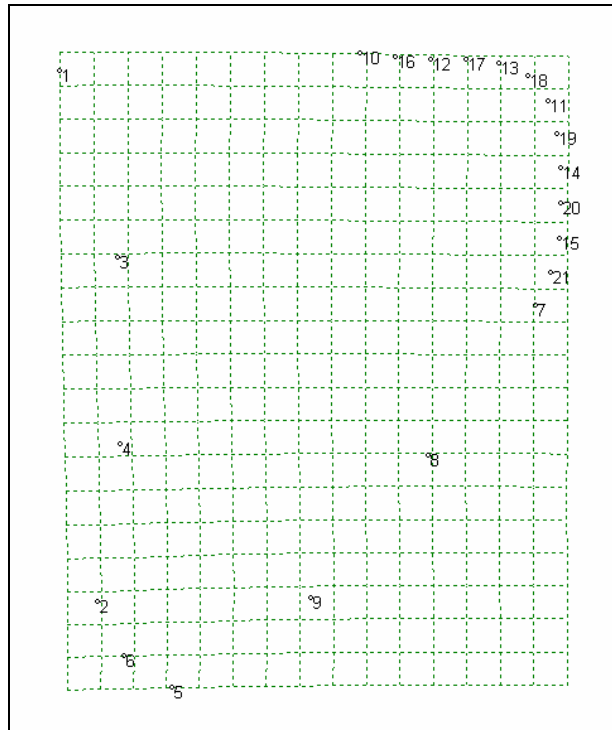


Figure 4.40: Consensus thin- plate spline for juvenile males (ages 13 – 19)

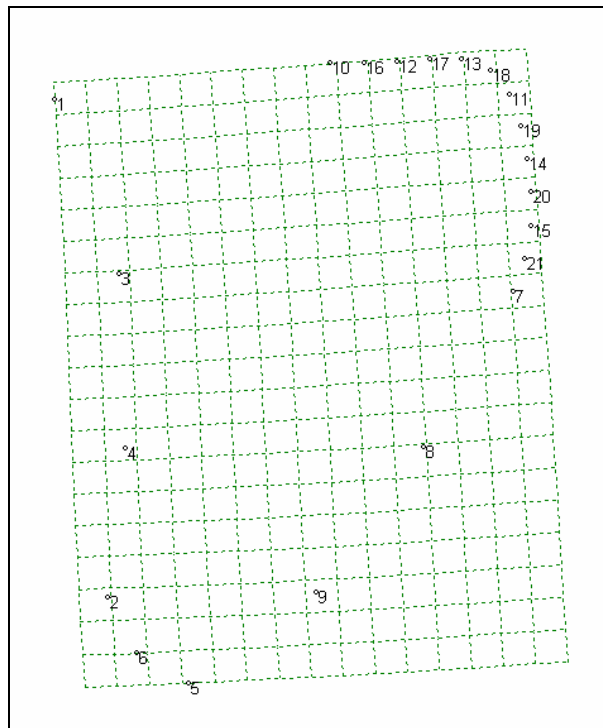


Figure 4.41: Consensus thin- plate spline (in vector mode) to show the separation of juvenile males (green arrow points) from juvenile females (black circles) (ages 13 – 19)



Figure 4.42: TwoGroup BC Superimposition plot for juvenile males and females ages 13 – 19 (□ = males; ○ = females). The lateral border is on the horizontal (x-) axis. Landmark 1 is represented by the point (0,0) and landmark 2 by the point (0,1)

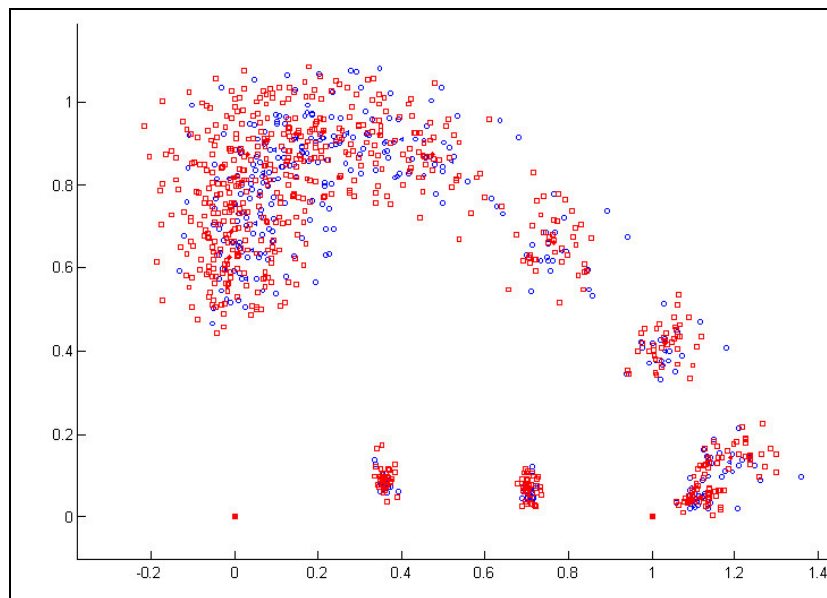


Figure 4.43: CVA plot for juvenile females and males ages 13 – 19 (○ = females; x = males). The lateral border is on the horizontal (x-) axis

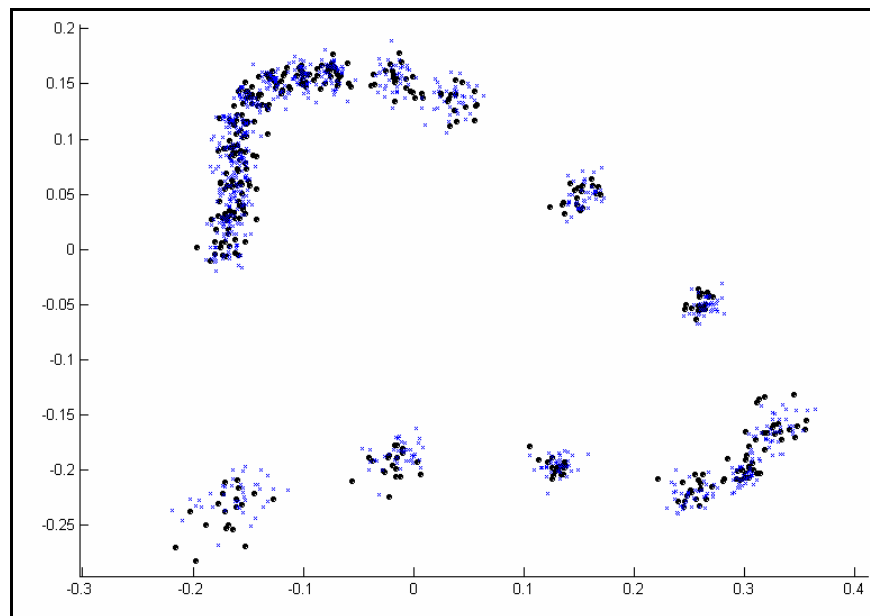


Figure 4.44: Mean of the CVA plot for juvenile females and males ages 13 - 19 (○ = females; x = males). The larger black circle and blue cross represent the mean shape for adult females and males respectively

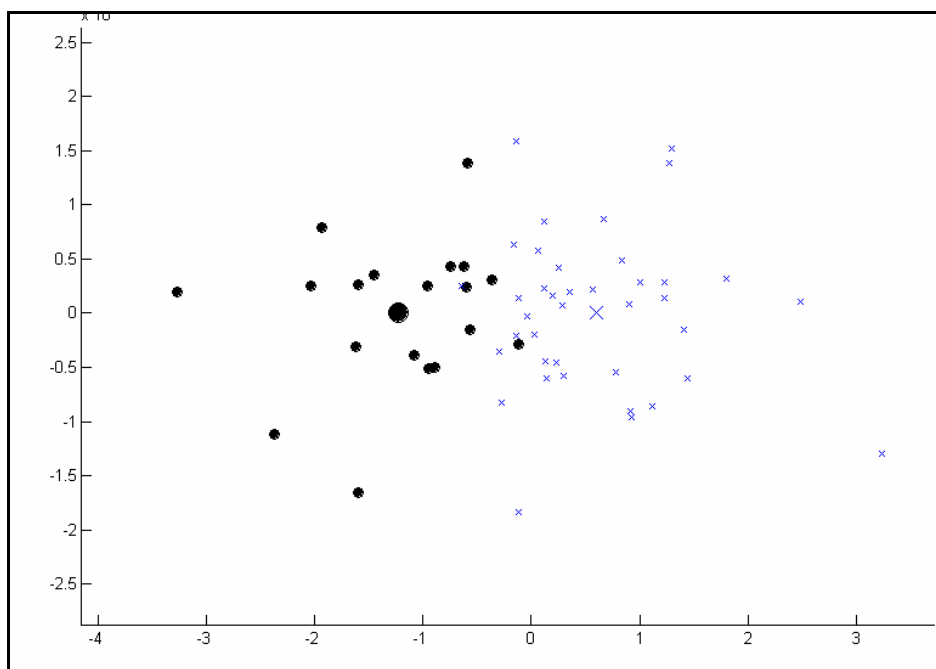


Figure 4.45: Relative warp analysis for the whole juvenile sample [1 – 6 : 1 year old juveniles (dark blue); 7 – 8: 2 year old juveniles (red); 9 – 11: 3 year old juveniles (yellow); 12 – 14: 4 year old juveniles (orange); 15: 6 year old juvenile (olive green); 16 – 17: 7 year old juveniles (maroon); 18: 8 year old juvenile (pink); 19: 9 year old juvenile (brown); 20: 10 year old juvenile (turquoise); 21 – 23: 12 year old juveniles (fuchsia); 24 – 30: 13 year old juveniles (bright green); 31 – 33: 14 year old juveniles (blue); 34 – 41: 15 year old juveniles (violet); 42 – 49: 16 year old juveniles (teal); 50 – 59: 17 year old juveniles (light pink); 60 – 70: 18 year old juveniles (light blue); 71 – 81: 19 year old juveniles (grey)]

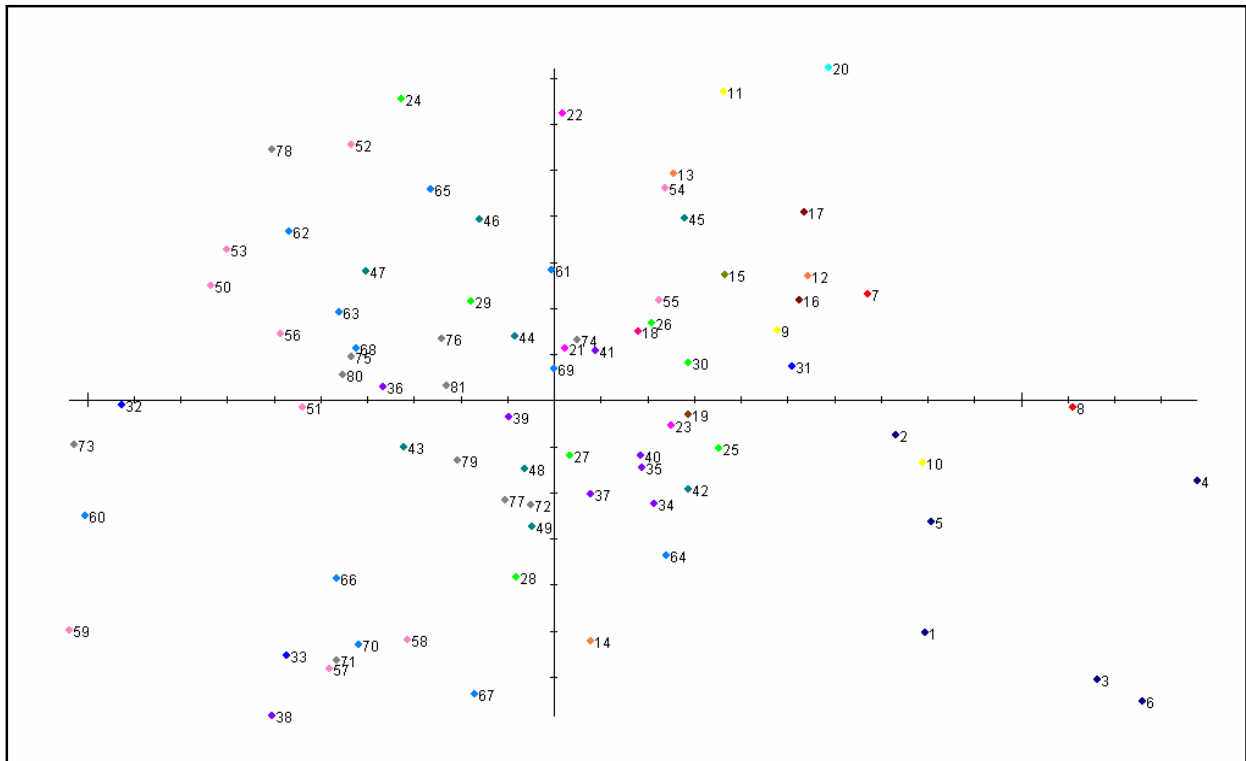


Figure 4.46: Relative warp analysis for the consensus of the juvenile sample [1: 1 year old juveniles (dark blue); 2: 2 year old juveniles (red); 3: 3 year old juveniles (yellow); 4: 4 year old juveniles (orange); 5: 6 year old juvenile (olive green); 6: 7 year old juveniles (maroon); 7: 8 year old juvenile (pink); 8: 9 year old juvenile (brown); 9: 10 year old juvenile (turquoise); 10: 12 year old juveniles (fuchsia); 11: 13 year old juveniles (bright green); 12: 14 year old juveniles (blue); 13: 15 year old juveniles (violet); 14: 16 year old juveniles (teal); 15: 17 year old juveniles (light pink); 16: 18 year old juveniles (light blue); 17: 19 year old juveniles (grey)]

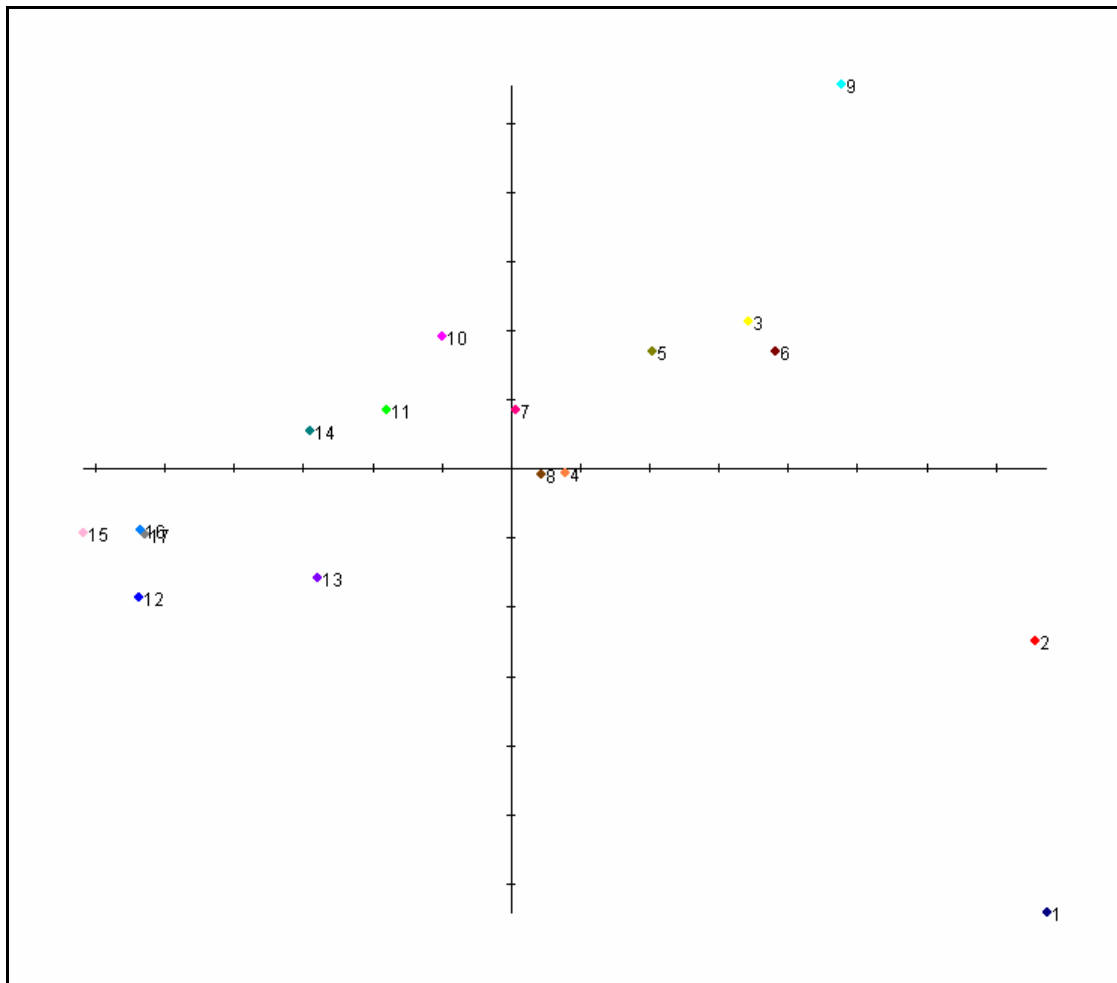


Figure 4.47: Relative warp analysis for one (green) and two (blue) year old juveniles

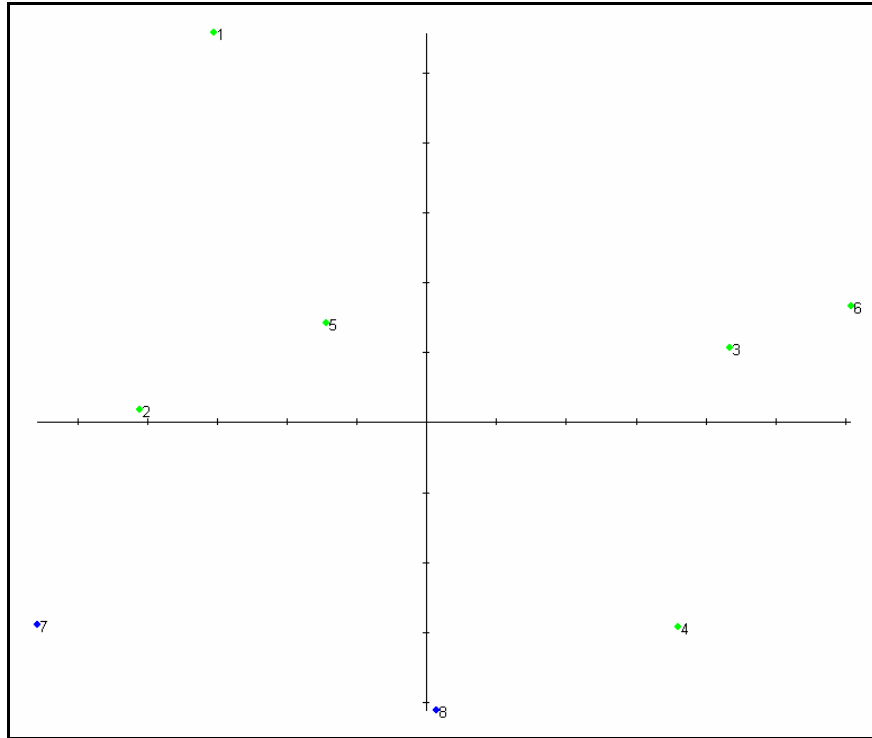


Figure 4.48: Consensus thin- plate spline for one year old juveniles

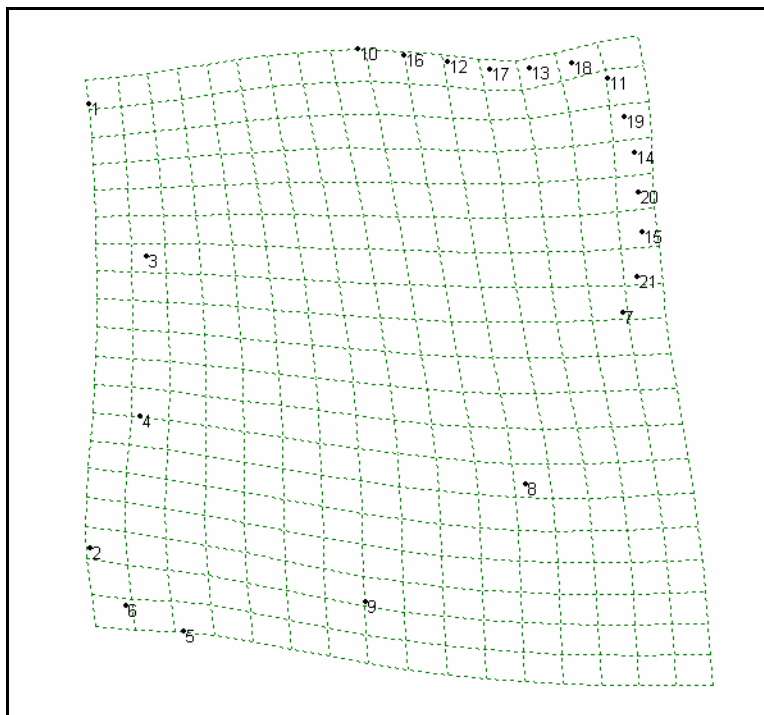


Figure 4.49: Consensus thin- plate spline for two year old juveniles

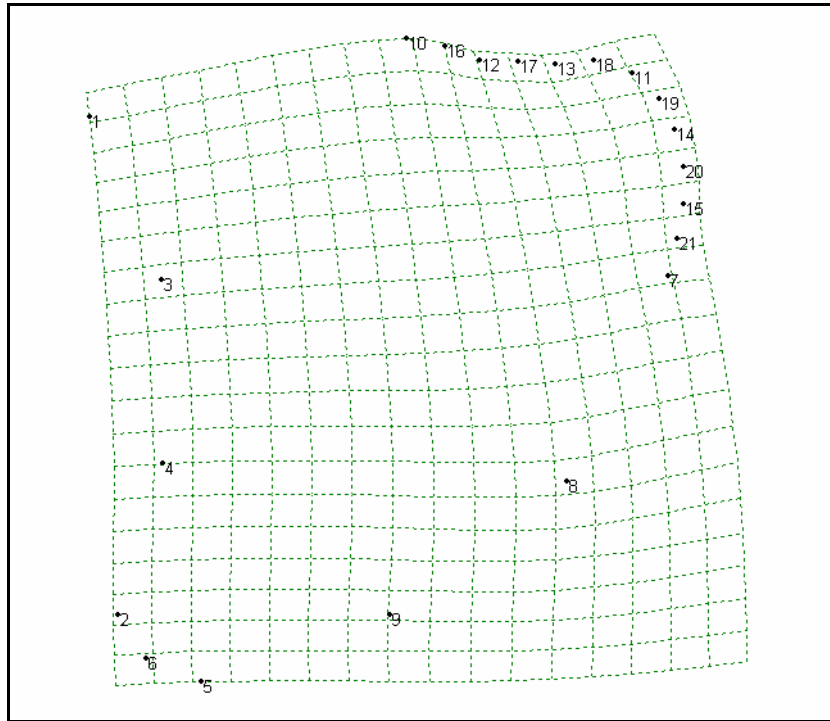


Figure 4.50: Consensus thin- plate spline (in vector mode) to show the separation of two year old juveniles (green arrow points) from one year old juveniles (black circles)

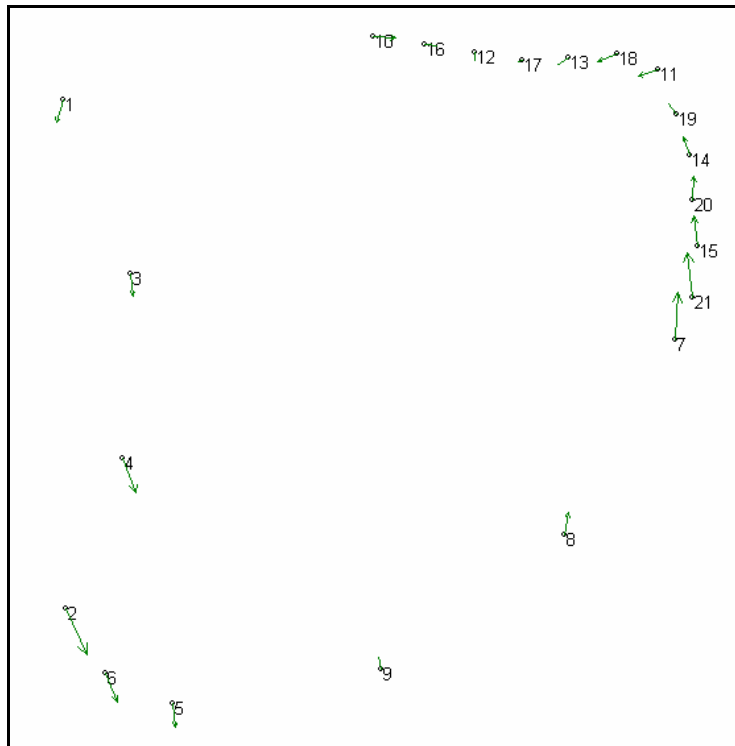


Figure 4.51: Relative Warp Analysis for two (green) and three (blue) year old juveniles

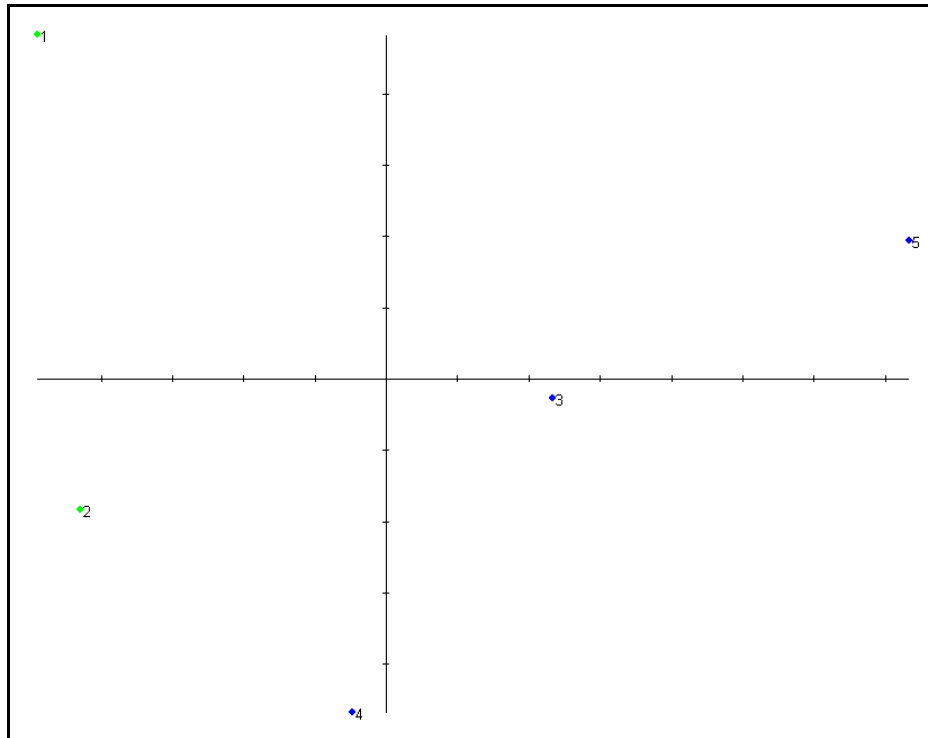


Figure 4.52: Consensus thin- plate spline for three year old juveniles

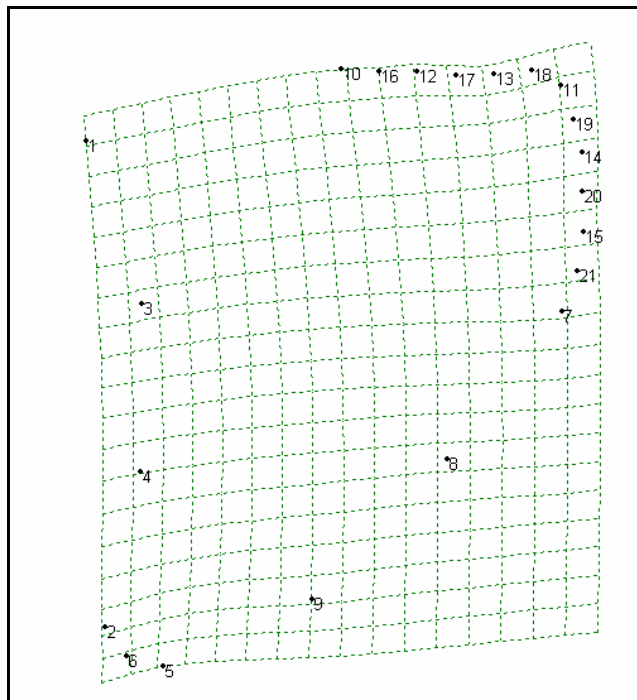


Figure 4.53: Consensus thin- plate spline (in vector mode) to show the differences between three year old juveniles (green arrow points) and two year old juveniles (black circles)

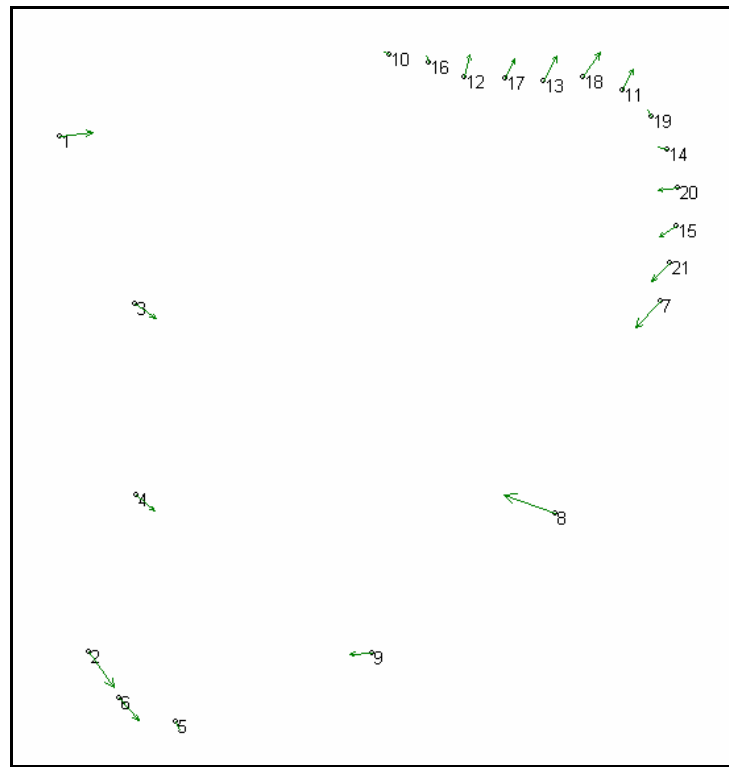


Figure 4.54: Relative Warp Analysis for three (green) and four (blue) year old juveniles

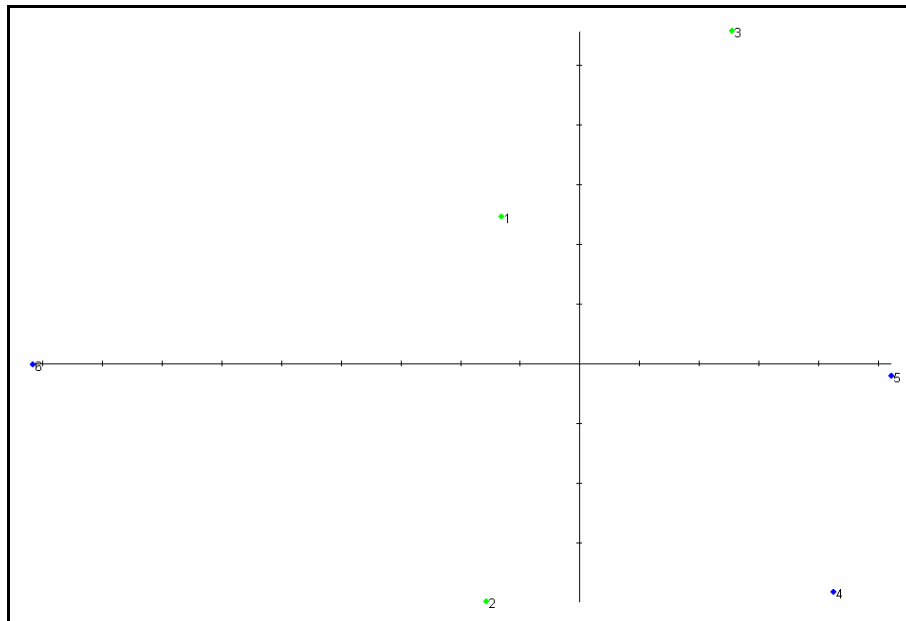


Figure 4.55: Consensus thin- plate spline for four year old juveniles

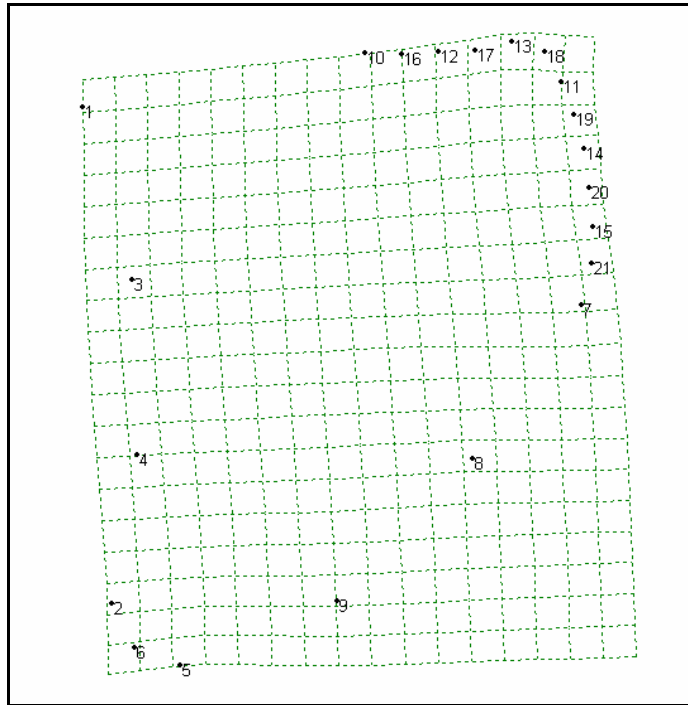


Figure 4.56: Consensus thin- plate spline (in vector mode) to show the separation of four year old juveniles (green arrow points) from three year old juveniles (black circles)

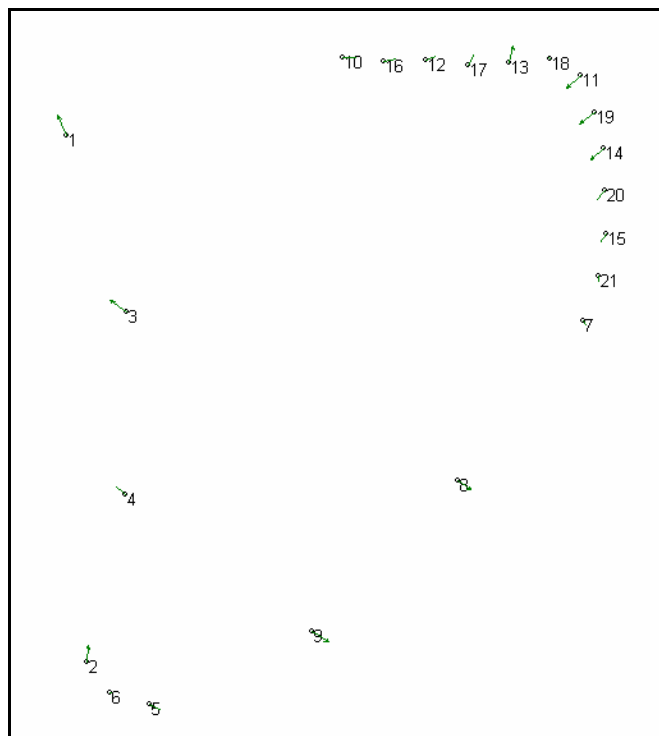


Figure 4.57: Relative Warp Analysis for four (green) and six (blue) year old juveniles

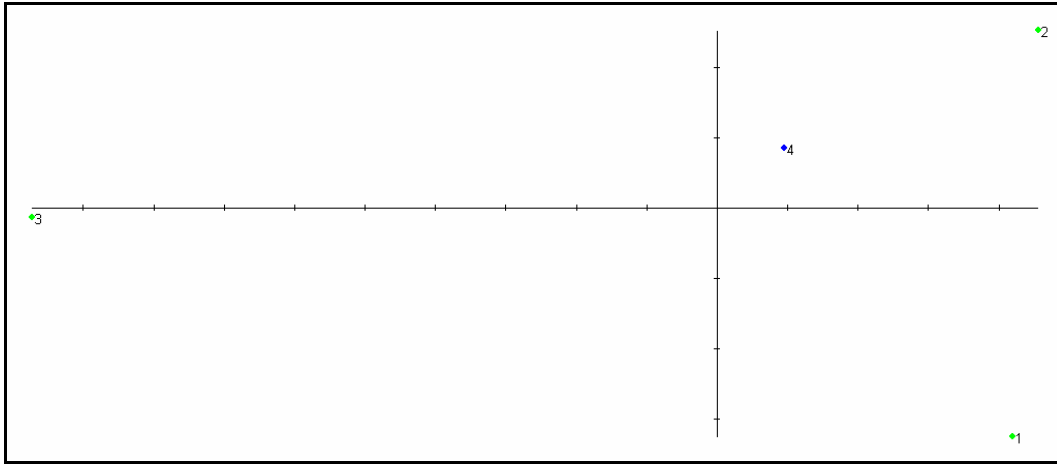


Figure 4.58: Consensus thin-plate spline for six year old juveniles

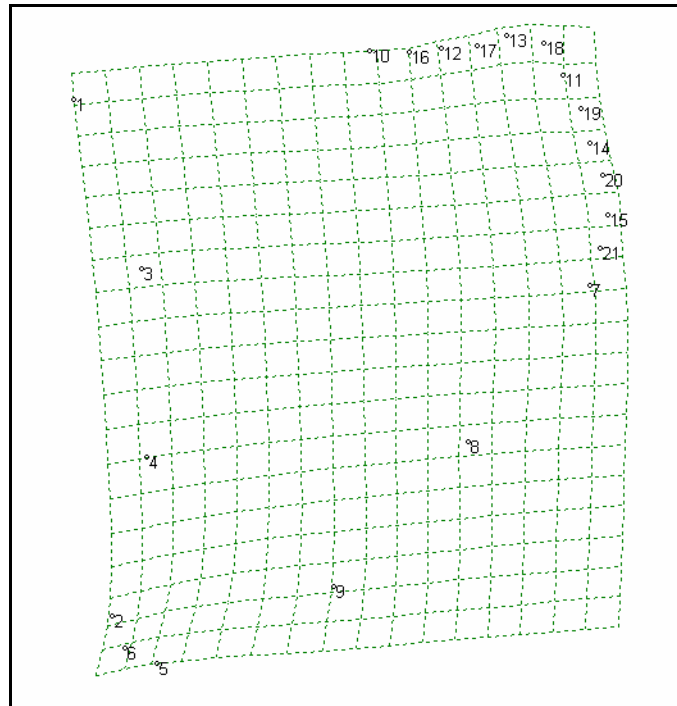


Figure 4.59: Consensus thin- plate spline (in vector mode) to show the separation of six year old juveniles (green arrow points) from four year old juveniles (black circles)

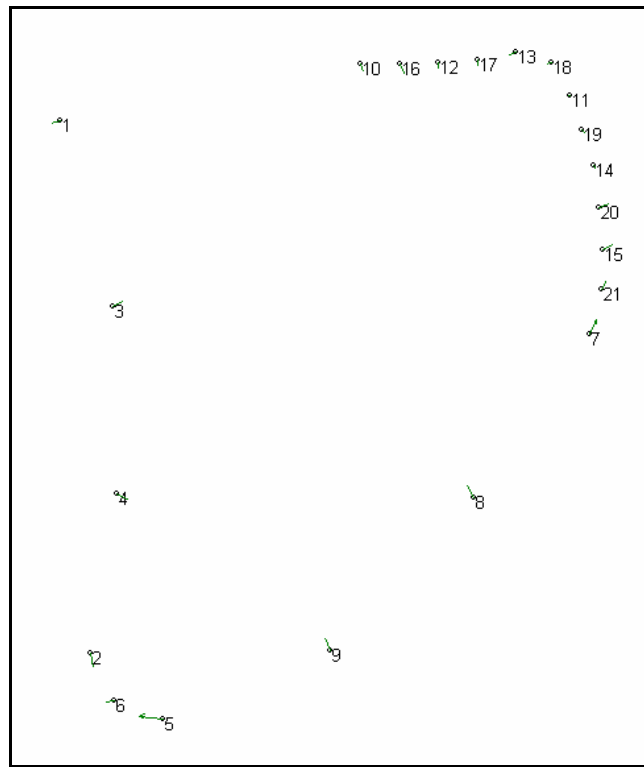


Figure 4.60: Relative Warp Analysis for six (green) and seven (blue) year old juveniles

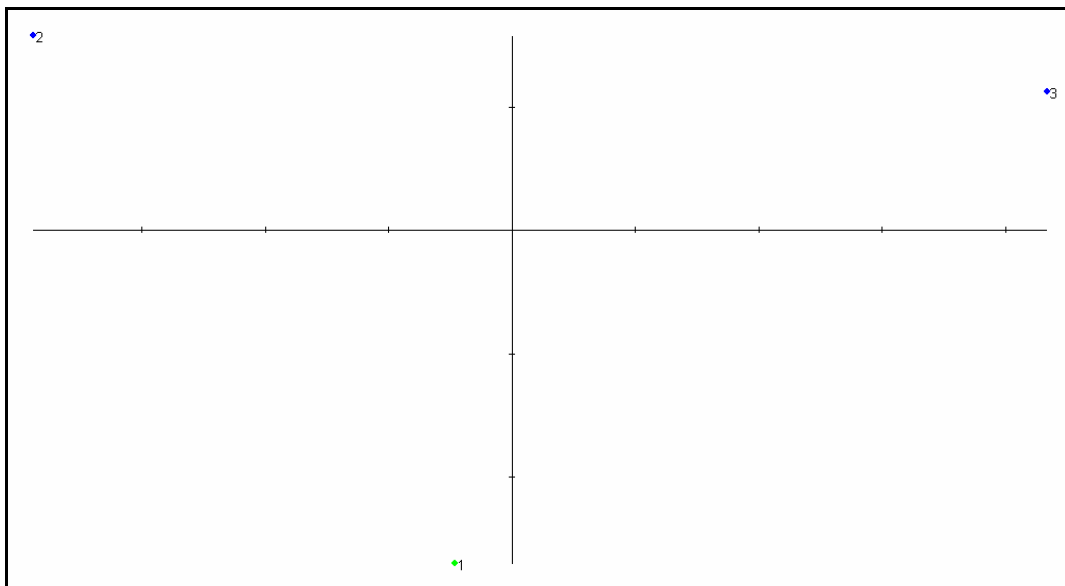


Figure 4.61: Consensus thin- plate spline for seven year old juveniles

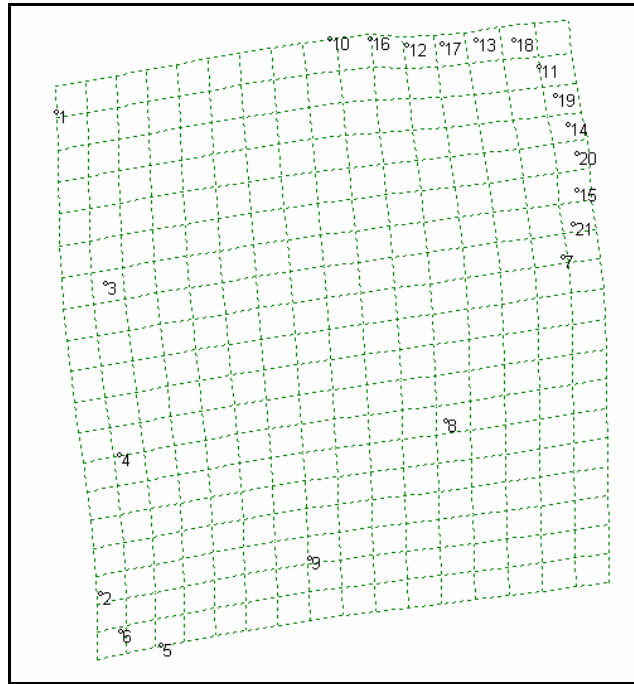


Figure 4.62: Consensus thin- plate spline (in vector mode) to show the separation of seven year old juveniles (green arrow points) from six year old juveniles (black circles)

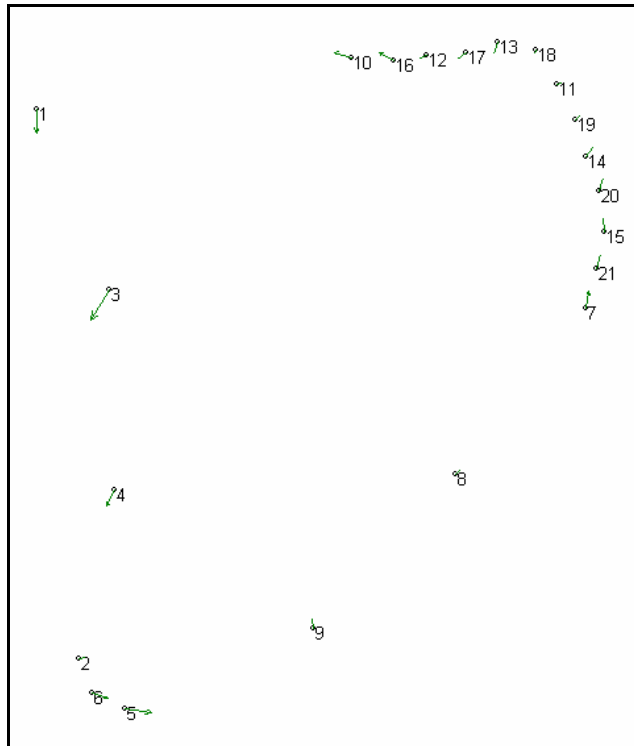


Figure 4.63: Relative Warp Analysis for seven (green) and eight (blue) year old juveniles

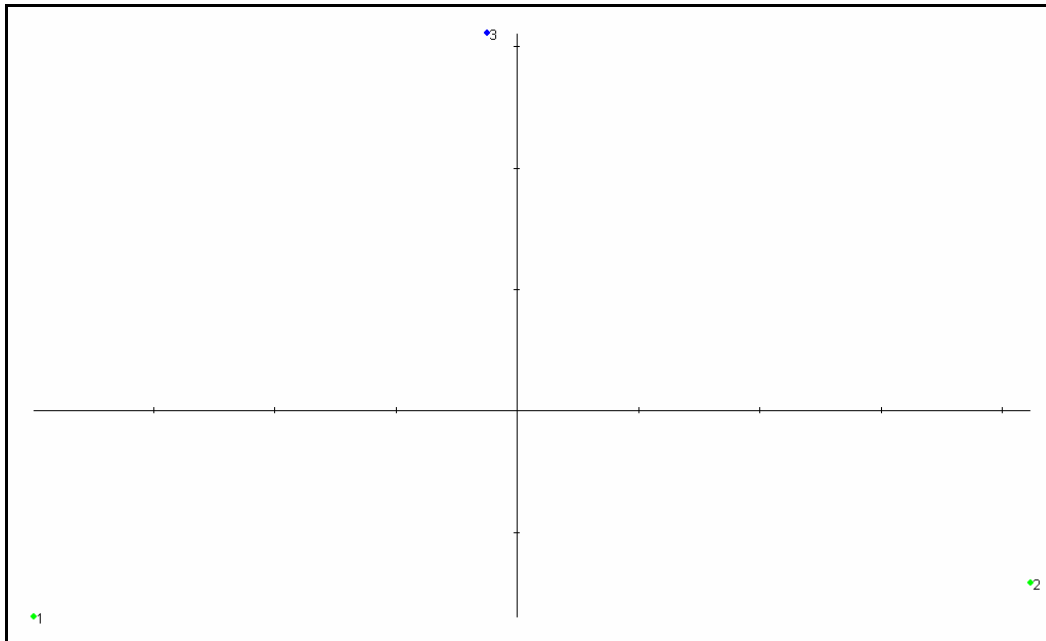


Figure 4.64: Consensus thin-plate spline for eight year old juveniles

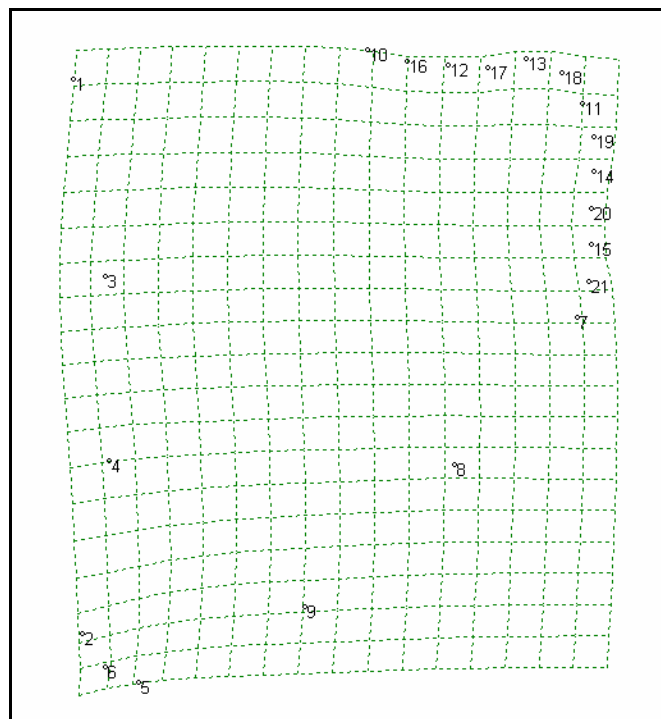


Figure 4.65: Consensus thin- plate spline (in vector mode) to show the separation of eight year old juveniles (green arrow points) from seven year old juveniles (black circles)

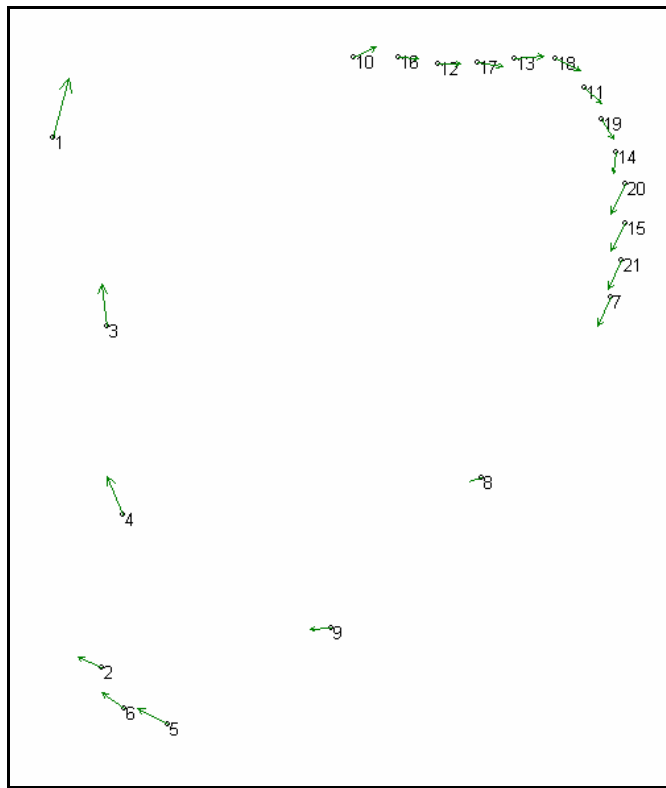


Figure 4.66: Consensus thin- plate spline for nine year old juveniles

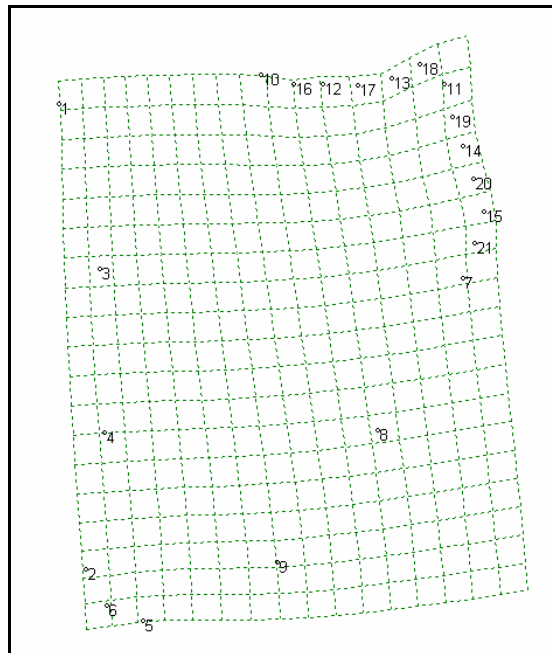


Figure 4.67: Consensus thin- plate spline (in vector mode) to show the separation of nine year old juveniles (green arrow points) from eight year old juveniles (black circles)

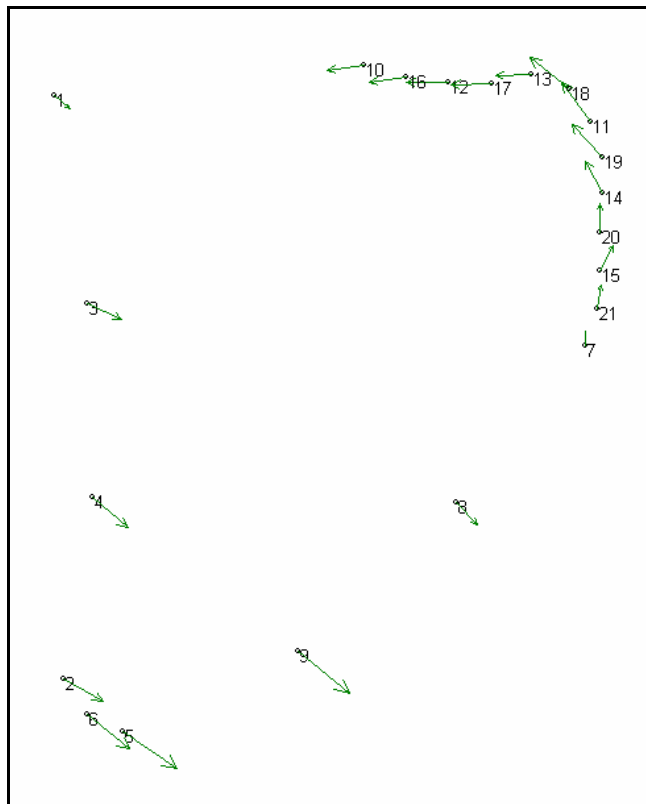


Figure 4.68: Consensus thin- plate spline for 10 year old juveniles

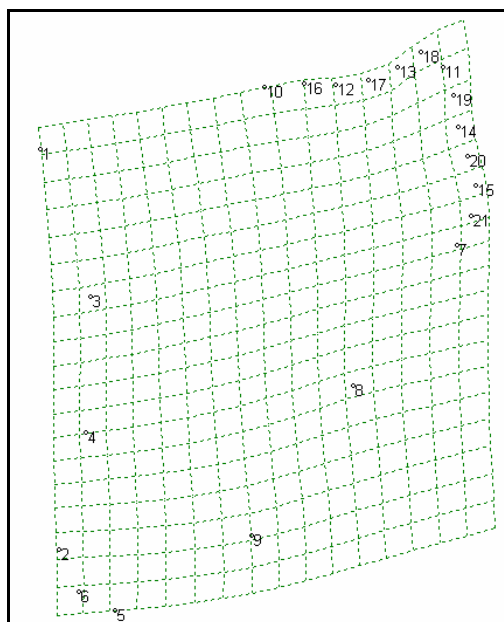


Figure 4.69: Consensus thin- plate spline (in vector mode) to show the separation of 10 year old juveniles (green arrow points) from nine year old juveniles (black circles)

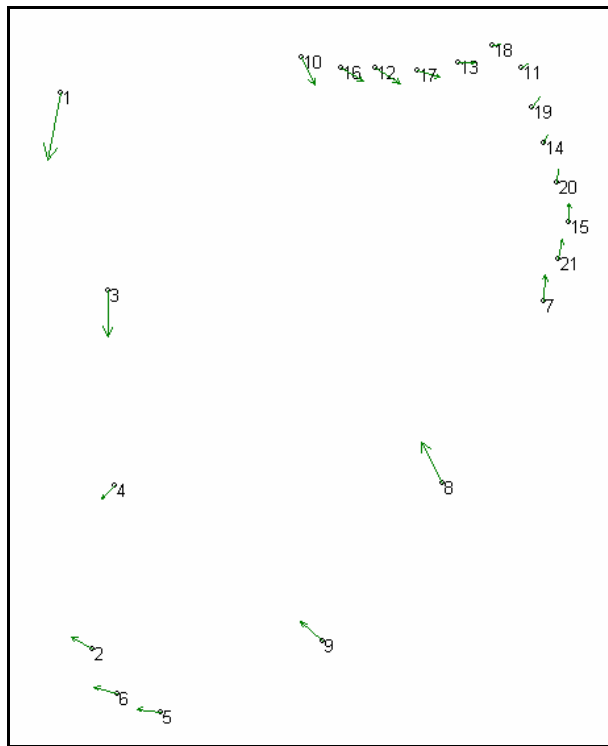


Figure 4.70: Relative Warp Analysis for 10 (green) and 12 (blue) year old juveniles

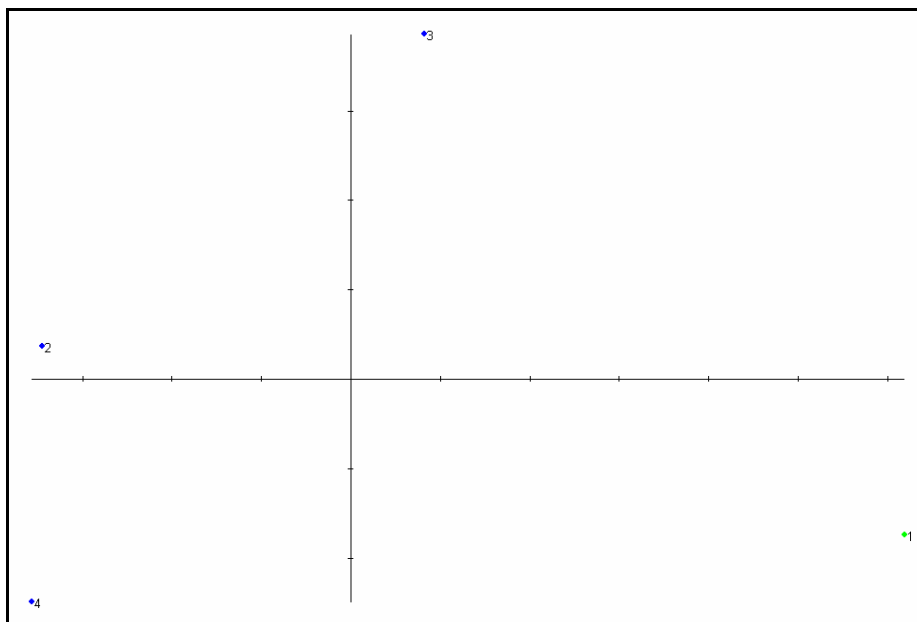


Figure 4.71: Consensus thin- plate spline for 12 year old juveniles

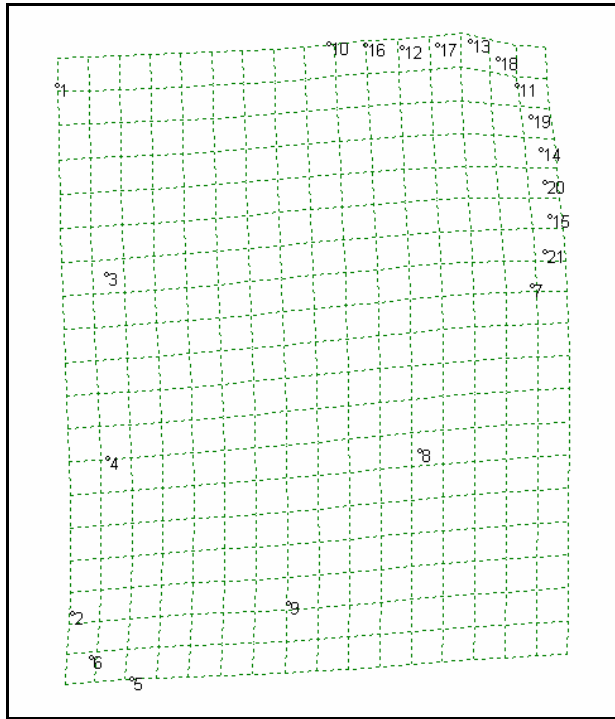


Figure 4.72: Consensus thin- plate spline (in vector mode) to show the separation of 12 year old juveniles (green arrow points) from 10 year old juveniles (black circles)

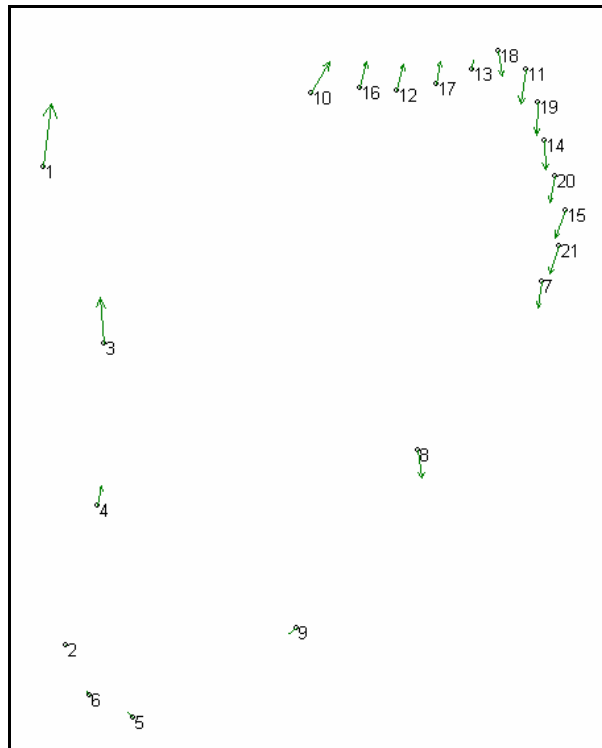


Figure 4.73: Relative Warp Analysis for 12 (green) and 13 (blue) year old juveniles

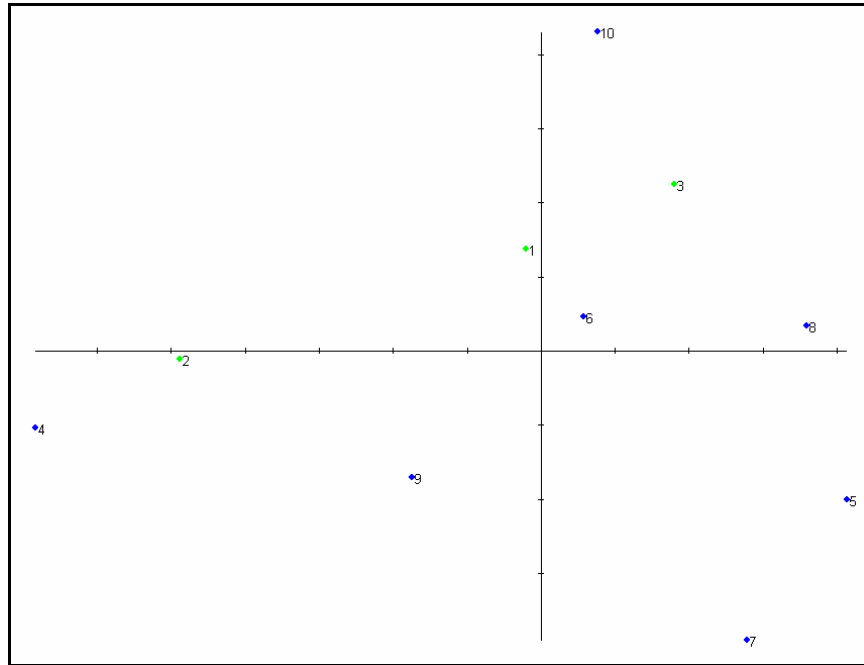


Figure 4.74: Consensus thin-plate spline for 13 year old juveniles

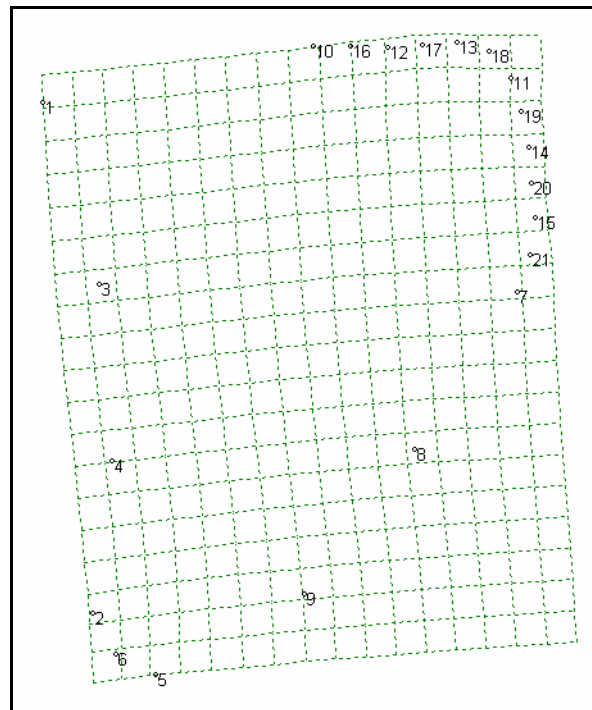


Figure 4.75: Consensus thin- plate spline (in vector mode) to show the separation of 13 year old juveniles (green arrow points) from 12 year old juveniles (black circles)



Figure 4.76: Relative Warp Analysis for 13 (green) and 14 (blue) year old individuals

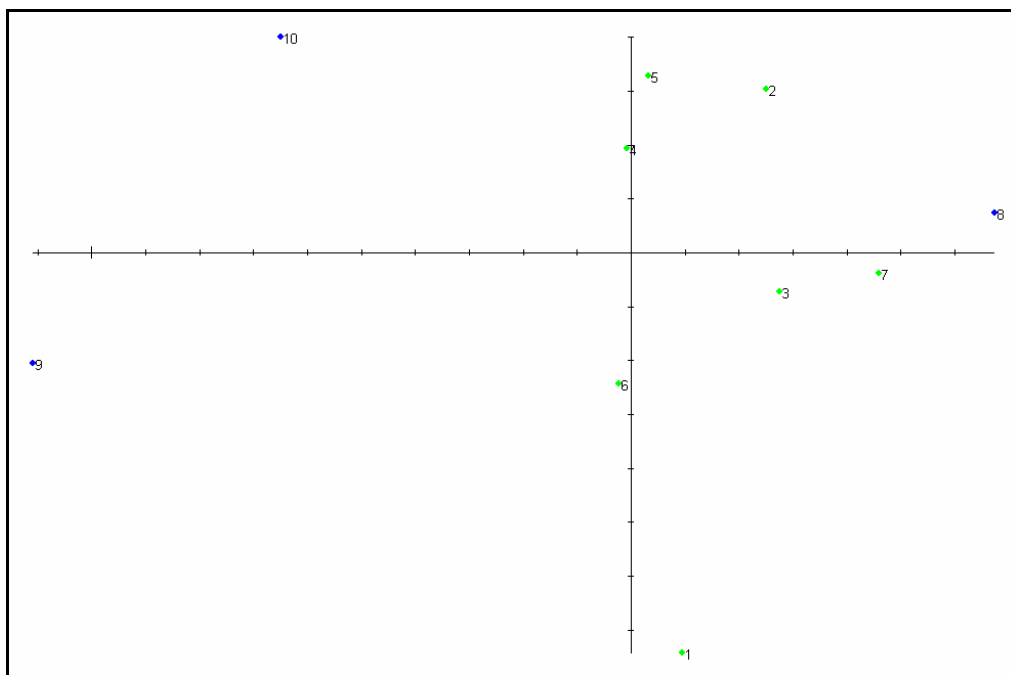


Figure 4.77: Consensus thin- plate spline for 14 year old juveniles

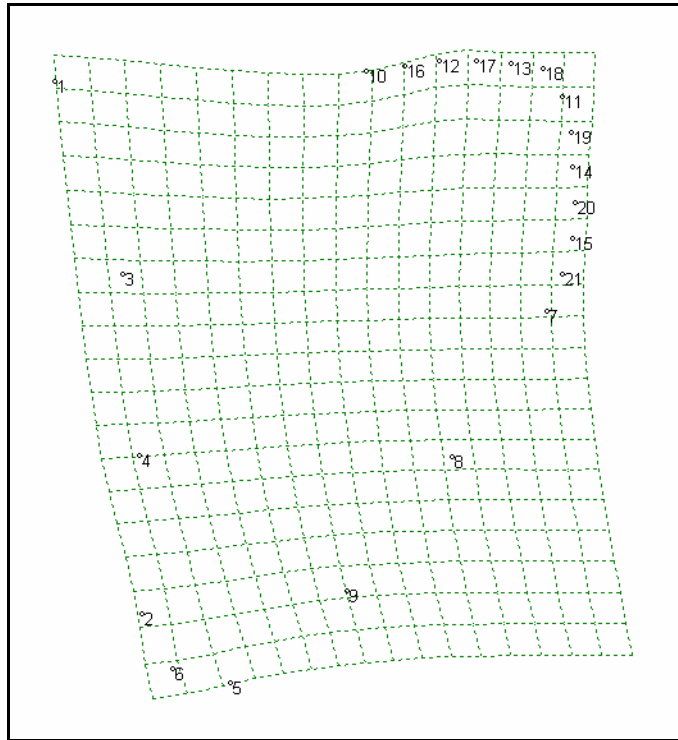


Figure 4.78: Consensus thin- plate spline (in vector mode) to show the separation of 14 year old juveniles (green arrow points) from 13 year old juveniles (black circles)

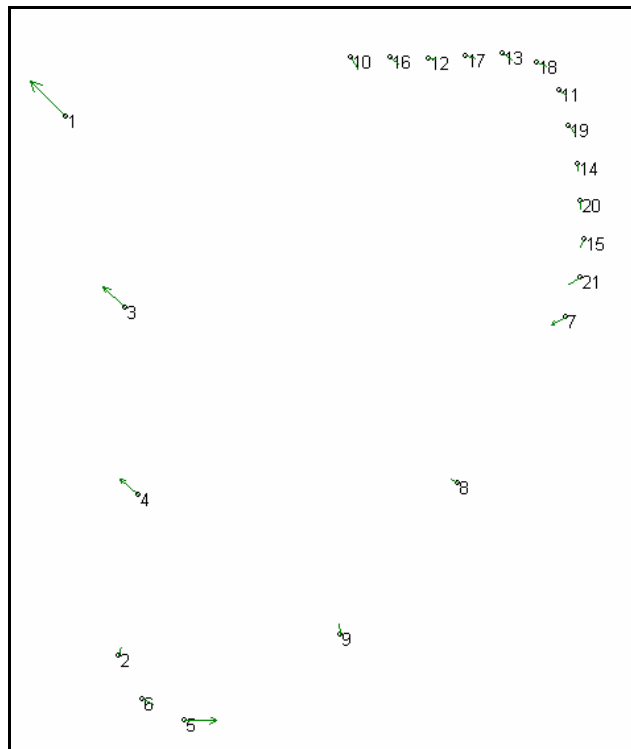


Figure 4.79: Relative Warp Analysis for 14 (green) and 15 (blue) year old individuals

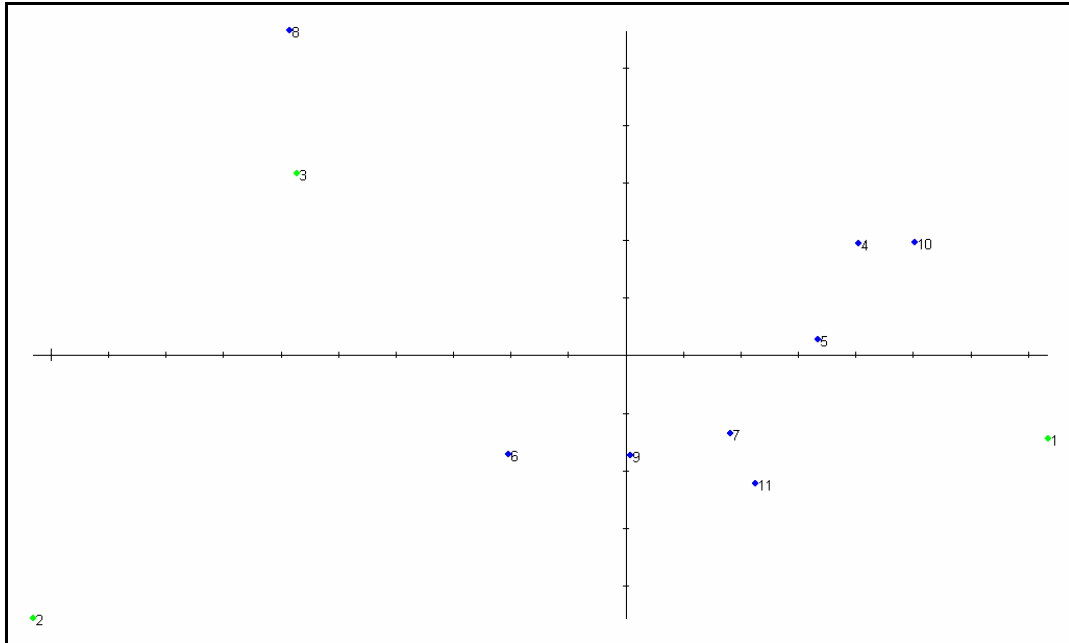


Figure 4.80: Consensus thin- plate spline for 15 year old juveniles

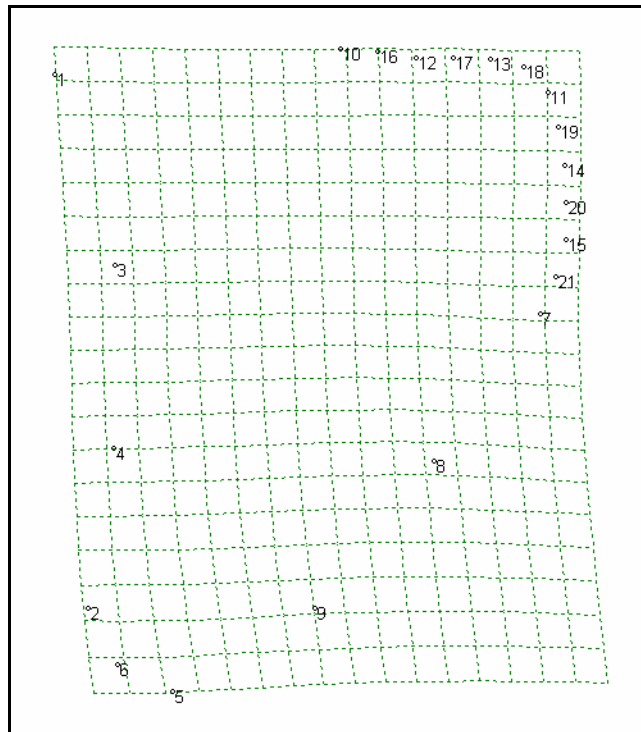


Figure 4.81: Consensus thin- plate spline (in vector mode) to show the separation of 15 year old juveniles (green arrow points) from 14 year old juveniles (black circles)

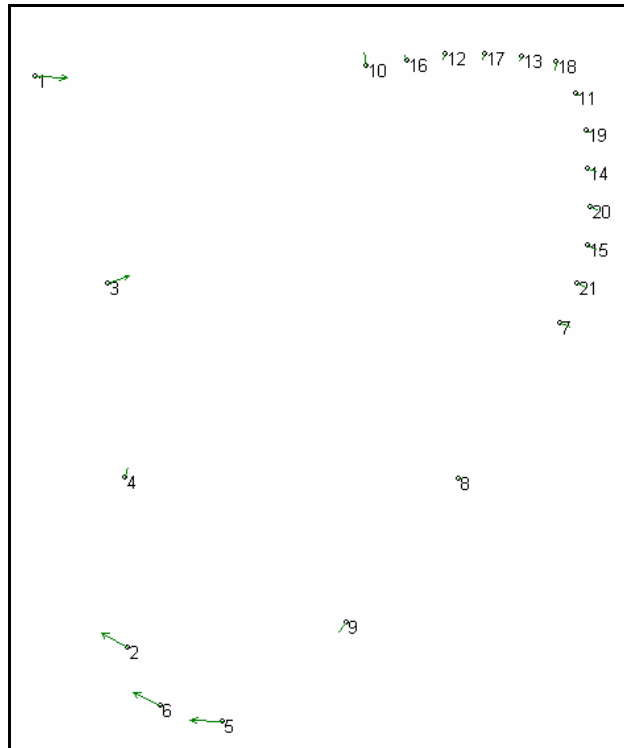


Figure 4.82: Relative Warp Analysis for 15 (green) and 16 (blue) year old juveniles

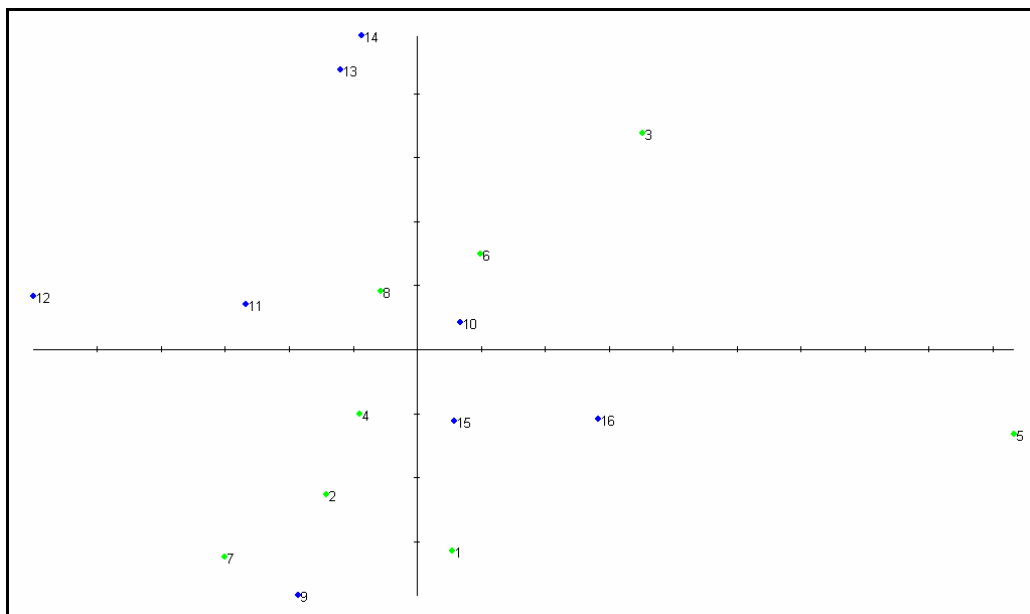


Figure 4.83: Consensus thin- plate spline for 16 year old juveniles

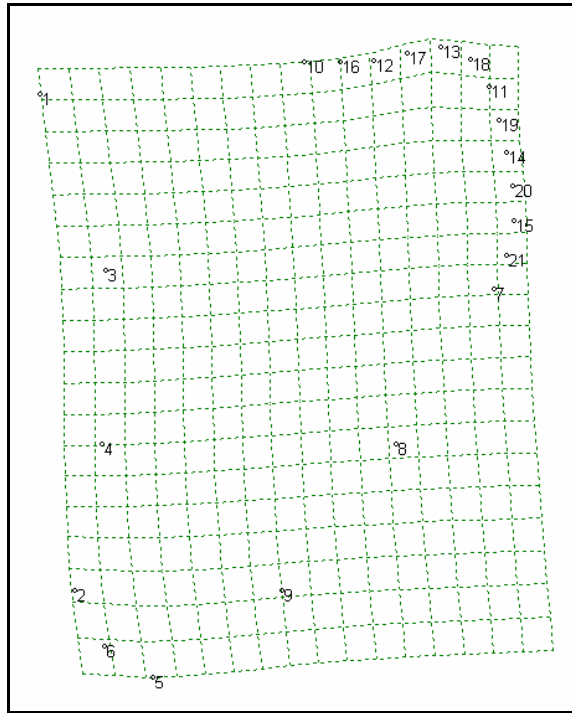


Figure 4.84: Consensus thin- plate spline (in vector mode) to show the separation of 16 year old juveniles (green arrow points) from 15 year old juveniles (black circles)

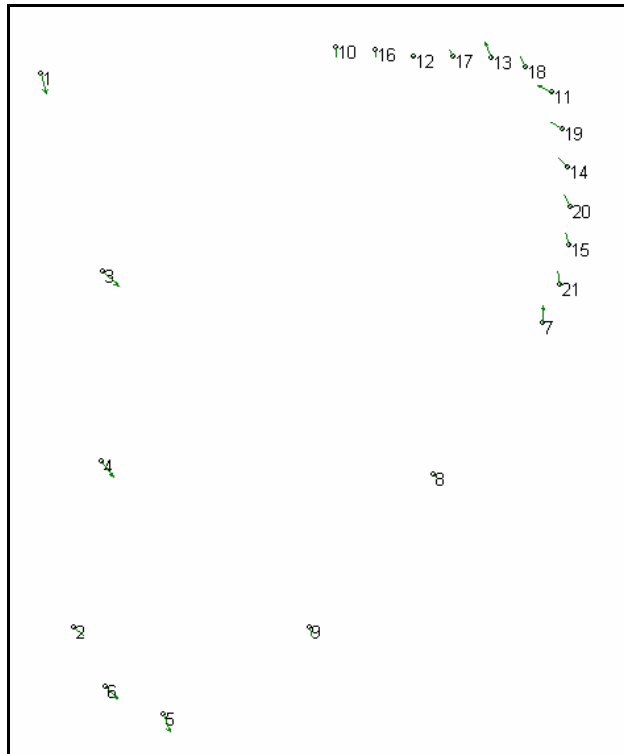


Figure 4.85: Relative Warp Analysis for 16 (green) and 17 (blue) year old juveniles

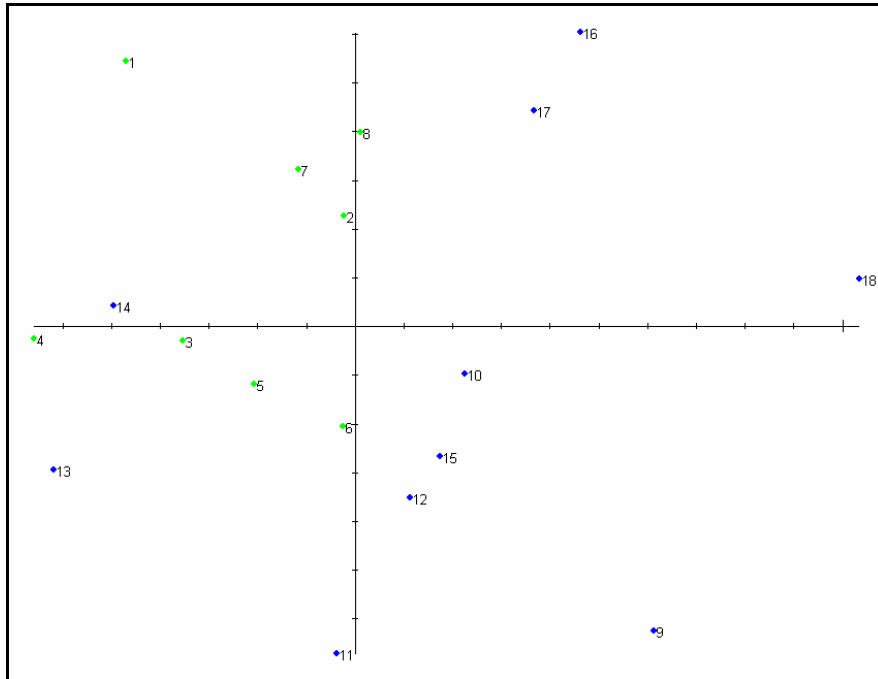


Figure 4.86: Consensus thin-plate spline for 17 year old juveniles

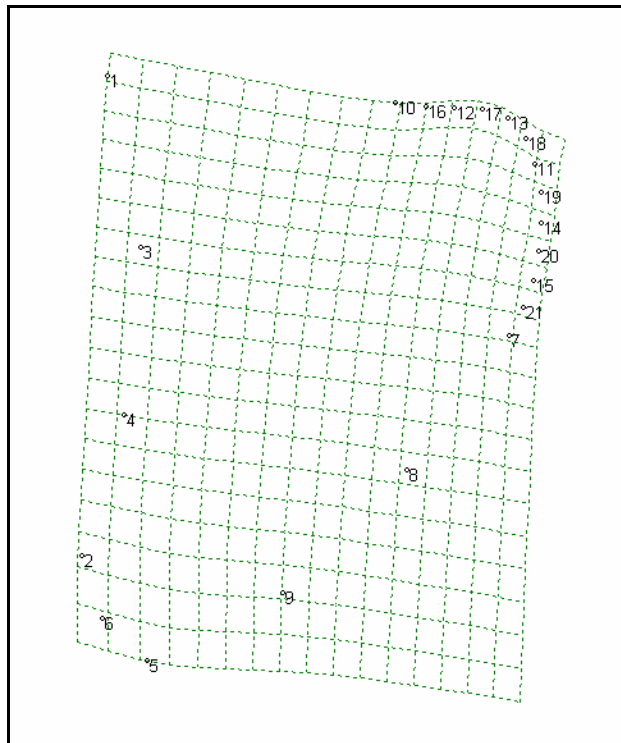


Figure 4.87: Consensus thin- plate spline (in vector mode) to show the separation of 17 year old juveniles (green arrow points) from 16 year old juveniles (black circles)

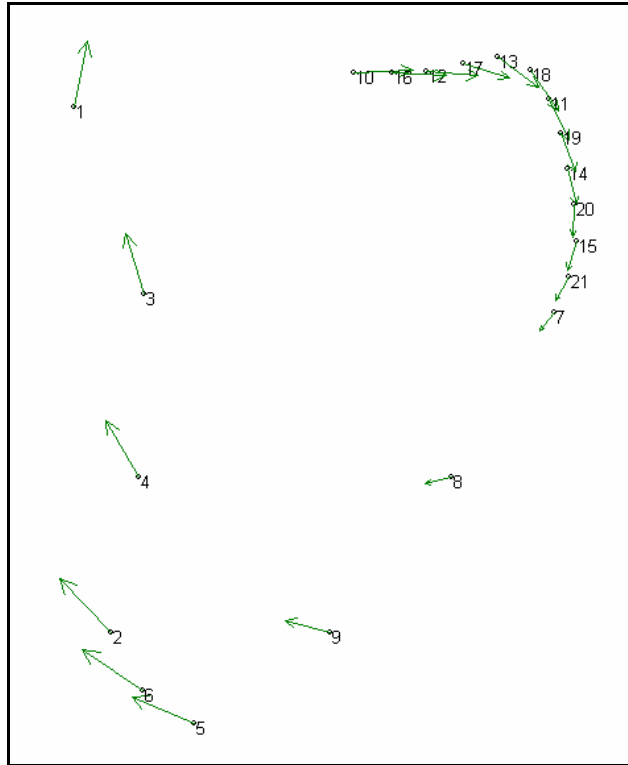


Figure 4.88: Relative Warp Analysis for 17 (green) and 18 (blue) year old juveniles

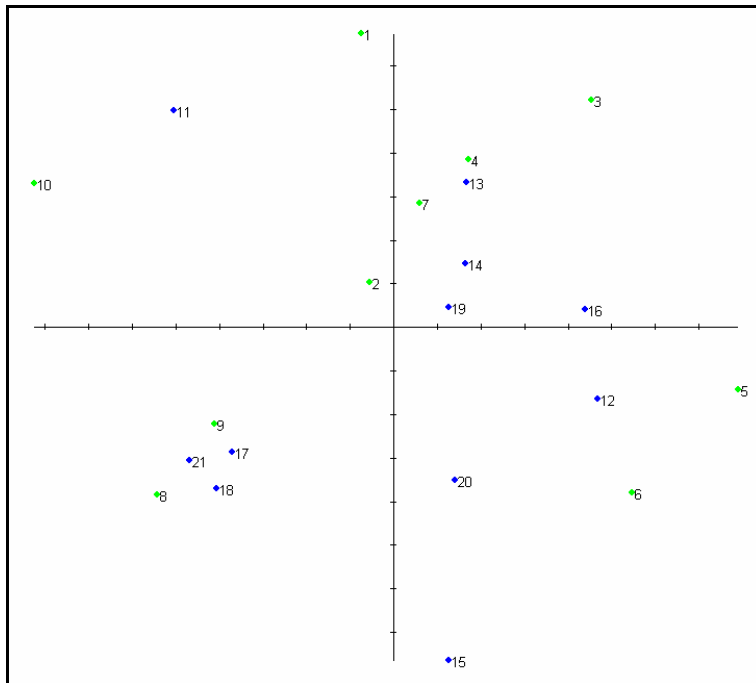


Figure 4.89: Consensus thin- plate spline for 18 year old juveniles

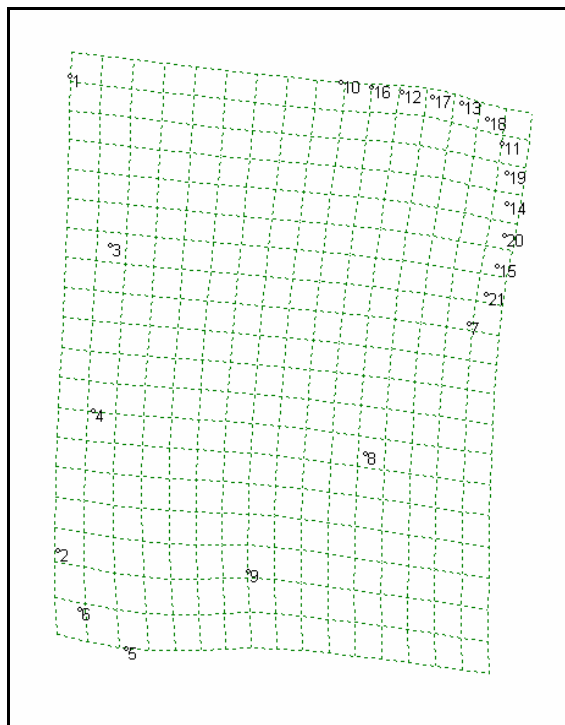


Figure 4.90: Consensus thin- plate spline (in vector mode) to show the separation of 18 year old juveniles (green arrow points) from 17 year old juveniles (black circles)

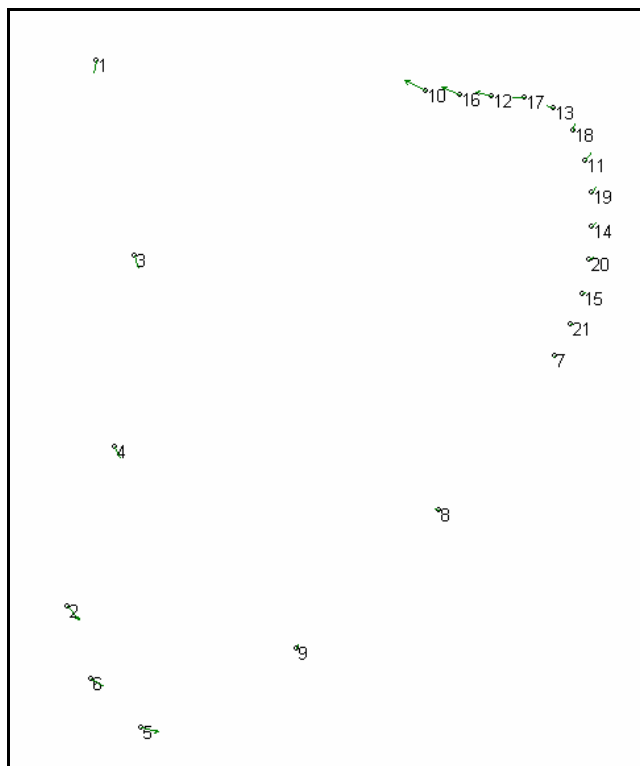


Figure 4.91: Relative Warp Analysis for 18 (green) and 19 (blue) year old juveniles

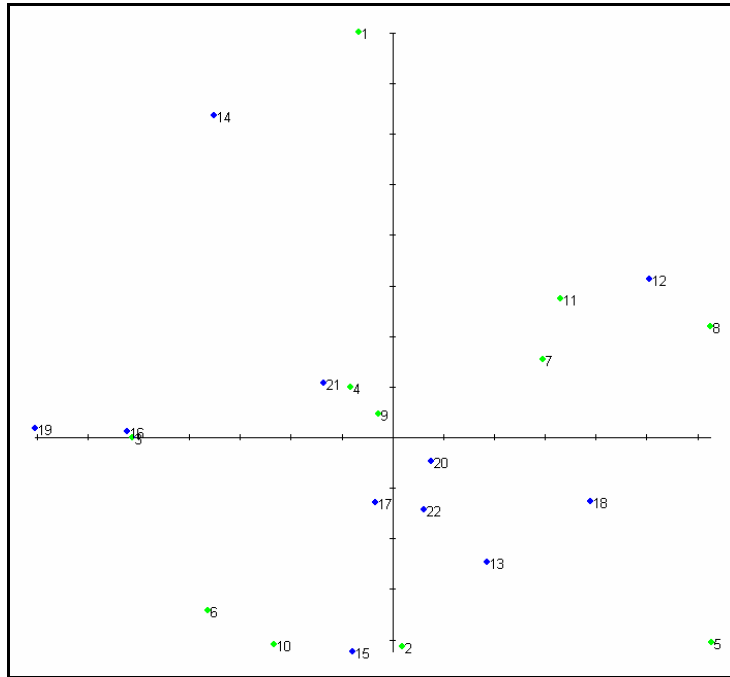


Figure 4.92: Consensus thin-plate spline for 19 year old juveniles

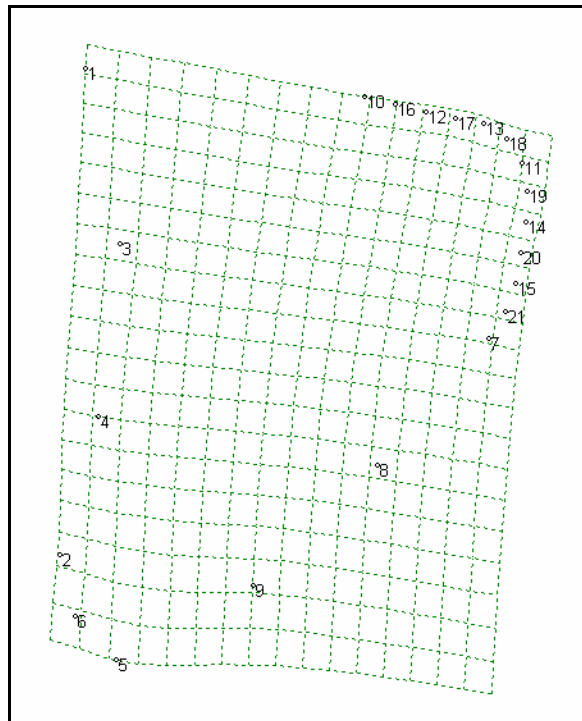


Figure 4.93: Consensus thin- plate spline (in vector mode) to show the separation of 19 year old juveniles (green arrow points) from 18 year old juveniles (black circles)

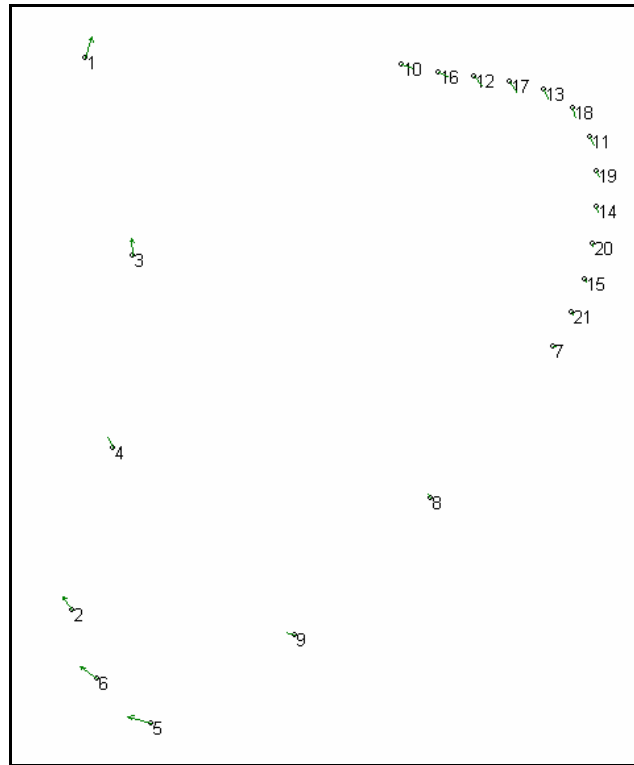


Figure 4.94: Relative Warp Analysis for 1 – 10 (green) and 12 – 19 (blue) year old juveniles

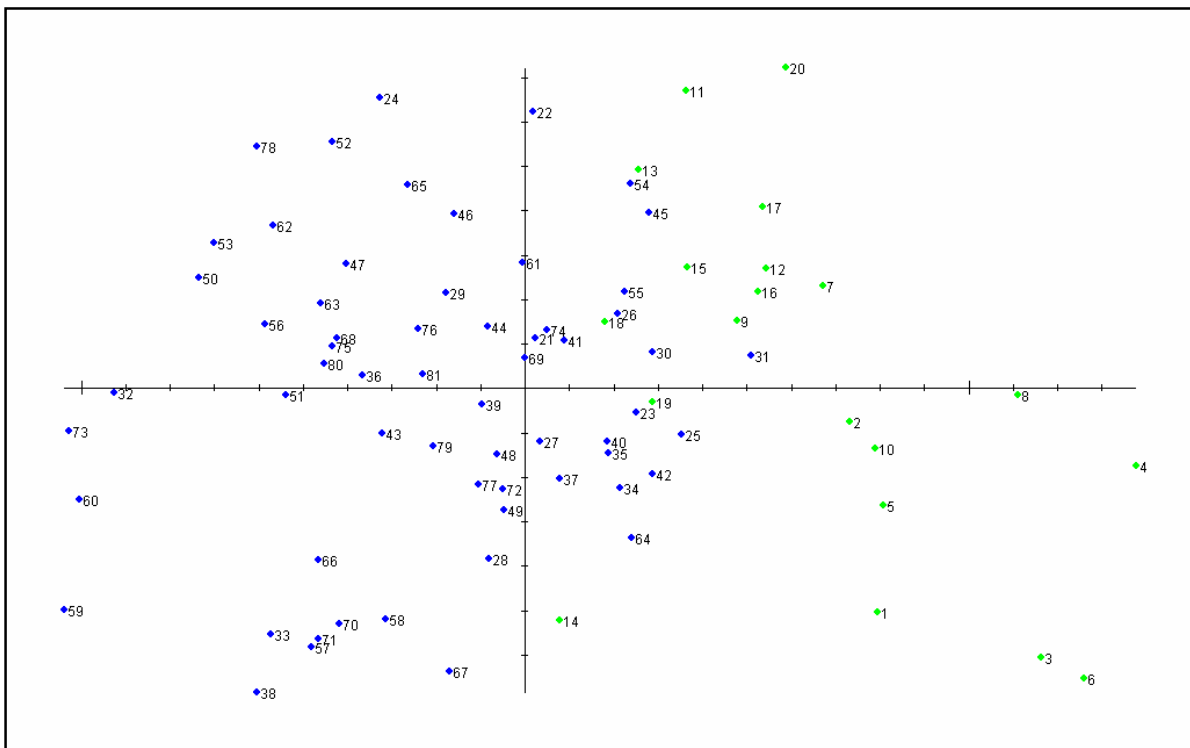


Figure 4.95: Consensus thin- plate spline for 1 – 10 year old juveniles

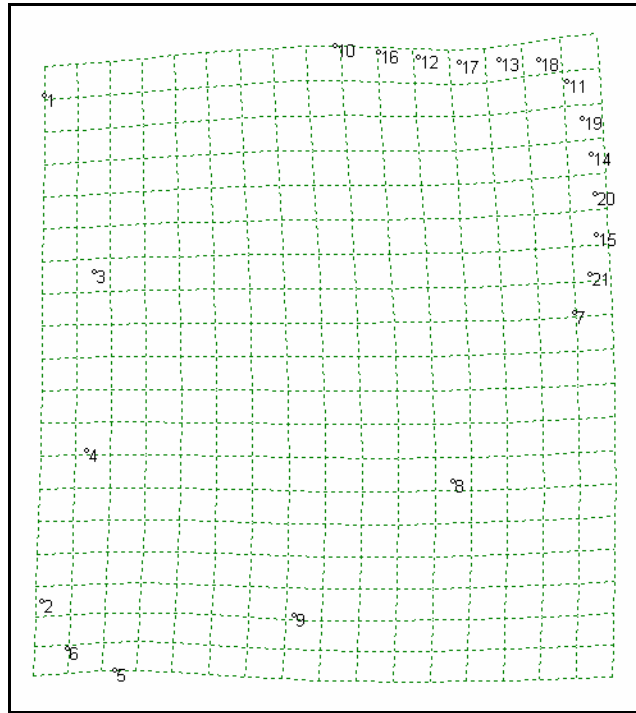


Figure 4.96: Consensus thin- plate spline for 12 – 19 year old juveniles

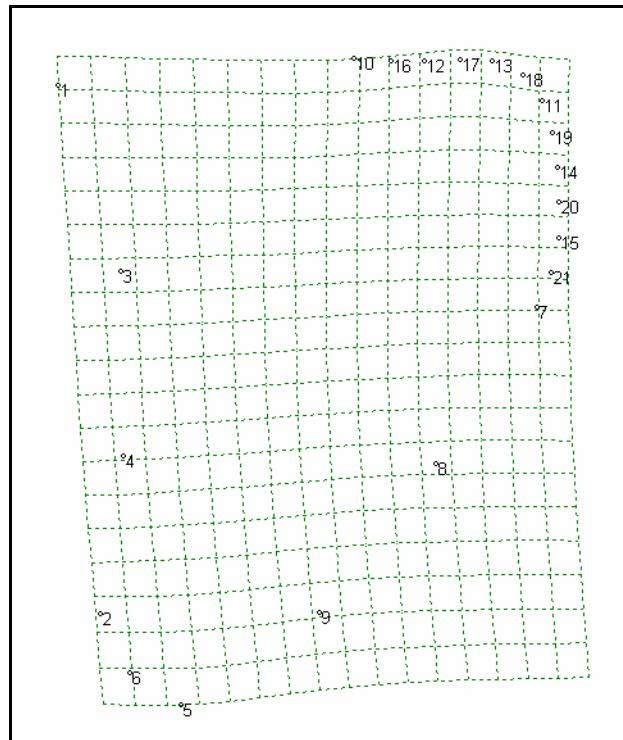


Figure 4.97: Consensus thin- plate spline (in vector mode) to show the separation of 12 – 19 year old juveniles (green arrow points) from 1 – 10 year old juveniles (black circles)

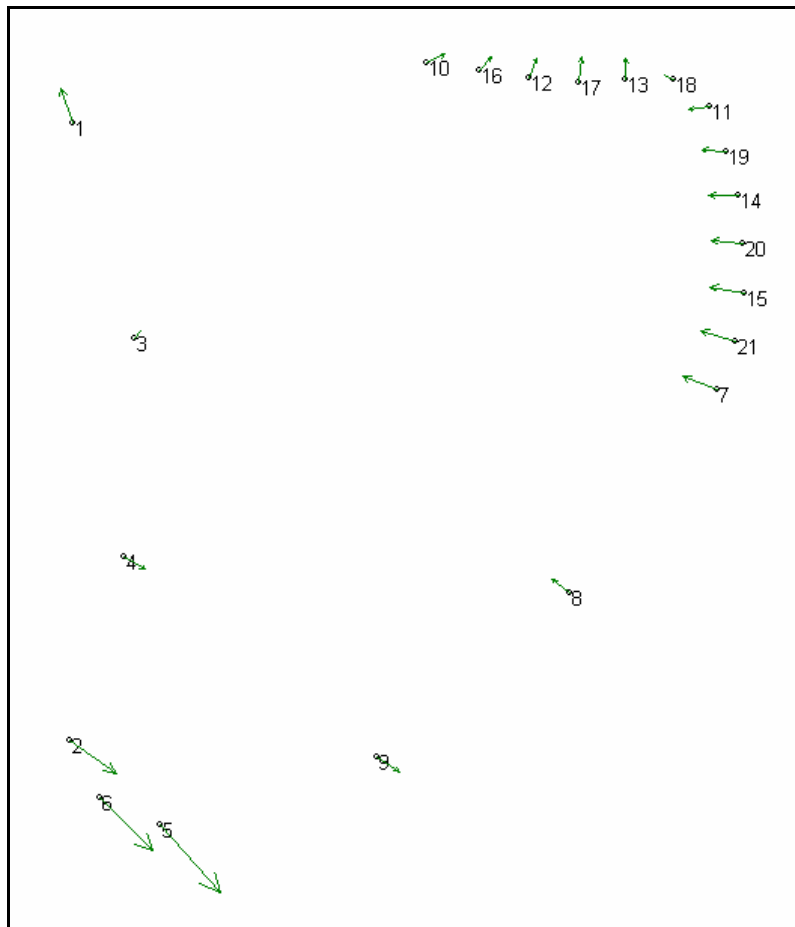


Figure 4.98: TwoGroup BC Superimposition plot for 1 – 10 and 12 – 19 year old individuals (○ = 1 – 10 year old; □ = 12 – 19 year old). The lateral border is on the horizontal (x-) axis. Landmark 1 is represented by the point (0,0) and landmark 2 by the point (0,1)

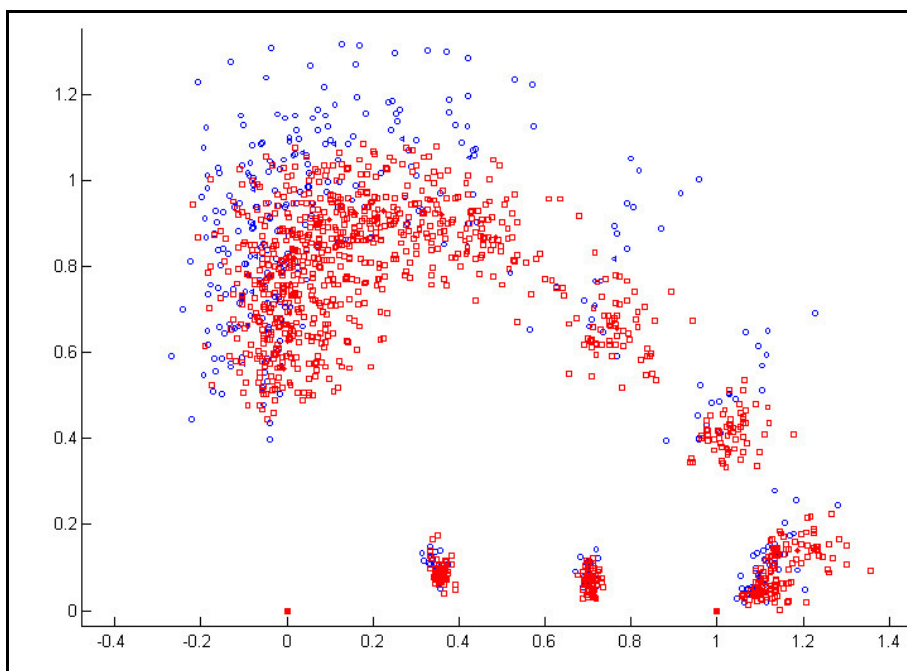


Figure 4.99: CVA plot for 1 – 10 and 12 – 19 year old individuals (○ = 1 – 10 year old; x = 12 – 19 year old). The lateral border is situated on the horizontal (x-) axis

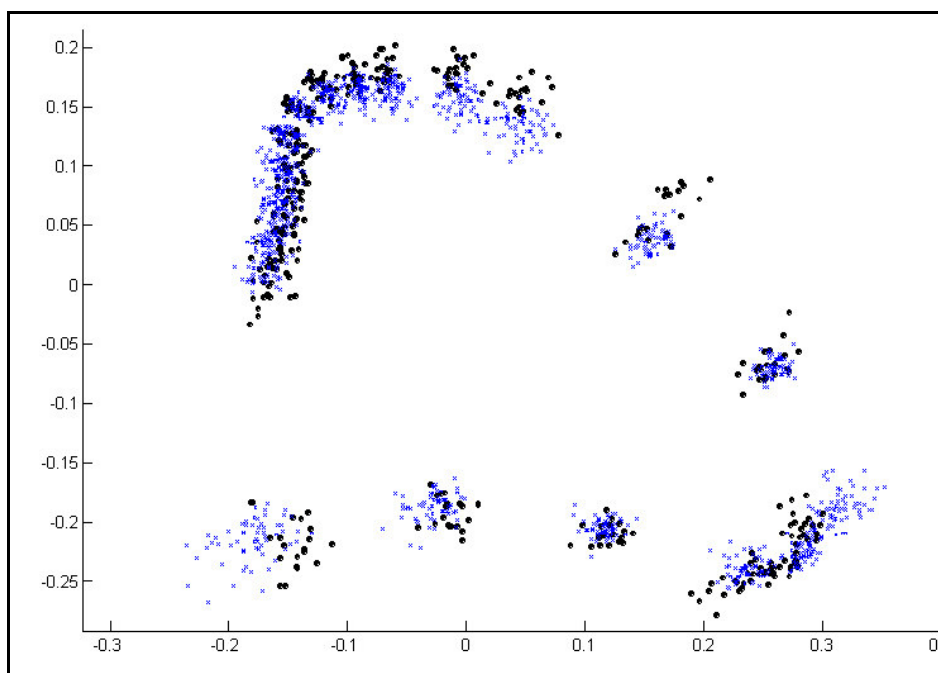


Figure 4.100: Mean of the CVA plot for 1 – 10 and 12 – 19 year old individuals (○ = 1 – 10 year old; x = 12 – 19 year old). The larger black circle and blue cross represent the mean shape for adult females and males respectively

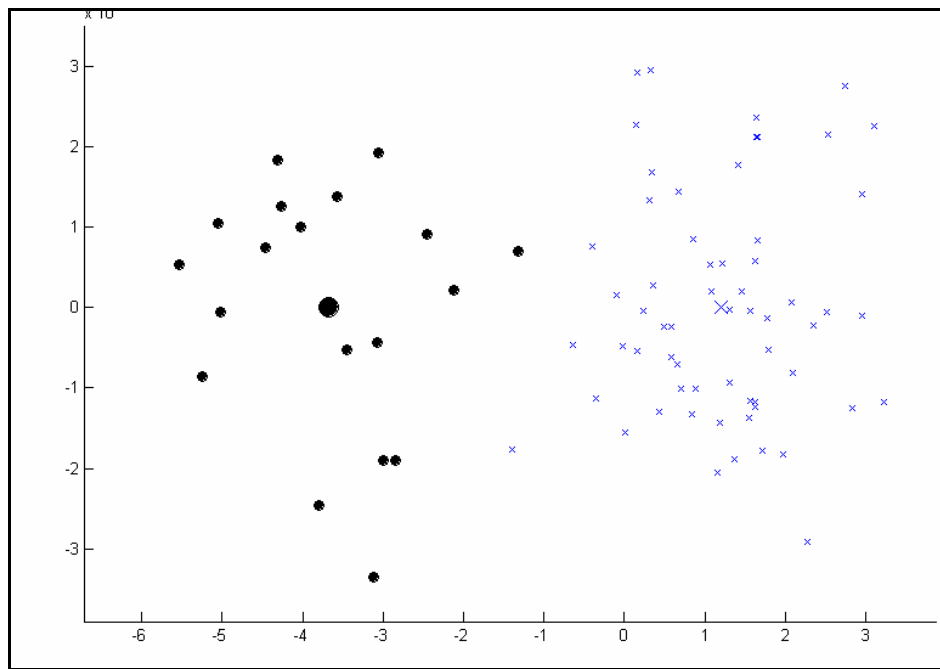


Figure 4.101: Relative Warp Analysis for lateral borders of whole juvenile group [1 – 6 : 1 year old juveniles (dark blue); 7 – 8: 2 year old juveniles (red); 9 – 11: 3 year old juveniles (yellow); 12 – 14: 4 year old juveniles (orange); 15: 6 year old juvenile (olive green); 16 – 17: 7 year old juveniles (maroon); 18: 8 year old juvenile (pink); 19: 9 year old juvenile (brown); 20: 10 year old juvenile (turquoise); 21 – 23: 12 year old juveniles (fuchsia); 24 – 30: 13 year old juveniles (bright green); 31 – 33: 14 year old juveniles (blue); 34 – 41: 15 year old juveniles (violet); 42 – 49: 16 year old juveniles (teal); 50 – 59: 17 year old juveniles (light pink); 60 – 70: 18 year old juveniles (light blue); 71 – 81: 19 year old juveniles (grey)]

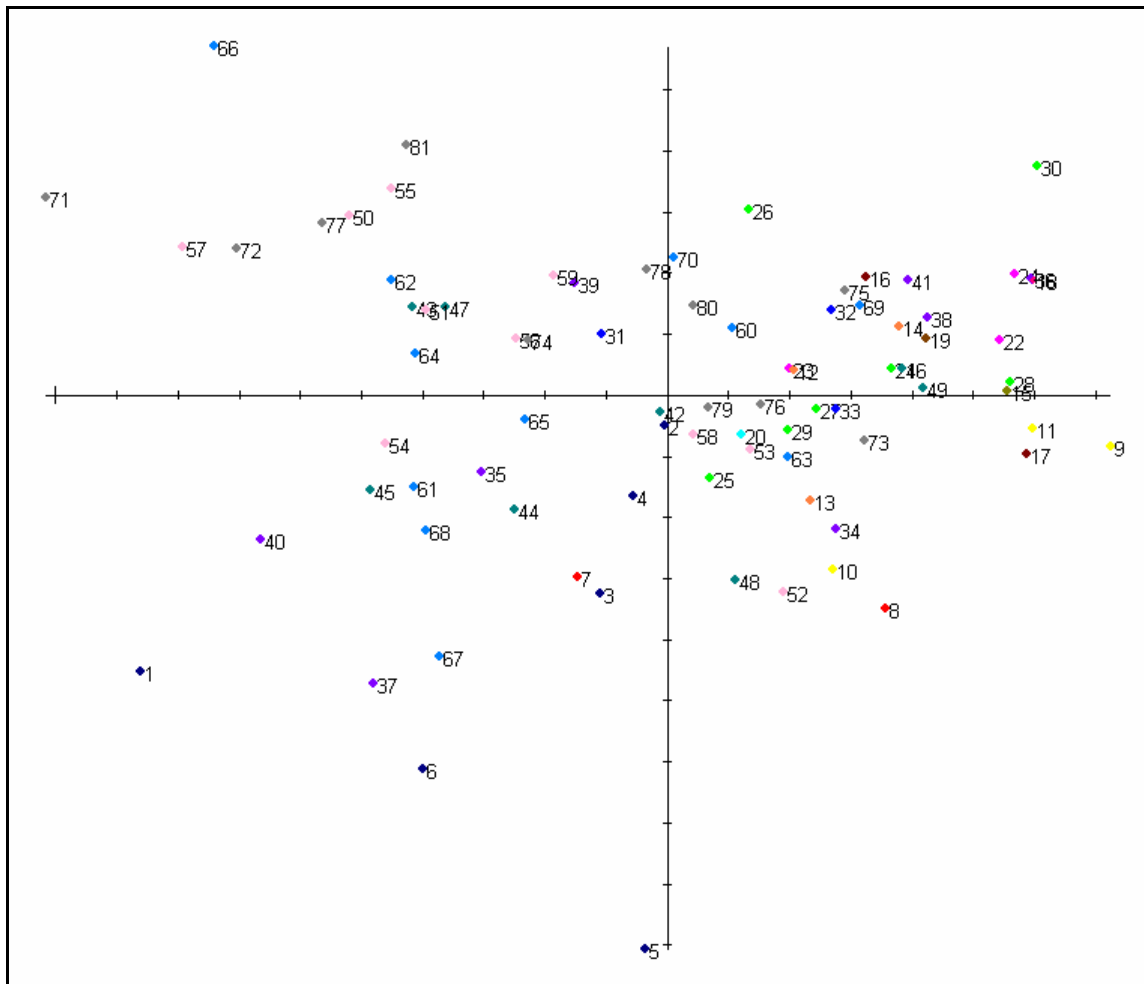


Figure 4.102: Relative Warp Analysis for the consensus of the lateral borders of the whole juvenile group [1: 1 year old juveniles (dark blue); 2: 2 year old juveniles (red); 3: 3 year old juveniles (yellow); 4: 4 year old juveniles (orange); 5: 6 year old juvenile (olive green); 6: 7 year old juveniles (maroon); 7: 8 year old juvenile (pink); 8: 9 year old juvenile (brown); 9: 10 year old juvenile (turquoise); 10: 12 year old juveniles (fuchsia); 11: 13 year old juveniles (bright green); 12: 14 year old juveniles (blue); 13: 15 year old juveniles (violet); 14: 16 year old juveniles (teal); 15: 17 year old juveniles (light pink); 16: 18 year old juveniles (light blue); 17: 19 year old juveniles (grey)]

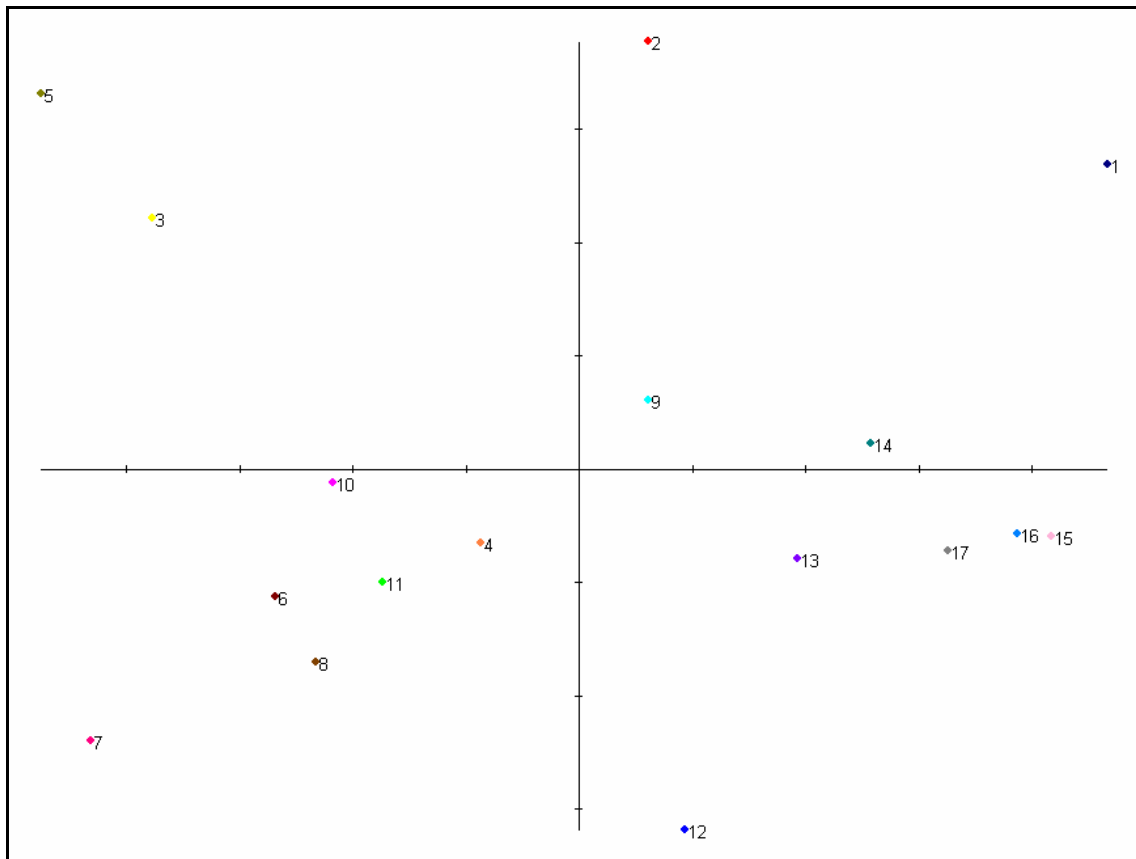


Figure 4.103: Relative Warp Analysis for the lateral border of one (green) and two (blue) year old juveniles

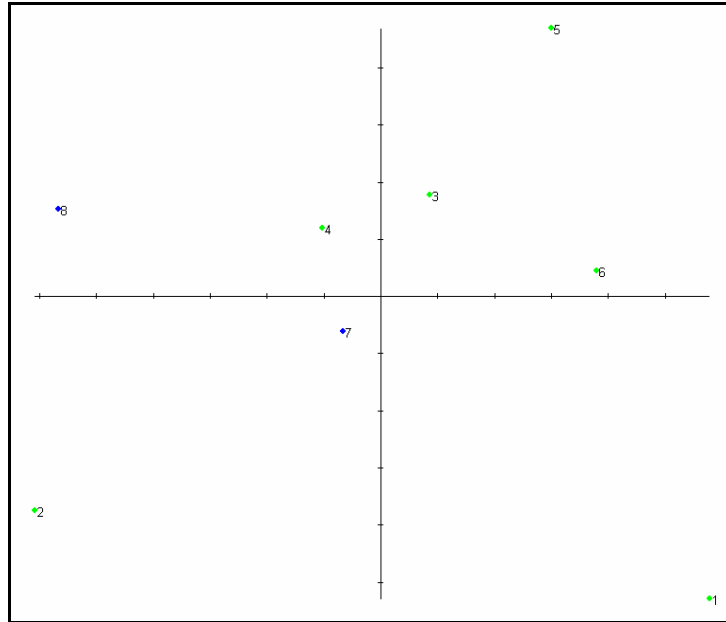


Figure 4.104: Consensus thin-plate spline (in vector mode) to show the separation of two year old juveniles (green arrow points) from one year old juveniles (black circles) along the lateral border

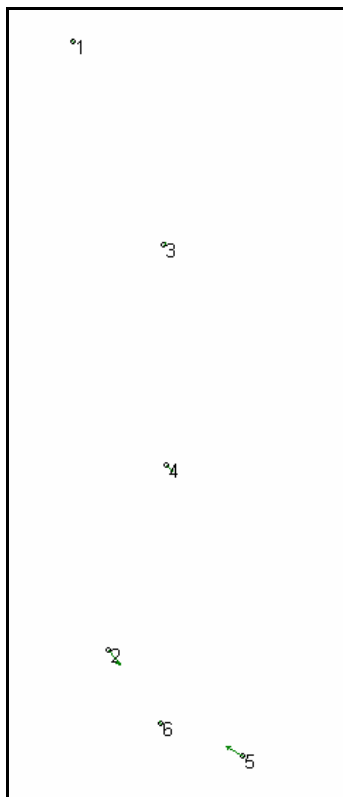


Figure 4.105: Relative Warp Analysis for the lateral border of two (green) and three (blue) year old juveniles

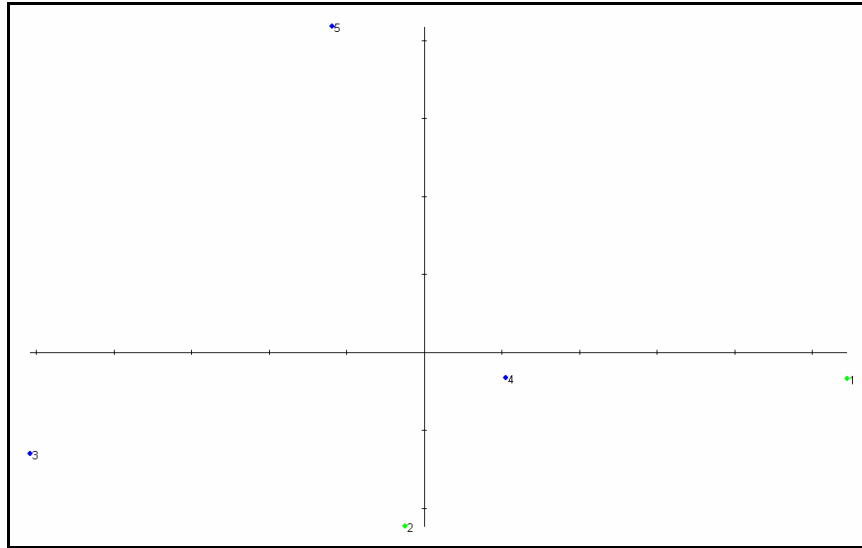


Figure 4.106: Consensus thin- plate spline (in vector mode) to show the separation of three year old juveniles (green arrow points) from two year old juveniles (black circles) along the lateral border

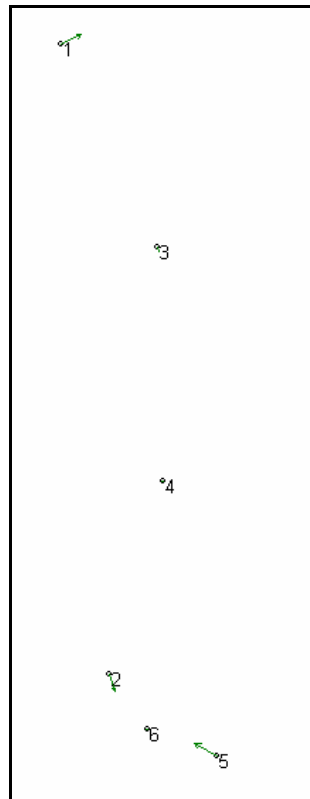


Figure 4.107: Relative Warp Analysis for the lateral border of three (green) and four (blue) year old juveniles

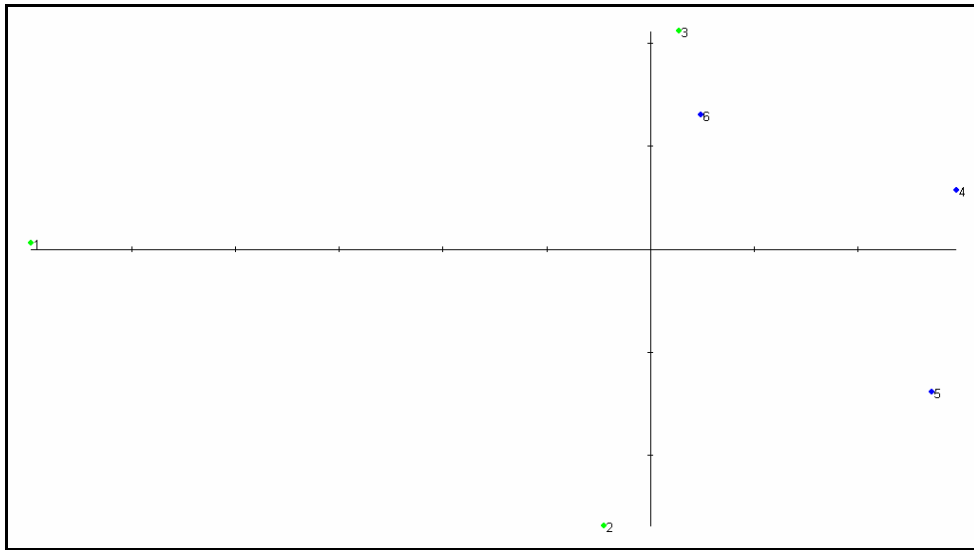


Figure 4.108: Consensus thin- plate spline (in vector mode) to show the separation of four year old juveniles (green arrow points) from three year old juveniles (black circles) along the lateral border

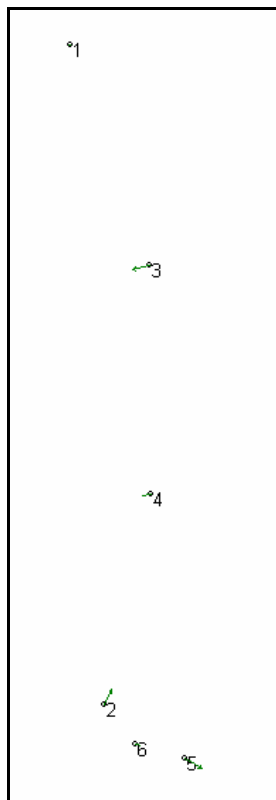


Figure 4.109: Relative Warp Analysis for the lateral border of four (green) and six (blue) year old juveniles

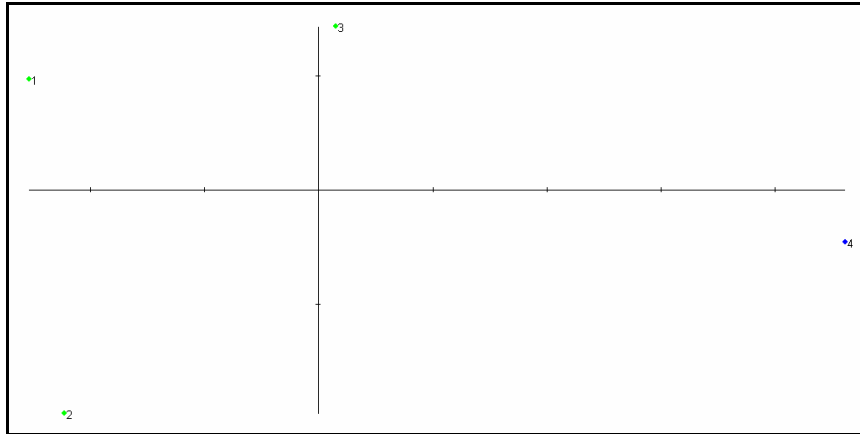


Figure 4.110: Consensus thin- plate spline (in vector mode) to show the separation of six year old juveniles (green arrow points) from four year old juveniles (black circles) along the lateral border

Figure 4.111: Consensus thin- plate spline (in vector mode) to show the separation of seven year old juveniles (green arrow points) from six year old juveniles (black circles) along the lateral border



Figure 4.112: Consensus thin- plate spline (in vector mode) to show the separation of eight year old juveniles (green arrow points) from seven year old juveniles (black circles) along the lateral border

Figure 4.113: Consensus thin- plate spline (in vector mode) to show the separation of nine year old juveniles (green arrow points) from eight year old juveniles (black circles) along the lateral border

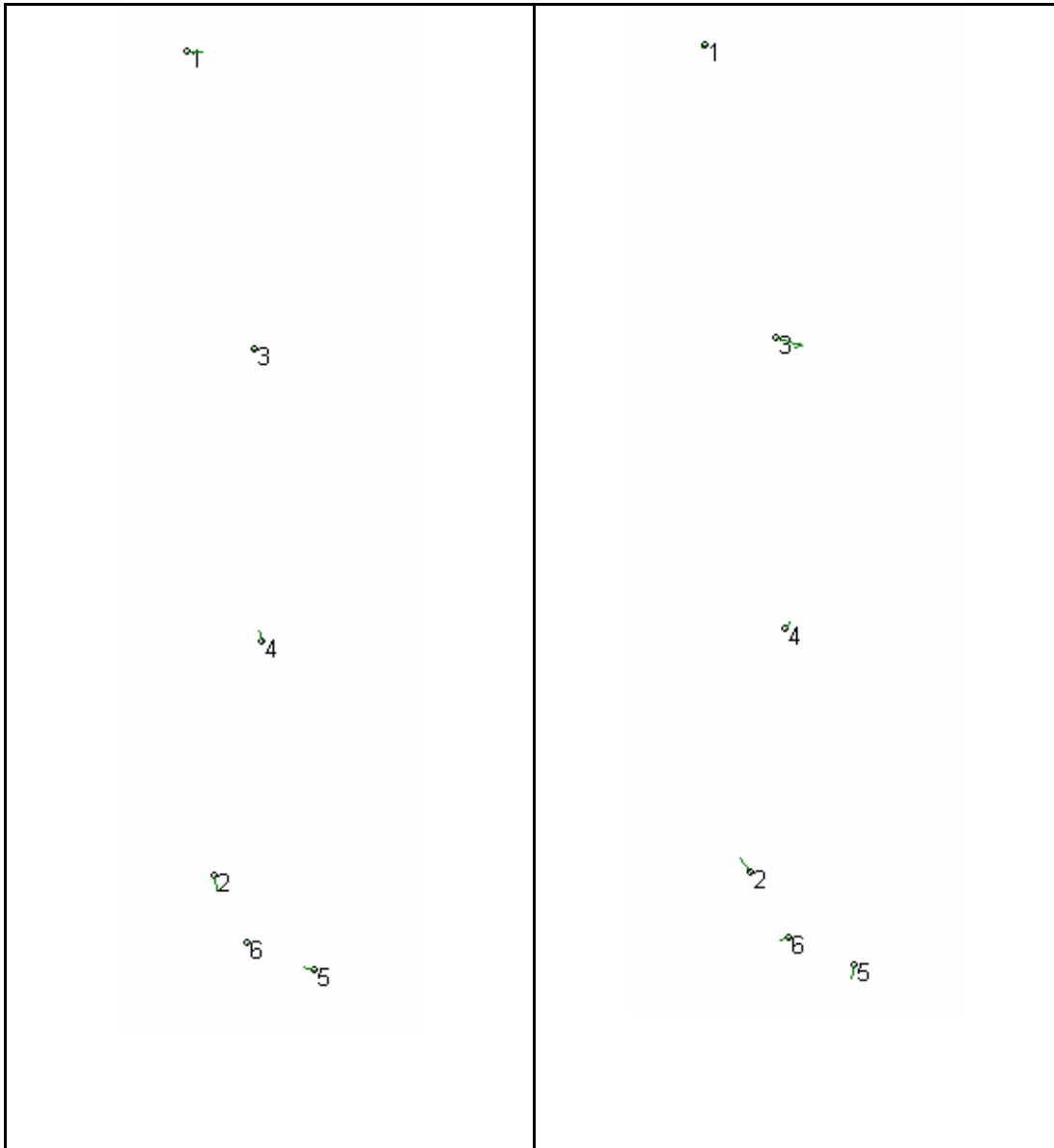


Figure 4.114: Consensus thin- plate spline (in vector mode) to show the separation of 10 year old juveniles (green arrow points) from nine year old juveniles (black circles) along the lateral border

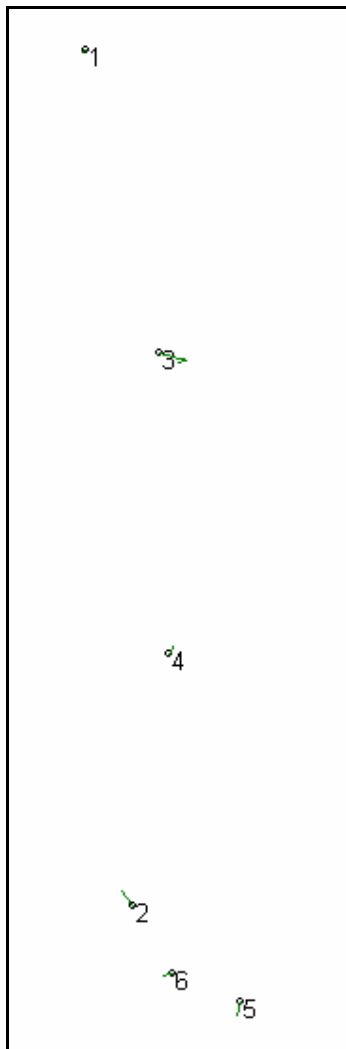


Figure 4.115: Relative Warp Analysis for the lateral border of 10 (green) and 12 (blue) year old juveniles

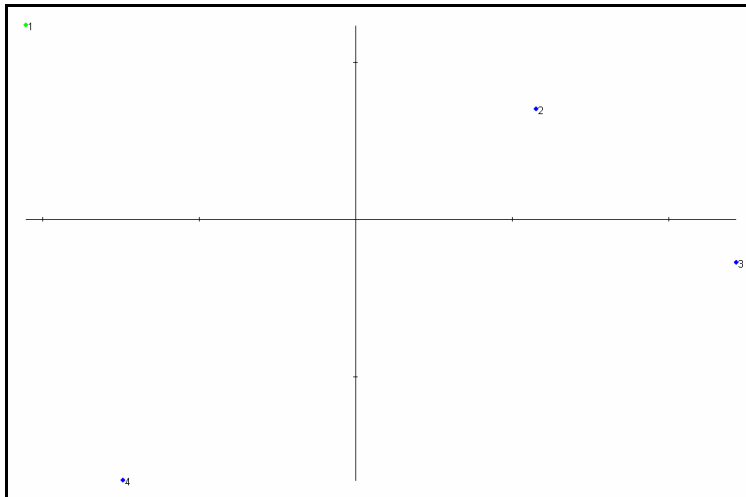


Figure 4.116: Consensus thin-plate spline (in vector mode) to show the separation of 12 year old juveniles (green arrow points) from 10 year old juveniles (black circles) along the lateral border

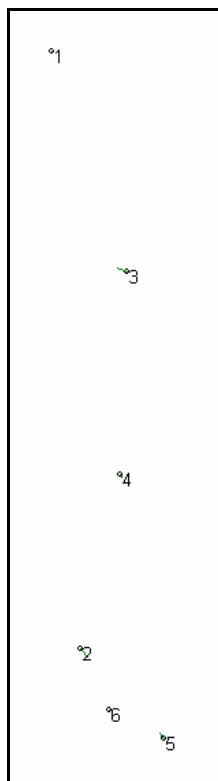


Figure 4.117: Relative Warp Analysis for the lateral border of 12 (green) and 13 (blue) year old juveniles

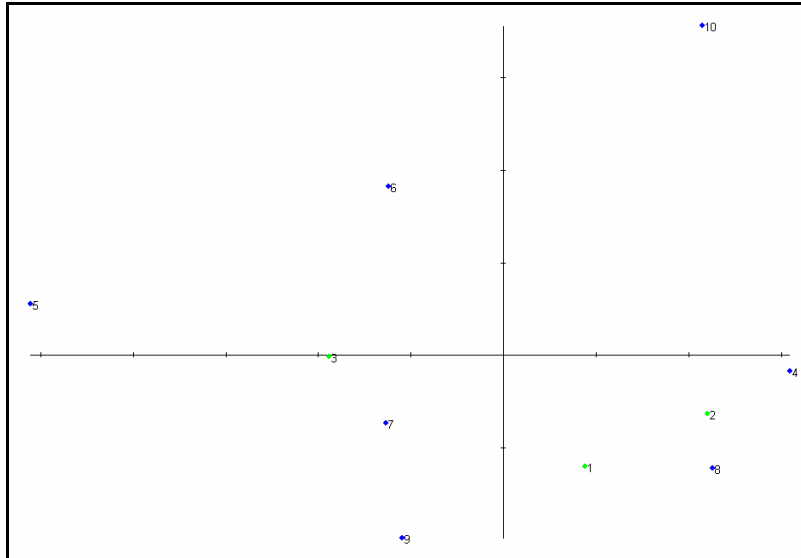


Figure 4.118: Consensus thin-plate spline (in vector mode) to show the separation of 13 year old juveniles (green arrow points) from 12 year old juveniles (black circles) along the lateral border

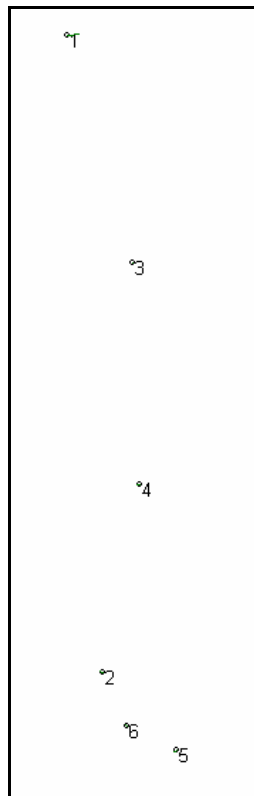


Figure 4.119: Relative Warp Analysis for the lateral border of 13 (green) and 14 (blue) year old juveniles

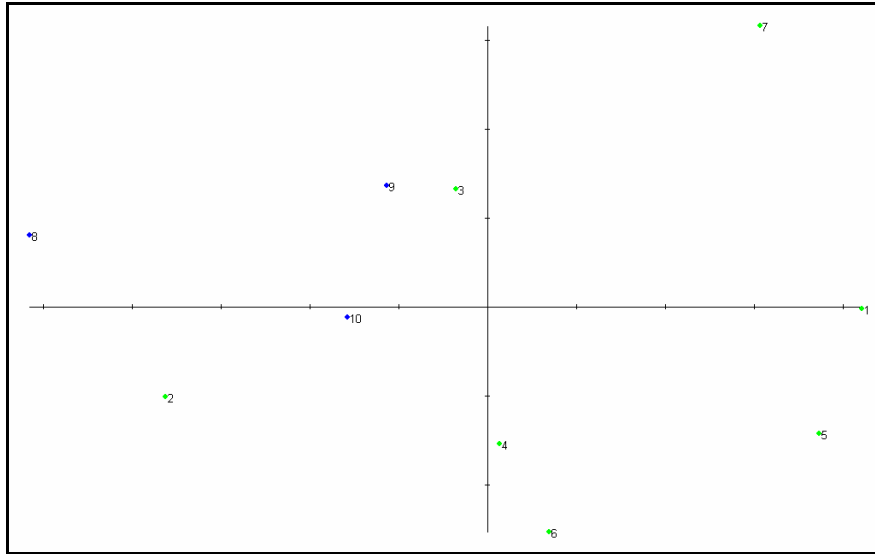


Figure 4.120: Consensus thin-plate spline (in vector mode) to show the separation of 14 year old juveniles (green arrow points) from 13 year old juveniles (black circles) along the lateral border

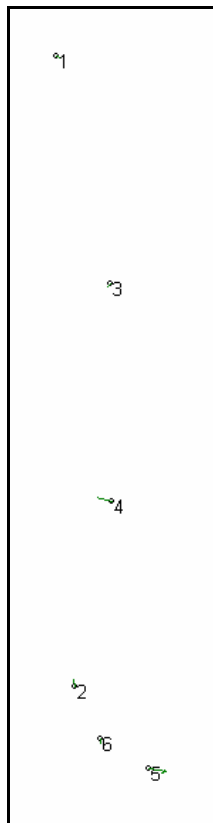


Figure 4.121: Relative Warp Analysis for the lateral border of 14 (green) and 15 (blue) year old juveniles

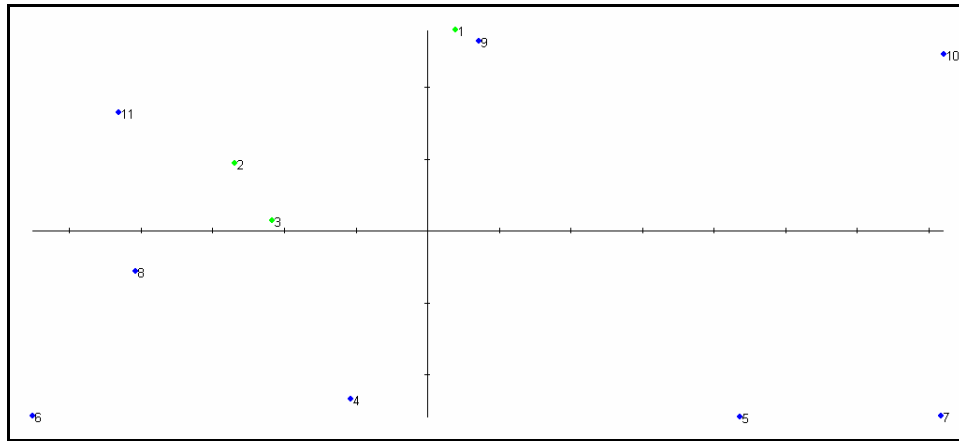


Figure 4.122: Consensus thin-plate spline (in vector mode) to show the separation of 15 year old juveniles (green arrow points) from 14 year old juveniles (black circles) along the lateral border

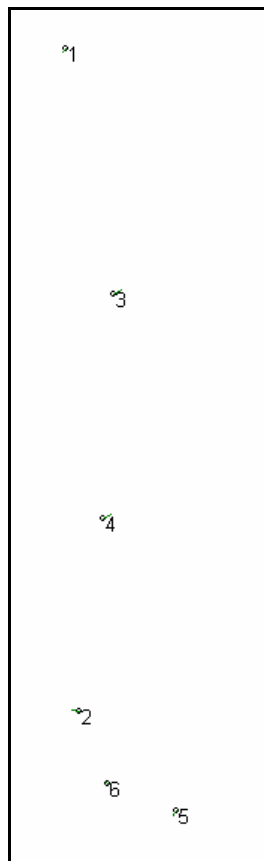


Figure 4.123: Relative Warp Analysis for the lateral border of 15 (green) and 16 (blue) year old juveniles

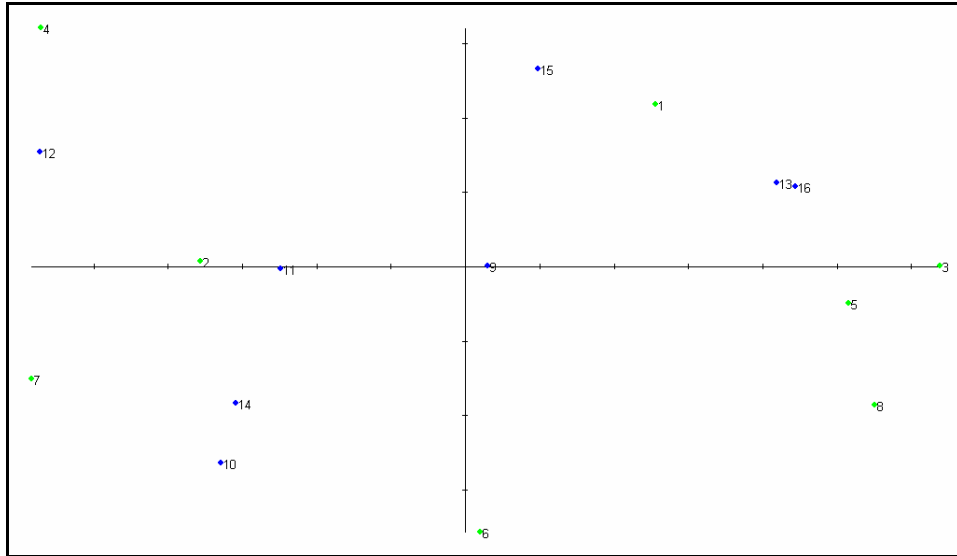


Figure 4.124: Consensus thin-plate spline (in vector mode) to show the separation of 16 year old juveniles (green arrow points) from 15 year old juveniles (black circles) along the lateral border

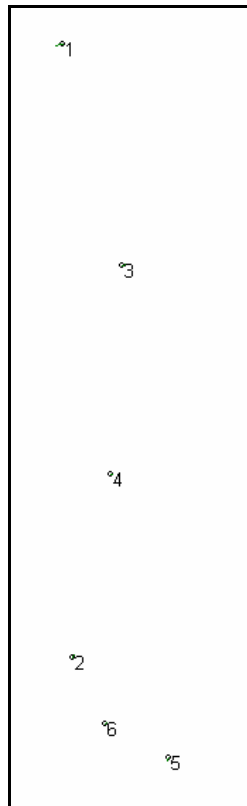


Figure 4.125: Relative Warp Analysis for the lateral border of 16 (green) and 17 (blue) year old juveniles

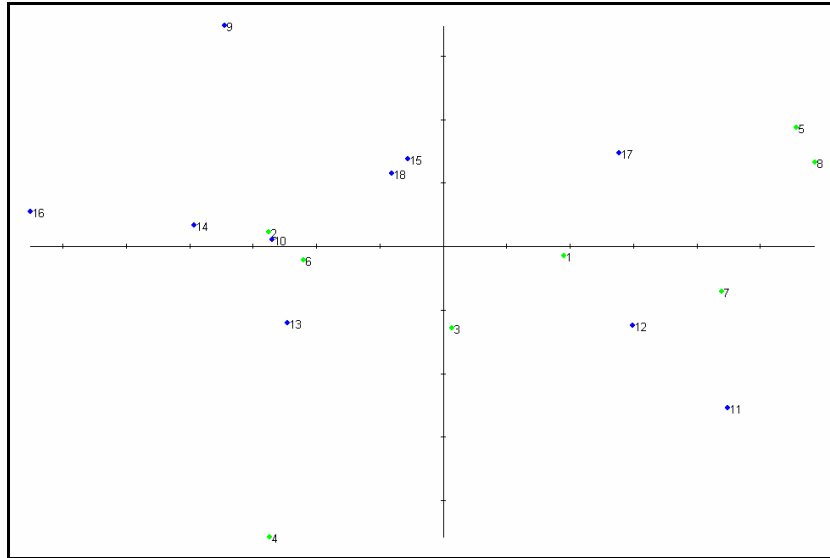


Figure 4.126 Consensus thin- plate spline (in vector mode) to show the separation of 17 year old juveniles (green arrow points) from 16 year old juveniles (black circles) along the lateral border

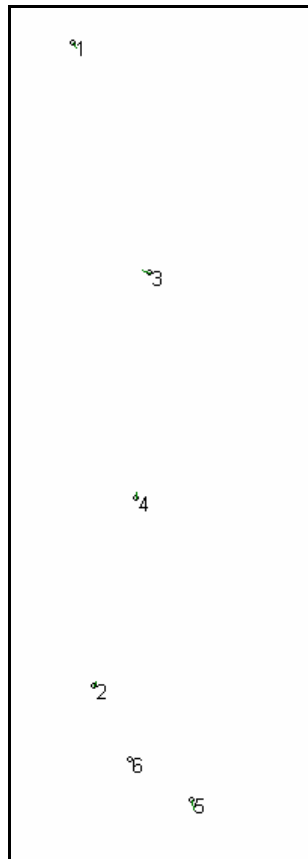


Figure 4.127: Relative Warp Analysis for the lateral border of 17 (green) and 18 (blue) year old juveniles

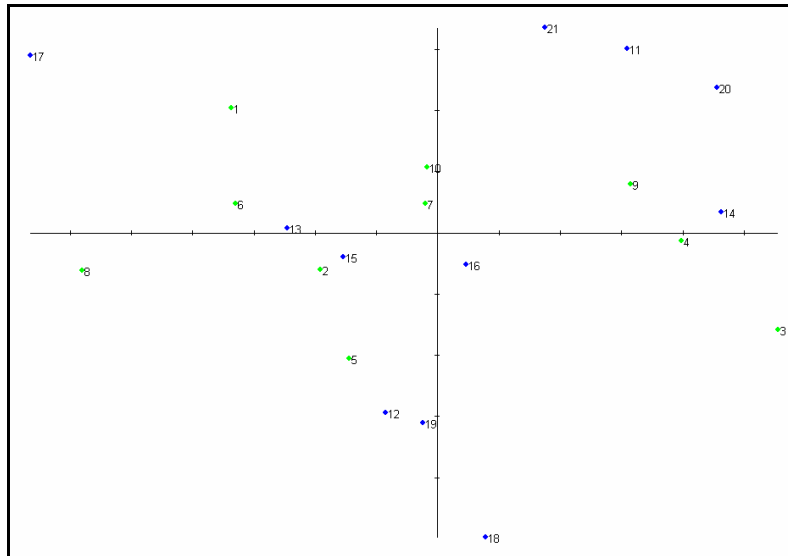


Figure 4.128: Consensus thin-plate spline (in vector mode) to show the separation of 18 year old juveniles (green arrow points) from 17 year old juveniles (black circles) along the lateral border

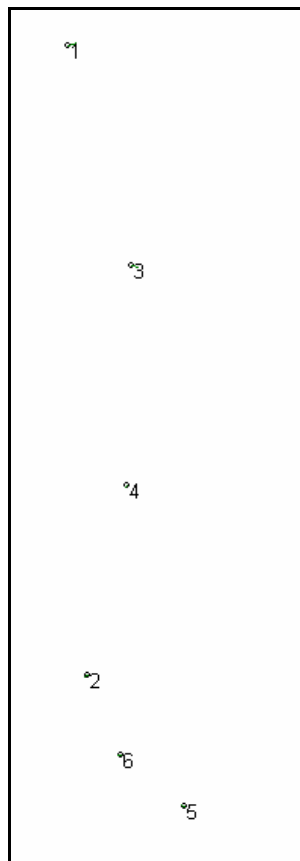


Figure 4.129: Relative Warp Analysis for the lateral border of 18 (green) and 19 (blue) year old juveniles

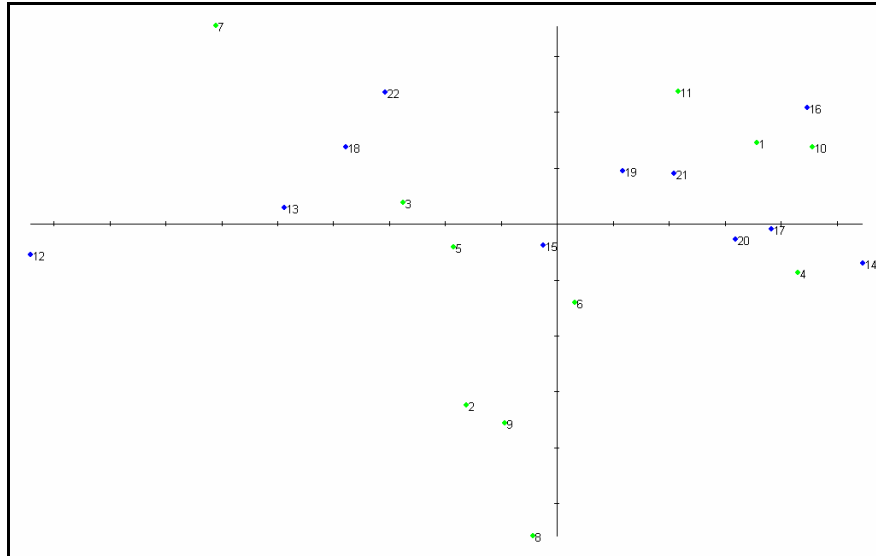


Figure 4.130: Consensus thin- plate spline (in vector mode) to show the separation of 19 year old juveniles (green arrow points) from 18 year old juveniles (black circles) along the lateral border

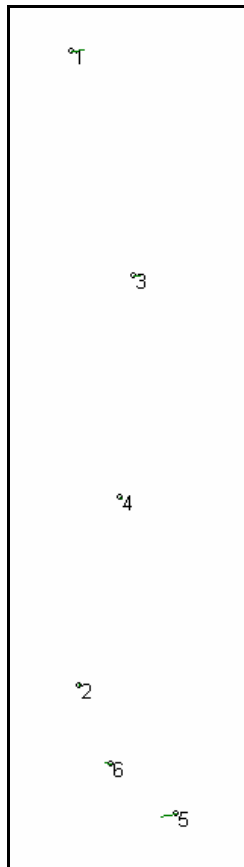


Figure 4.131: Relative Warp Analysis for the medial border of the whole juvenile sample [1 – 6 : 1year old juveniles (dark blue); 7 – 8: 2 year old juveniles (red); 9 – 11: 3 year old juveniles (yellow); 12 – 14: 4 year old juveniles (orange); 15: 6 year old juvenile (olive green); 16 – 17: 7 year old juveniles (maroon); 18: 8 year old juvenile (pink); 19: 9 year old juvenile (brown); 20: 10 year old juvenile (turquoise); 21 – 23: 12 year old juveniles (fuchsia); 24 – 30: 13 year old juveniles (bright green); 31 – 33: 14 year old juveniles (blue); 34 – 41: 15 year old juveniles (violet); 42 – 49: 16 year old juveniles (teal); 50 – 59: 17 year old juveniles (light pink); 60 – 70: 18 year old juveniles (light blue); 71 – 81: 19 year old juveniles (grey)]

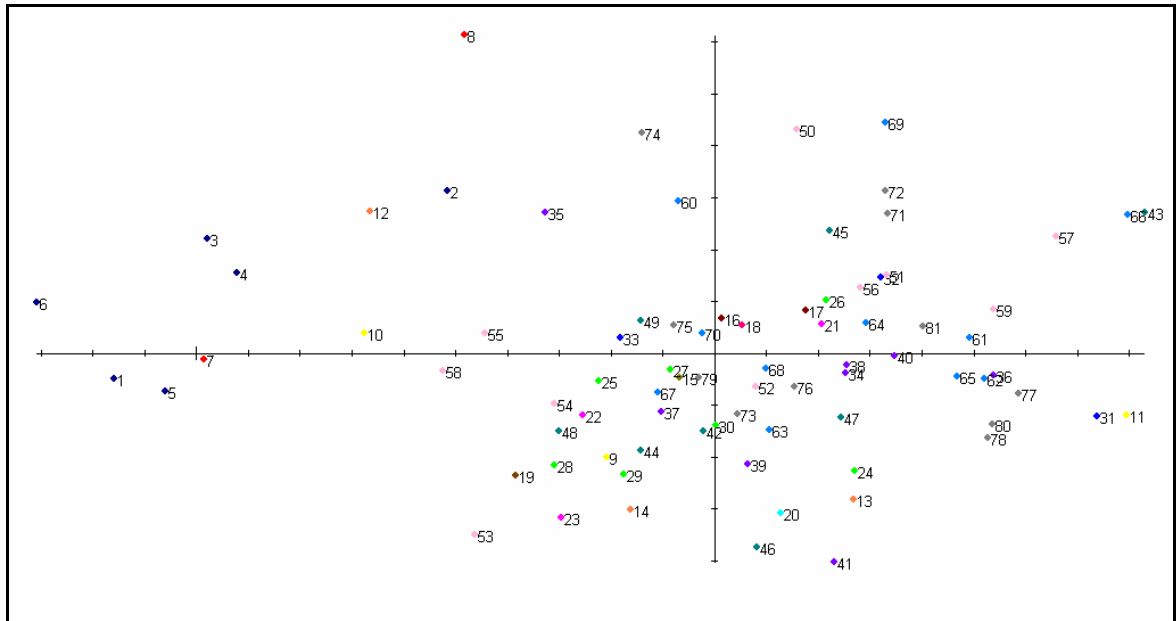


Figure 4.132: Relative Warp Analysis for the consensus of the medial border of the whole juvenile sample [1: 1 year old juveniles (dark blue); 2: 2 year old juveniles (red); 3: 3 year old juveniles (yellow); 4: 4 year old juveniles (orange); 5: 6 year old juvenile (olive green); 6: 7 year old juveniles (maroon); 7: 8 year old juvenile (pink); 8: 9 year old juvenile (brown); 9: 10 year old juvenile (turquoise); 10: 12 year old juveniles (fuchsia); 11: 13 year old juveniles (bright green); 12: 14 year old juveniles (blue); 13: 15 year old juveniles (violet); 14: 16 year old juveniles (teal); 15: 17 year old juveniles (light pink); 16: 18 year old juveniles (light blue); 17: 19 year old juveniles (grey)]

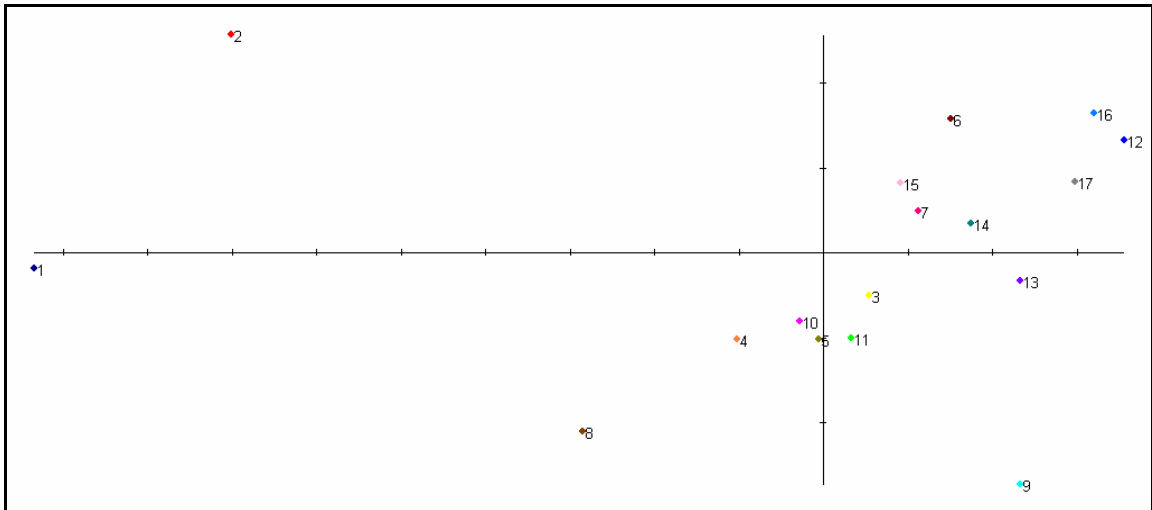


Figure 4.133: Relative Warp Analysis for the medial border of one (green) and two (blue) year old juveniles

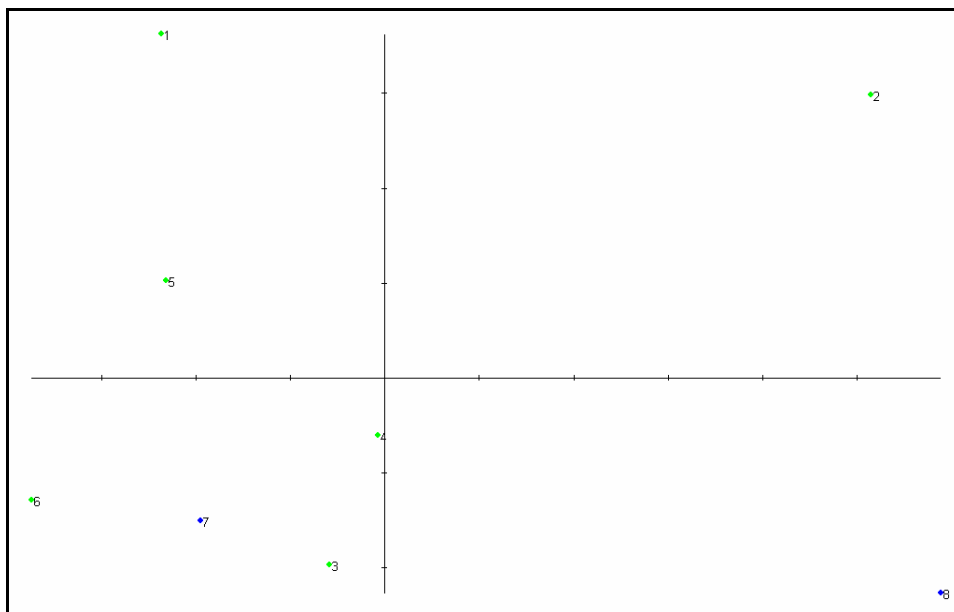


Figure 4.134: Consensus thin- plate spline (in vector mode) to show the separation of two year old juveniles (green arrow points) from one year old juveniles (black circles) along the medial border

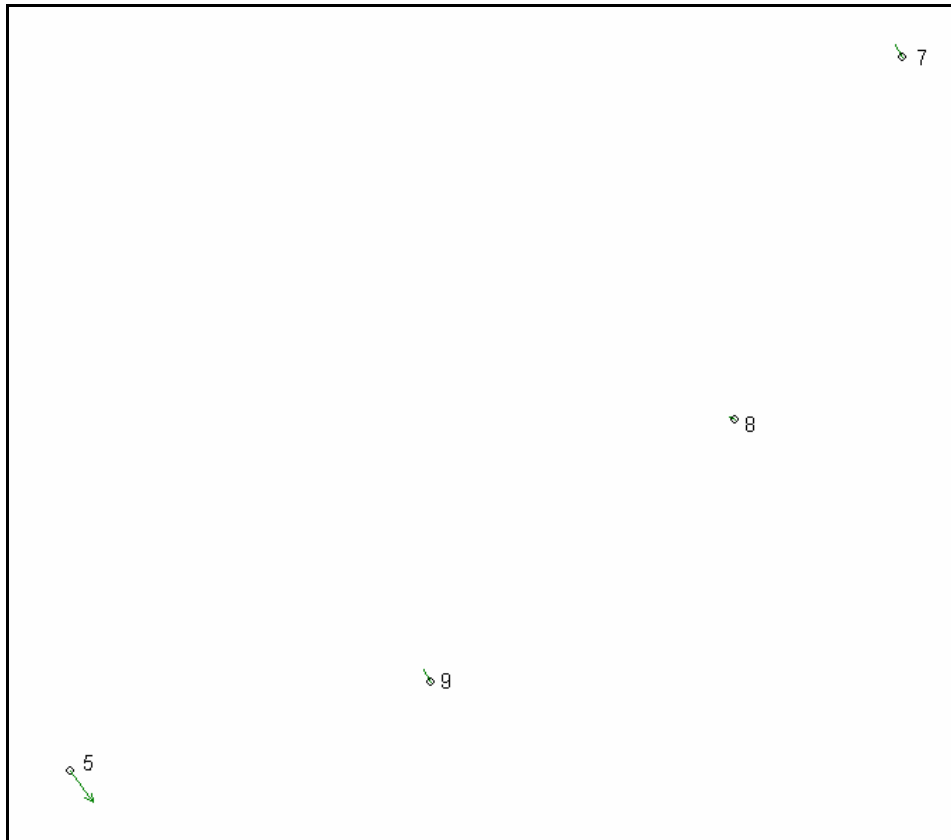


Figure 4.135: Relative Warp Analysis for the medial border of two (green) and three (blue) year old juveniles

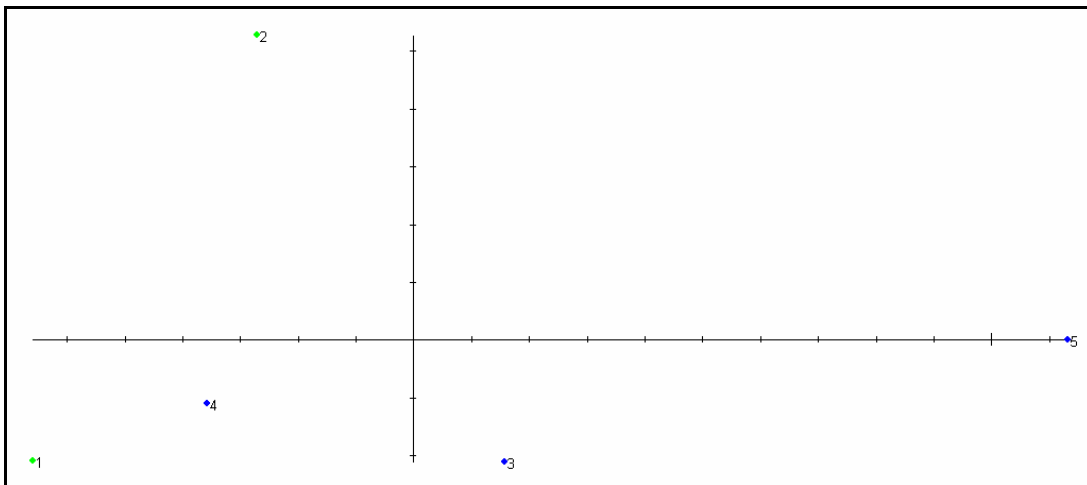


Figure 4.136: Consensus thin- plate spline (in vector mode) to show the separation of three year old juveniles (green arrow points) from two year old juveniles (black circles) along the medial border

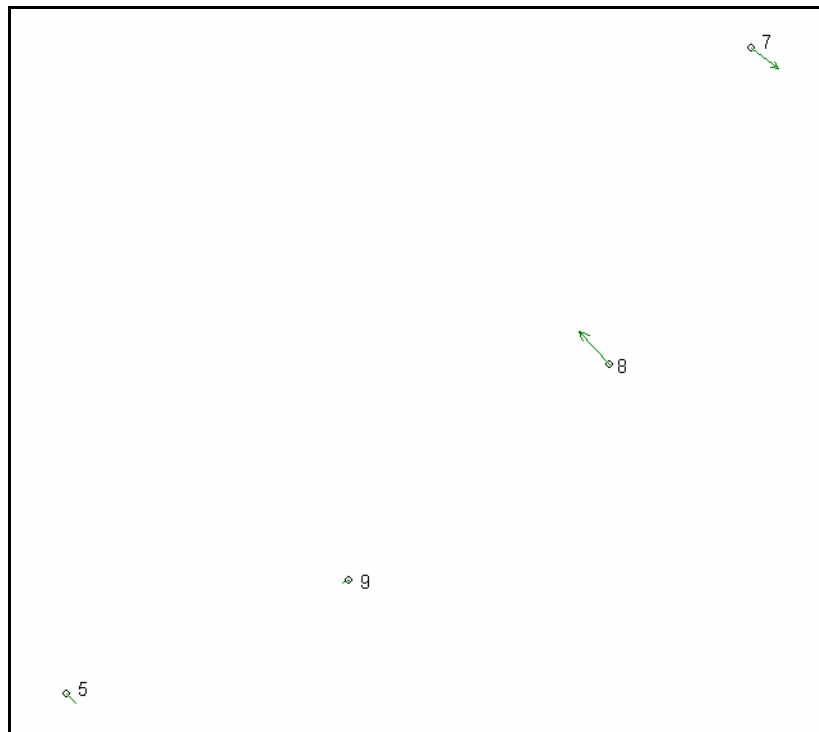


Figure 4.137: Relative Warp Analysis for the medial border of three (green) and four (blue) year old juveniles

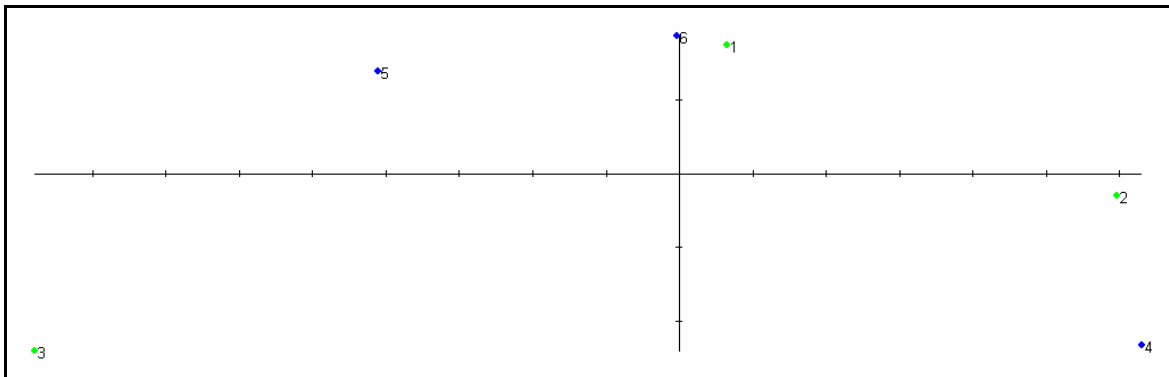


Figure 4.138: Consensus thin- plate spline (in vector mode) to show the separation of four year old juveniles (green arrow points) from three year old juveniles (black circles) along the medial border

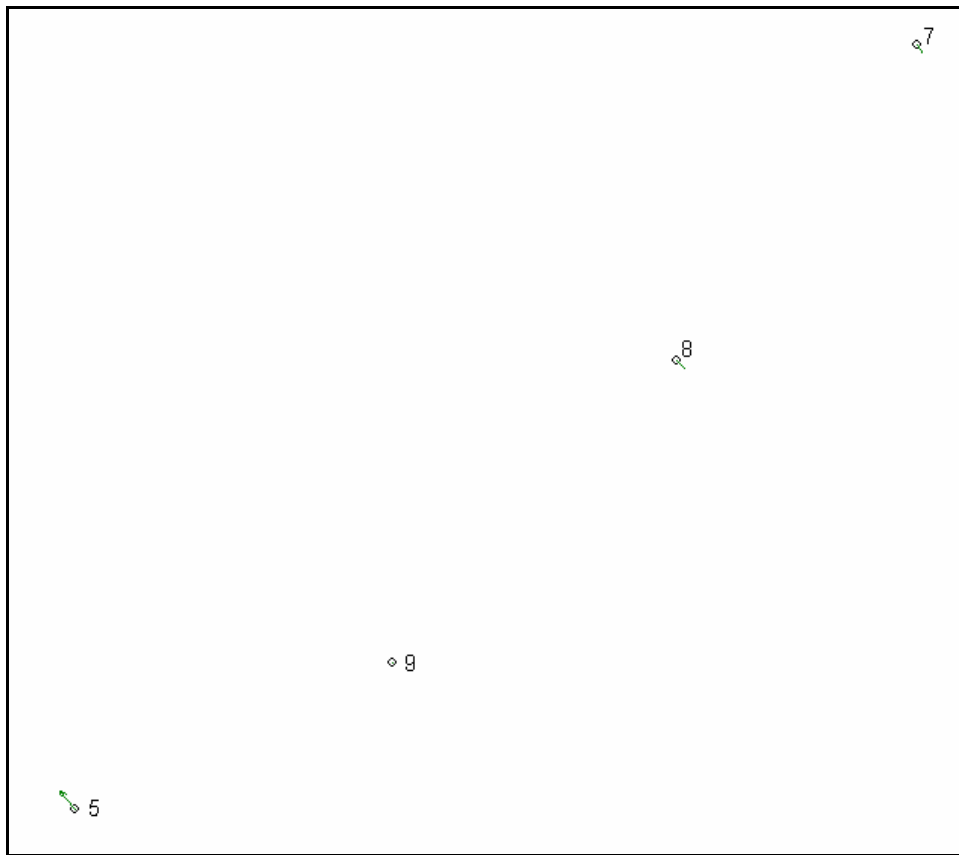


Figure 4.139: Relative Warp Analysis for the medial border of four (green) and six (blue) year old juveniles

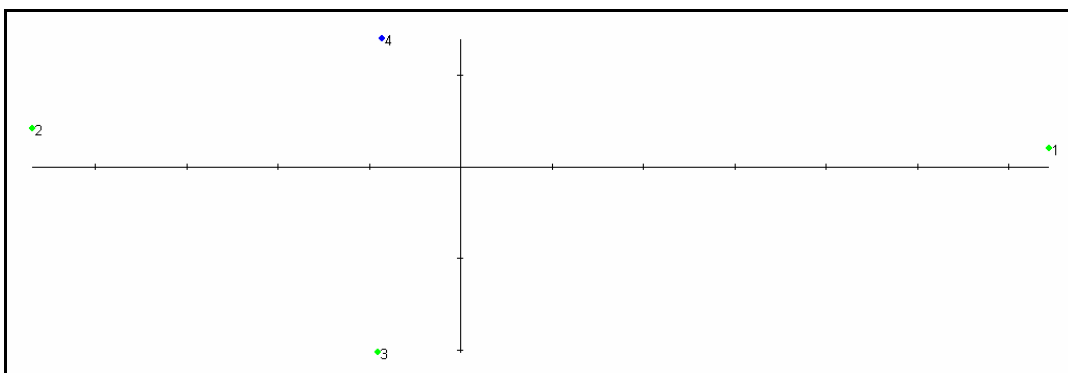


Figure 4.140: Consensus thin- plate spline (in vector mode) to show the separation of six year old juveniles (green arrow points) from four year old juveniles (black circles) along the medial border



Figure 4.141: Consensus thin- plate spline (in vector mode) to show the separation of seven year old juveniles (green arrow points) from six year old juveniles (black circles) along the medial border

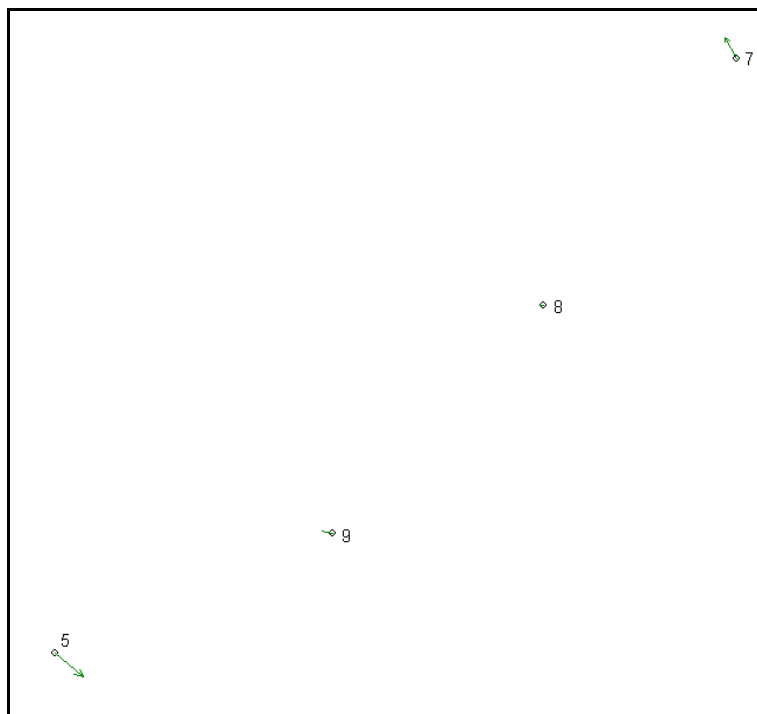


Figure 4.142: Consensus thin- plate spline (in vector mode) to show the separation of eight year old juveniles (green arrow points) from seven year old juveniles (black circles) along the medial border

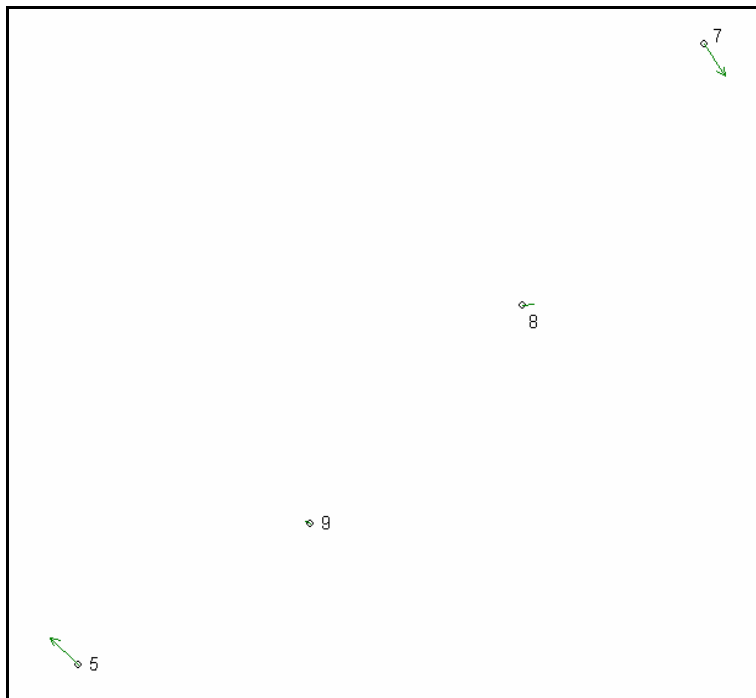


Figure 4.143: Consensus thin- plate spline (in vector mode) to show the separation of nine year old juveniles (green arrow points) from eight year old juveniles (black circles) along the medial border

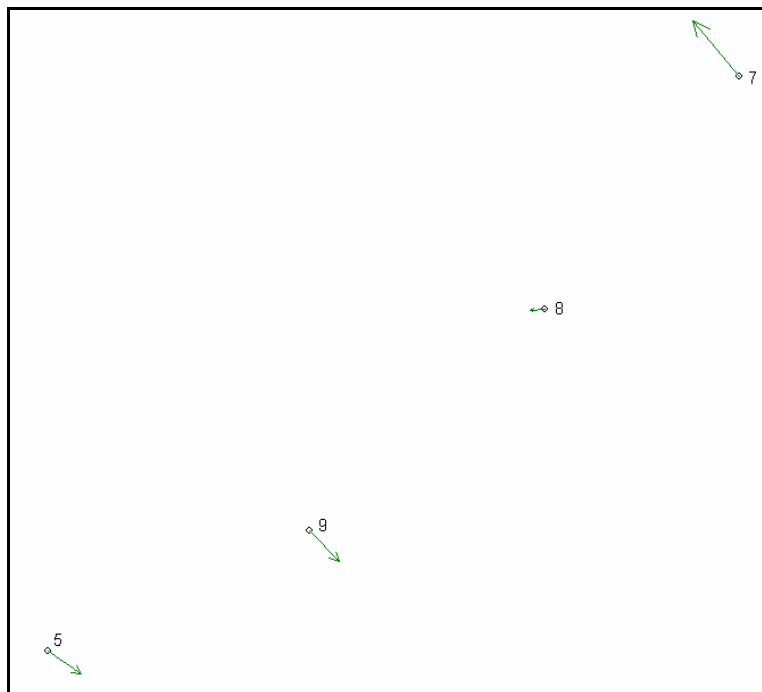


Figure 4.144: Consensus thin- plate spline (in vector mode) to show the separation of 10 year old juveniles (green arrow points) from nine year old juveniles (black circles) along the medial border

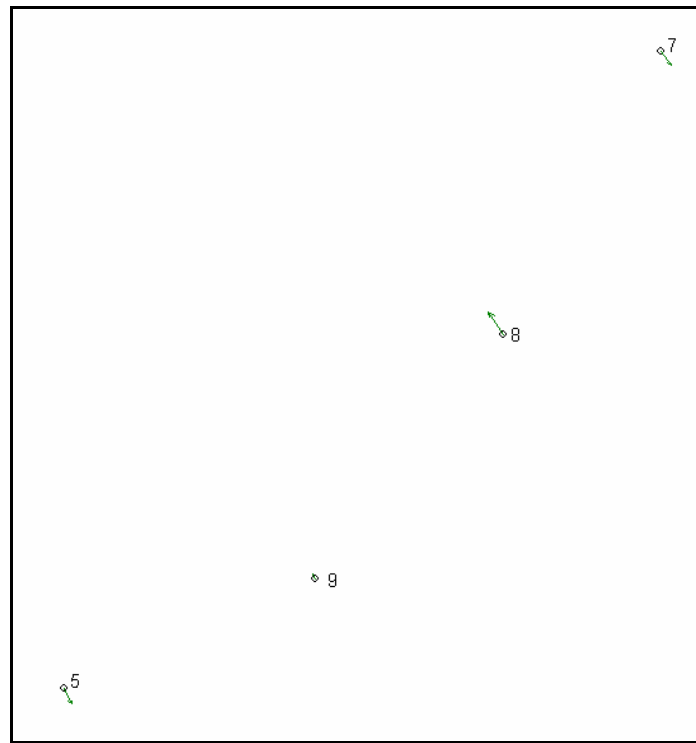


Figure 4.145: Relative Warp Analysis for the medial border of 10 (green) and 12 (blue) year old juveniles

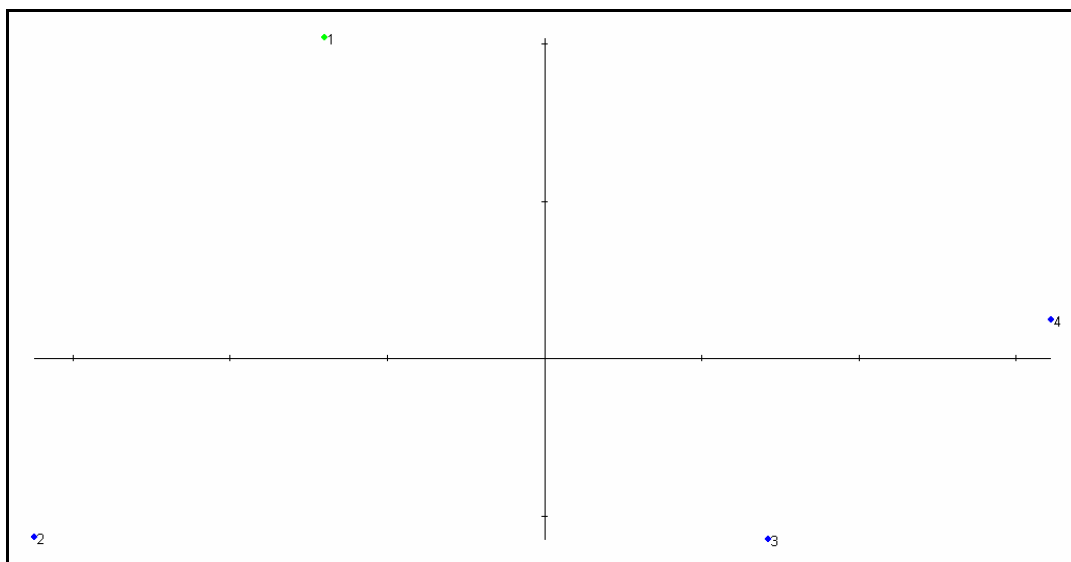


Figure 4.146: Consensus thin- plate spline (in vector mode) to show the separation of 12 year old juveniles (green arrow points) from 10 year old juveniles (black circles) along the medial border

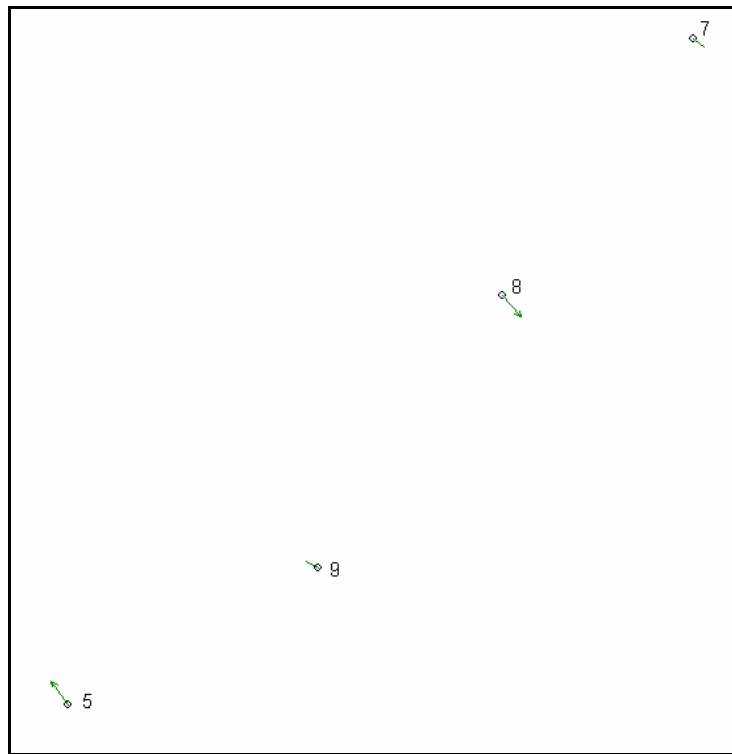


Figure 4.147: Relative Warp Analysis for the medial border of 12 (green) and 13 (blue) year old juveniles

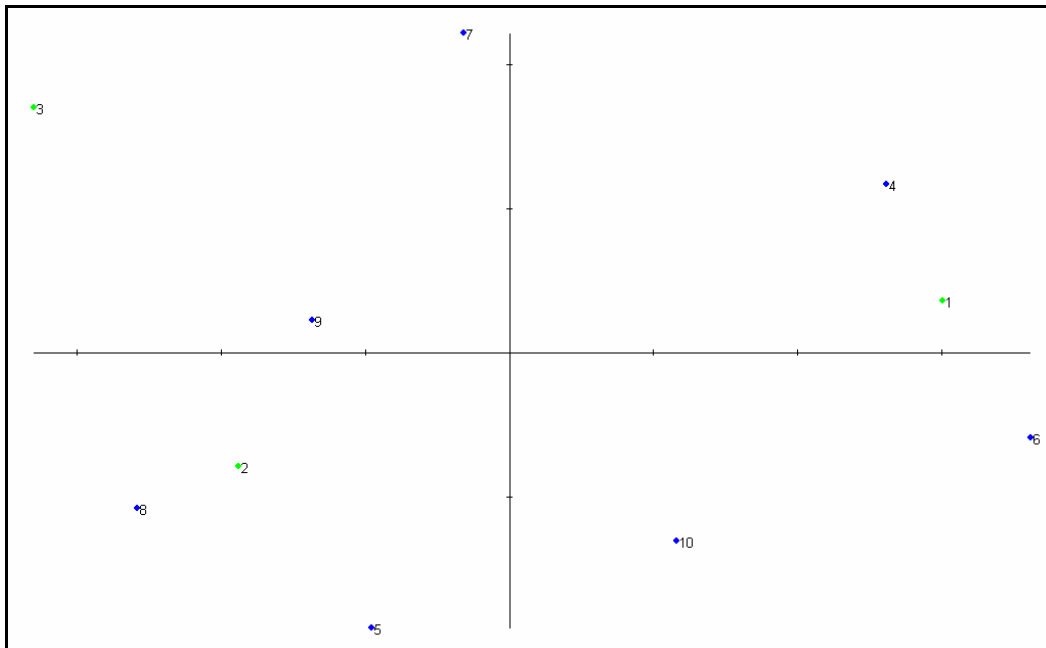


Figure 4.148: Consensus thin- plate spline (in vector mode) to show the separation of 13 year old juveniles (green arrow points) from 12 year old juveniles (black circles) along the medial border

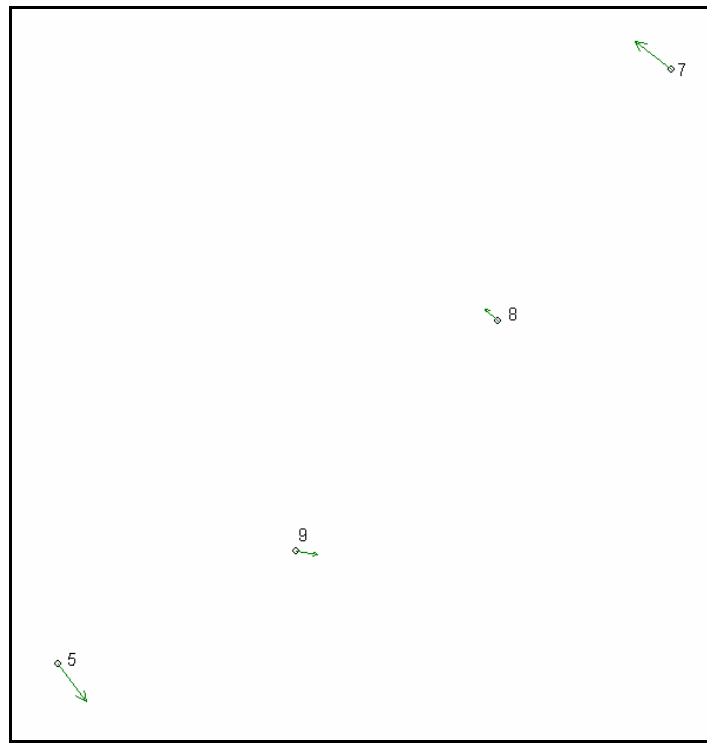


Figure 4.149: Relative Warp Analysis for the medial border of 13 (green) and 14 (blue) year old juveniles

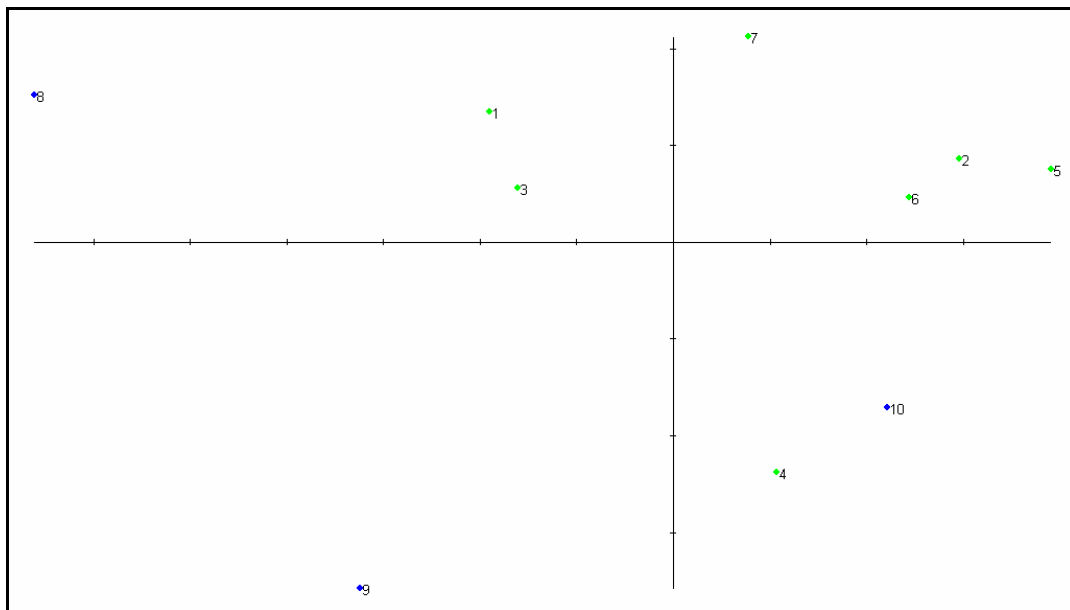


Figure 4.150: Consensus thin- plate spline (in vector mode) to show the separation of 14 year old juveniles (green arrow points) from 13 year old juveniles (black circles) along the medial border

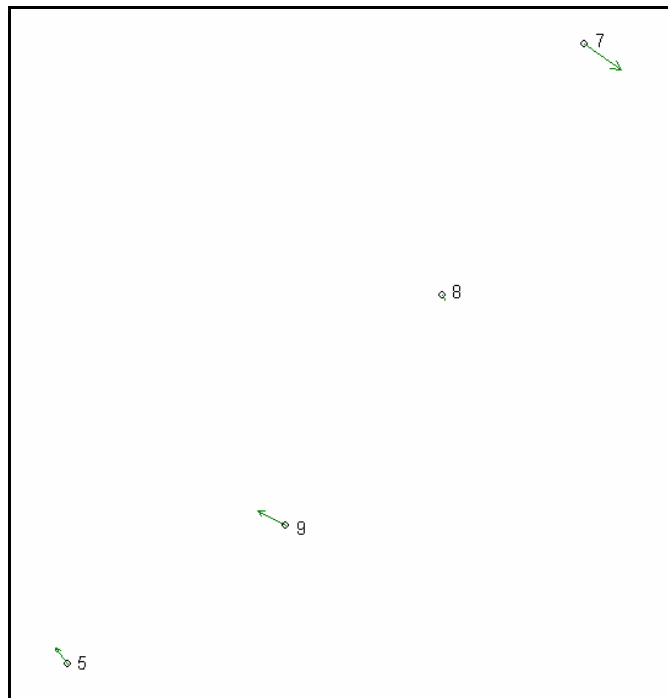


Figure 4.151: Relative Warp Analysis for the medial border of 14 (green) and 15 (blue) year old juveniles

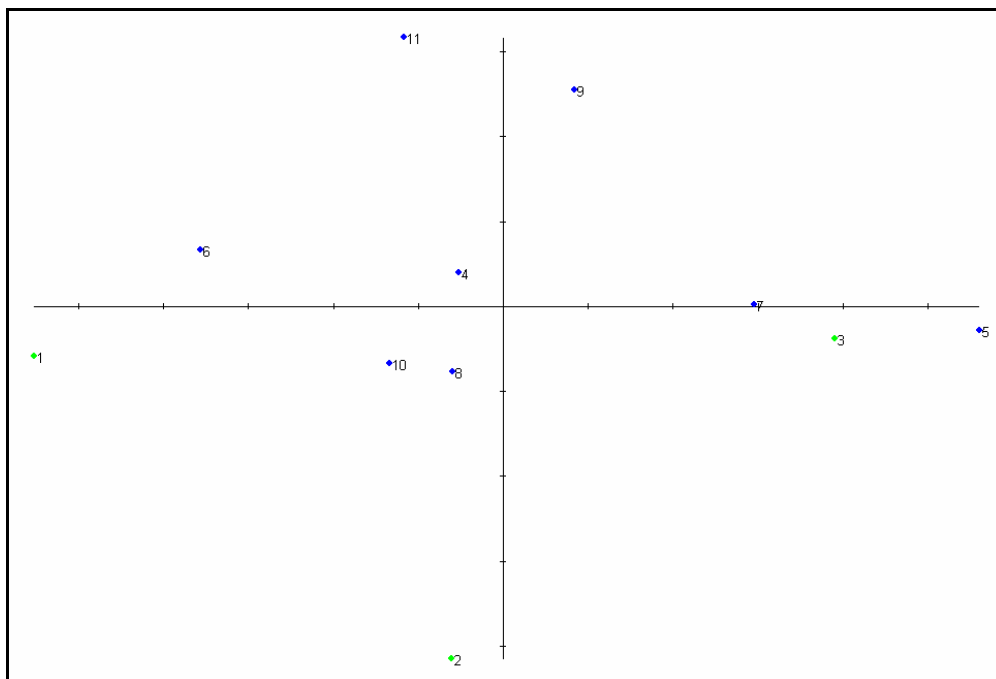


Figure 4.152: Consensus thin- plate spline (in vector mode) to show the separation of 15 year old juveniles (green arrow points) from 14 year old juveniles (black circles) along the medial border

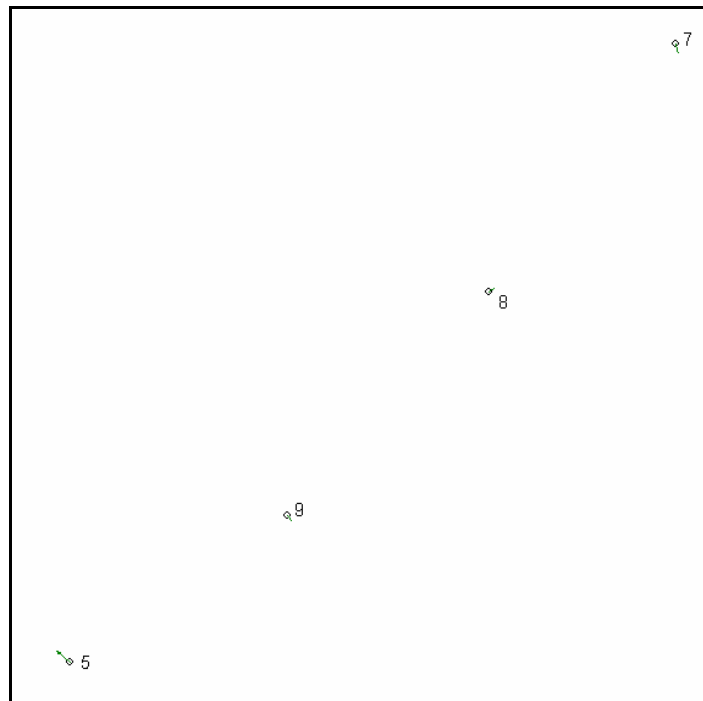


Figure 4.153: Relative Warp Analysis for the medial border of 15 (green) and 16 (blue) year old juveniles

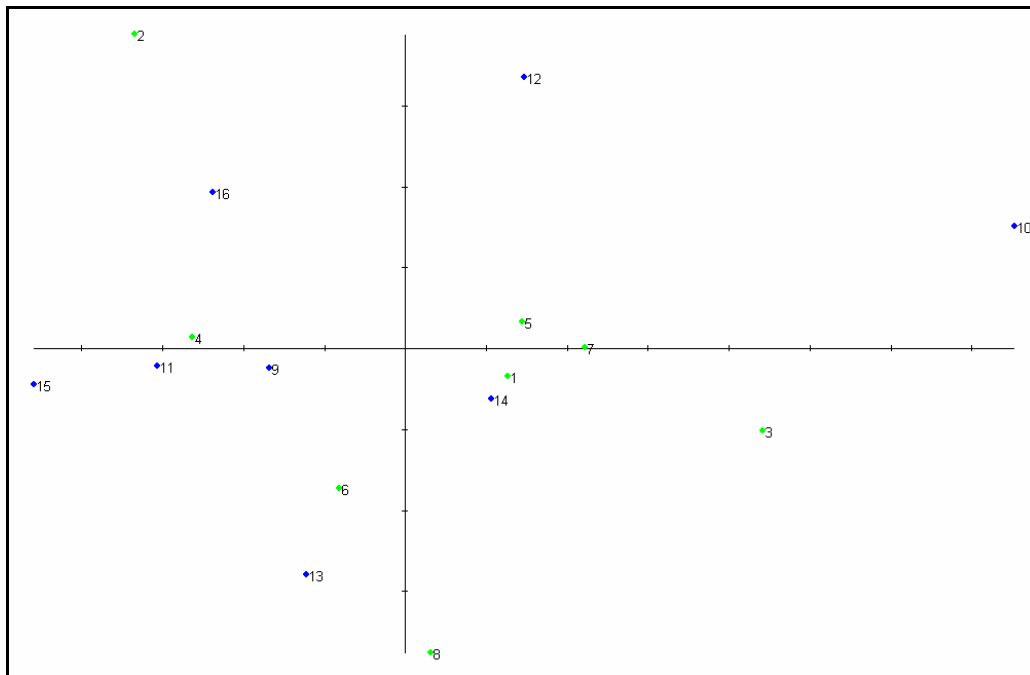


Figure 4.154: Consensus thin- plate spline (in vector mode) to show the separation of 16 year old juveniles (green arrow points) from 15 year old juveniles (black circles) along the medial border

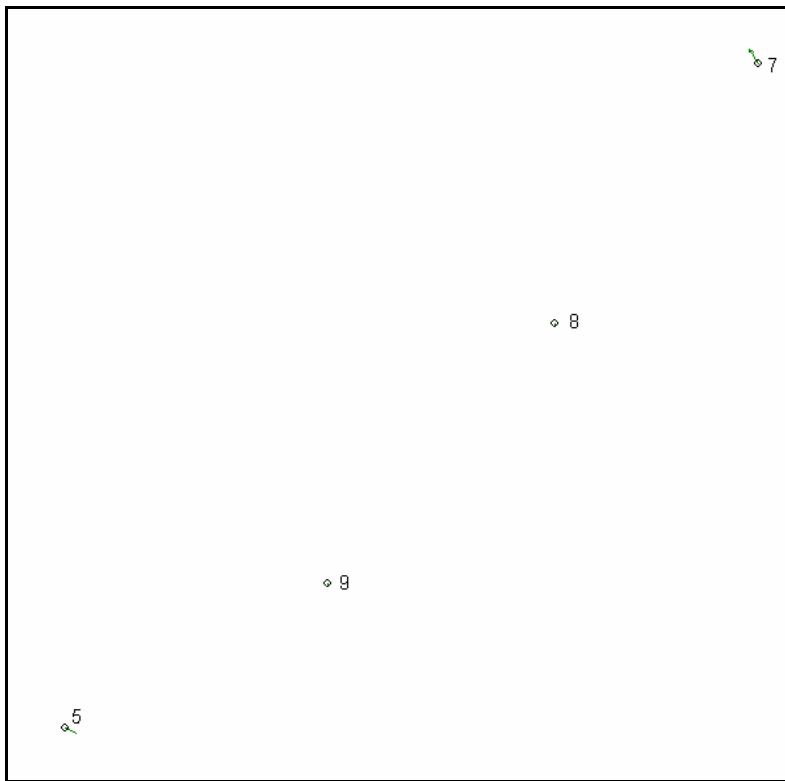


Figure 4.155: Relative Warp Analysis for the medial border of 16 (green) and 17 (blue) year old juveniles

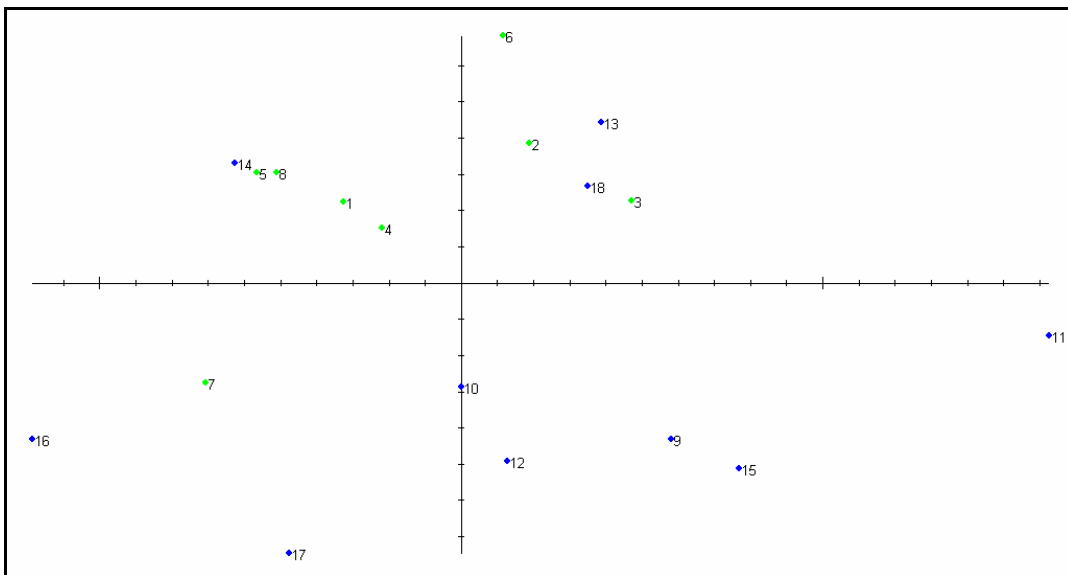


Figure 4.156: Consensus thin- plate spline (in vector mode) to show the separation of 17 year old juveniles (green arrow points) from 16 year old juveniles (black circles) along the medial border

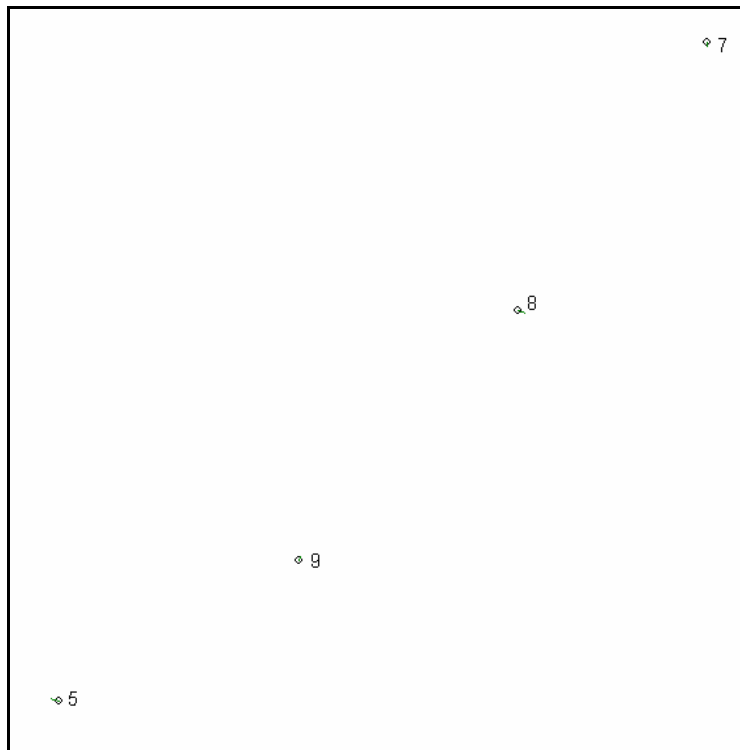


Figure 4.157: Relative Warp Analysis for the medial border of 17 (green) and 18 (blue) year old juveniles

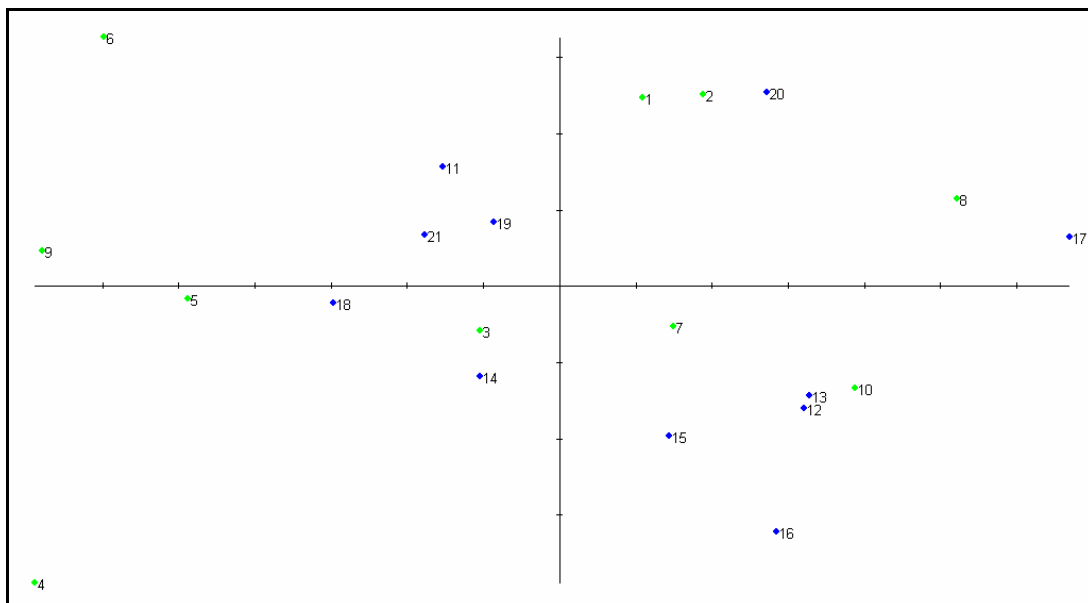


Figure 4.158: Consensus thin- plate spline (in vector mode) to show the separation of 18 year old juveniles (green arrow points) from 17 year old juveniles (black circles) along the medial border

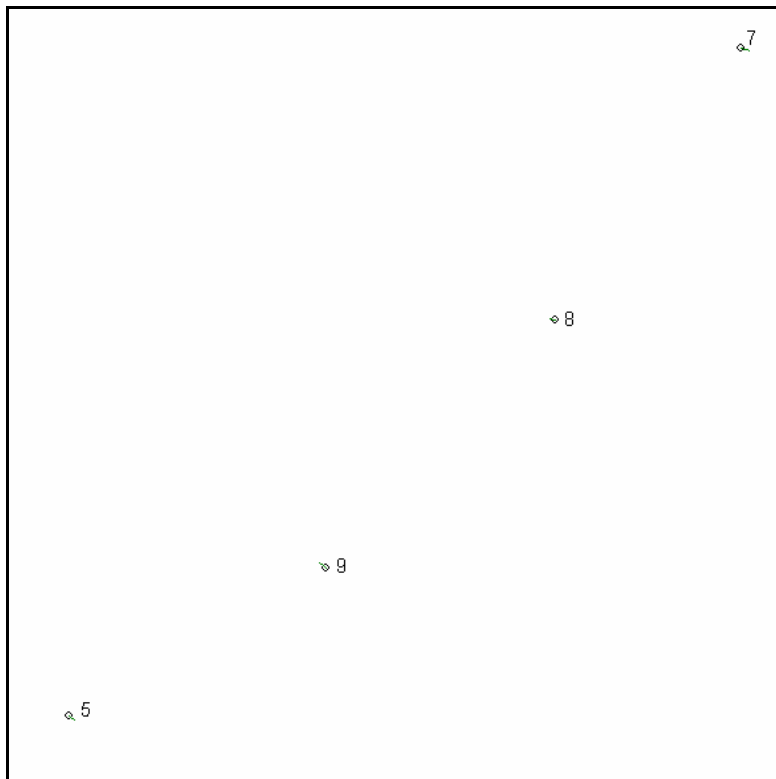


Figure 4.159: Relative Warp Analysis for the medial border of 18 (green) and 19 (blue) year old juveniles

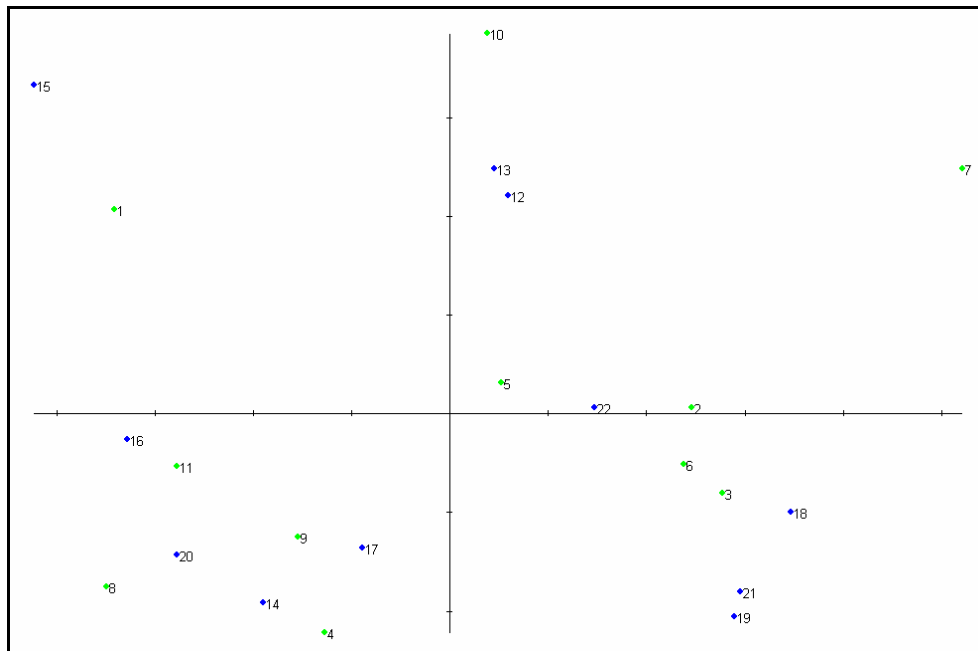


Figure 4.160: Consensus thin- plate spline (in vector mode) to show the separation of 19 year old juveniles (green arrow points) from 18 year old juveniles (black circles) along the medial border

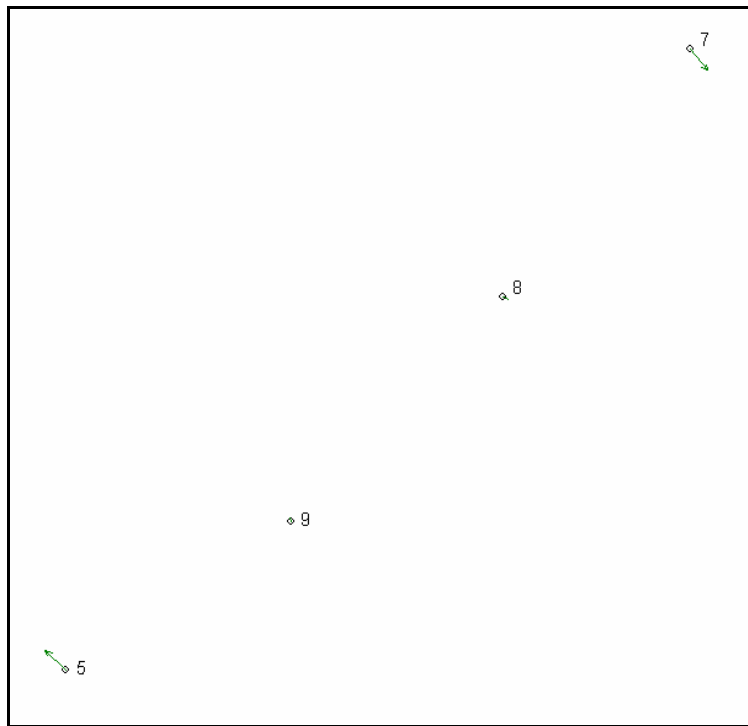


Figure 4.161: Relative warp analysis for the supraspinous border of the whole juvenile group [1 – 6 : 1year old juveniles (dark blue); 7 – 8: 2 year old juveniles (red); 9 – 11: 3 year old juveniles (yellow); 12 – 14: 4 year old juveniles (orange); 15: 6 year old juvenile (olive green); 16 – 17: 7 year old juveniles (maroon); 18: 8 year old juvenile (pink); 19: 9 year old juvenile (brown); 20: 10 year old juvenile (turquoise); 21 – 23: 12 year old juveniles (fuchsia); 24 – 30: 13 year old juveniles (bright green); 31 – 33: 14 year old juveniles (blue); 34 – 41: 15 year old juveniles (violet); 42 – 49: 16 year old juveniles (teal); 50 – 59: 17 year old juveniles (light pink); 60 – 70: 18 year old juveniles (light blue); 71 – 81: 19 year old juveniles (grey)]

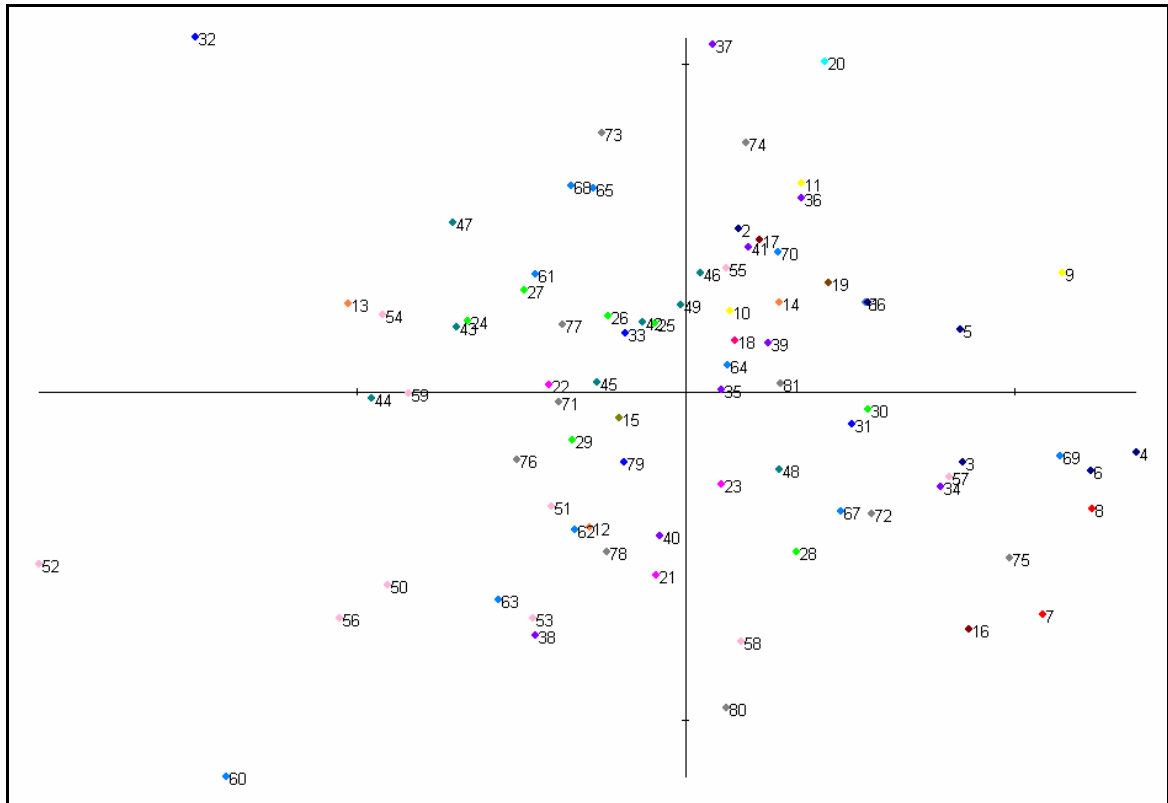


Figure 4.162: Relative Warp Analysis for the consensus of the supraspinous border of the whole juvenile group [1: 1 year old juveniles (dark blue); 2: 2 year old juveniles (red); 3: 3 year old juveniles (yellow); 4: 4 year old juveniles (orange); 5: 6 year old juvenile (olive green); 6: 7 year old juveniles (maroon); 7: 8 year old juvenile (pink); 8: 9 year old juvenile (brown); 9: 10 year old juvenile (turquoise); 10: 12 year old juveniles (fuchsia); 11: 13 year old juveniles (bright green); 12: 14 year old juveniles (blue); 13: 15 year old juveniles (violet); 14: 16 year old juveniles (teal); 15: 17 year old juveniles (light pink); 16: 18 year old juveniles (light blue); 17: 19 year old juveniles (grey)]

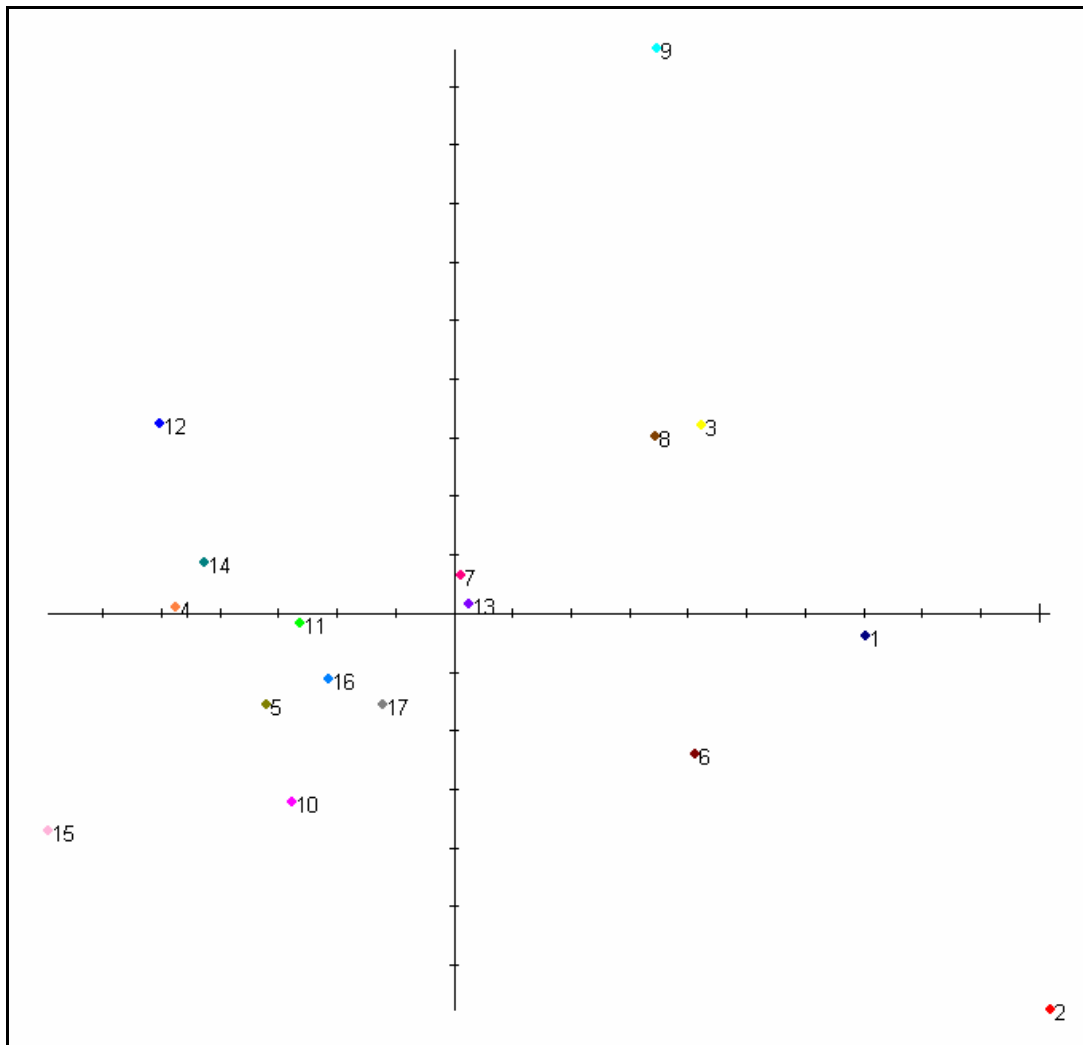


Figure 4.163: Relative Warp Analysis for the supraspinous border of one (green) and two (blue) year old juveniles

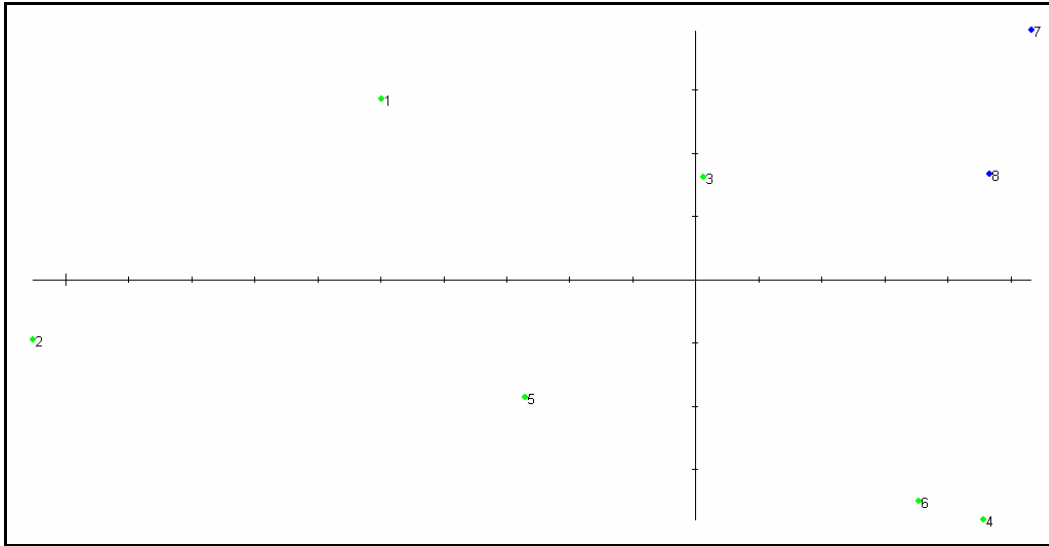


Figure 4.164: Consensus thin-plate spline (in vector mode) to show the separation of two year old juveniles (green arrow points) from one year old juveniles (black circles) along the supraspinous border

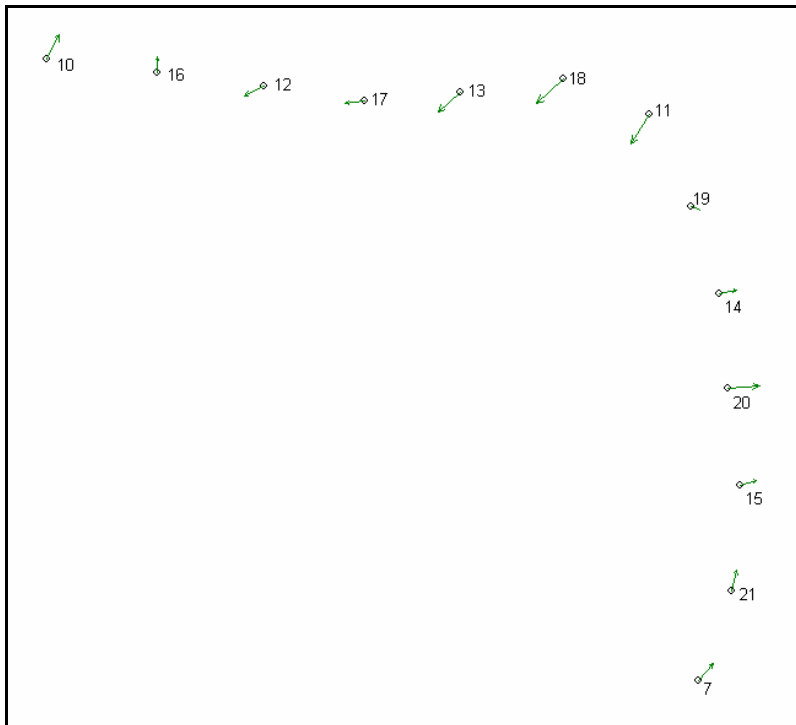


Figure 4.165: Relative Warp Analysis for the supraspinous border of two (green) and three (blue) year old juveniles

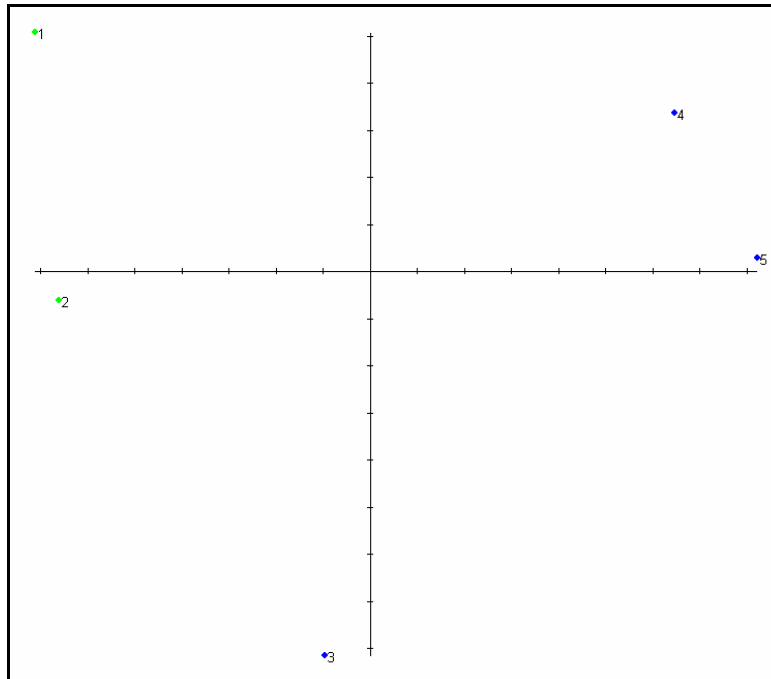


Figure 4.166: Consensus thin-plate spline (in vector mode) to show the separation of three year old juveniles (green arrow points) from two year old juveniles (black circles) along the supraspinous border

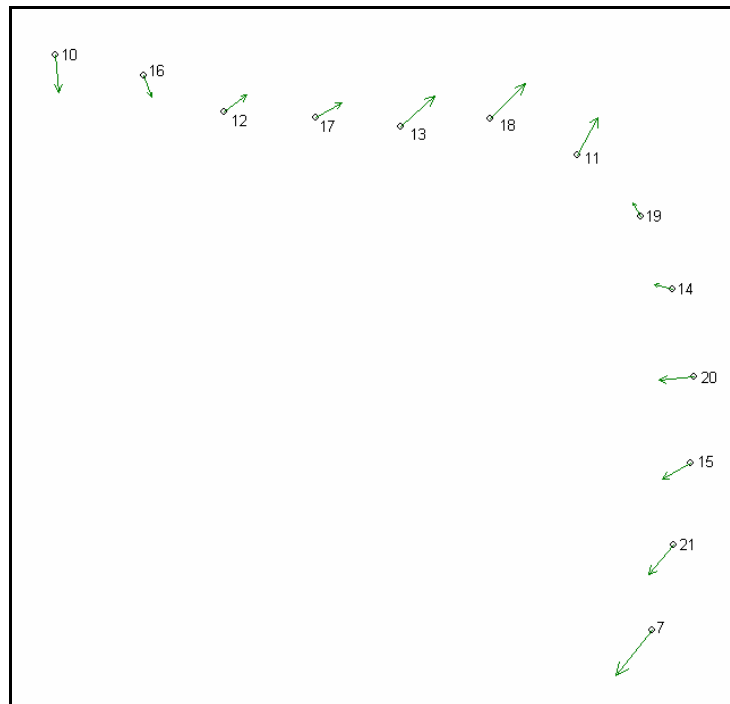


Figure 4.167: Relative Warp Analysis for the supraspinous border of three (green) and four (blue) year old juveniles

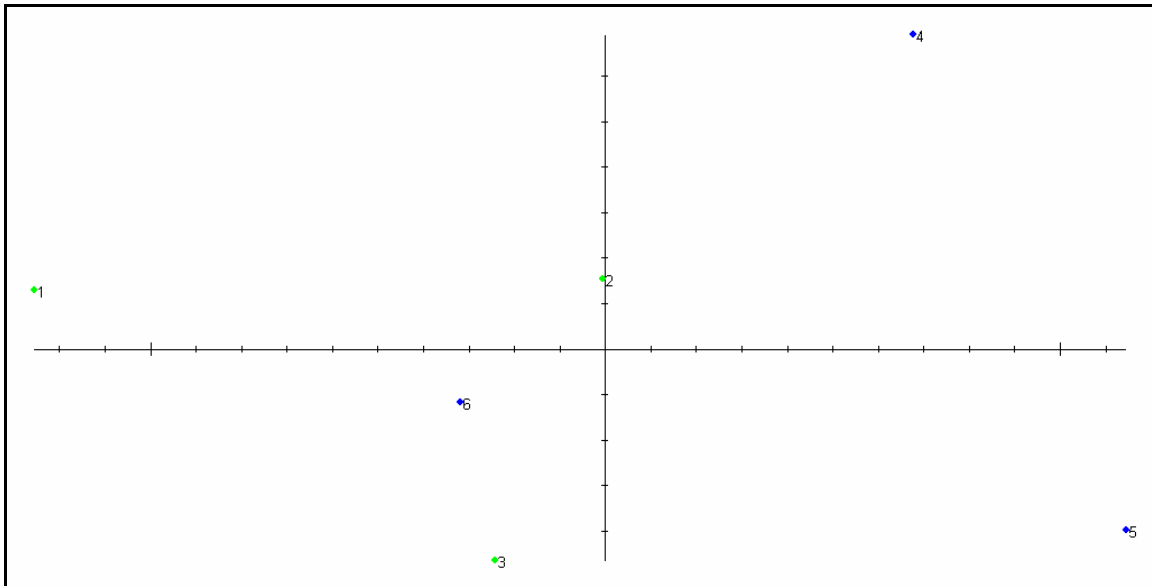


Figure 4.168: Consensus thin-plate spline (in vector mode) to show the separation of four year old juveniles (green arrow points) from three year old juveniles (black circles) along the supraspinous border

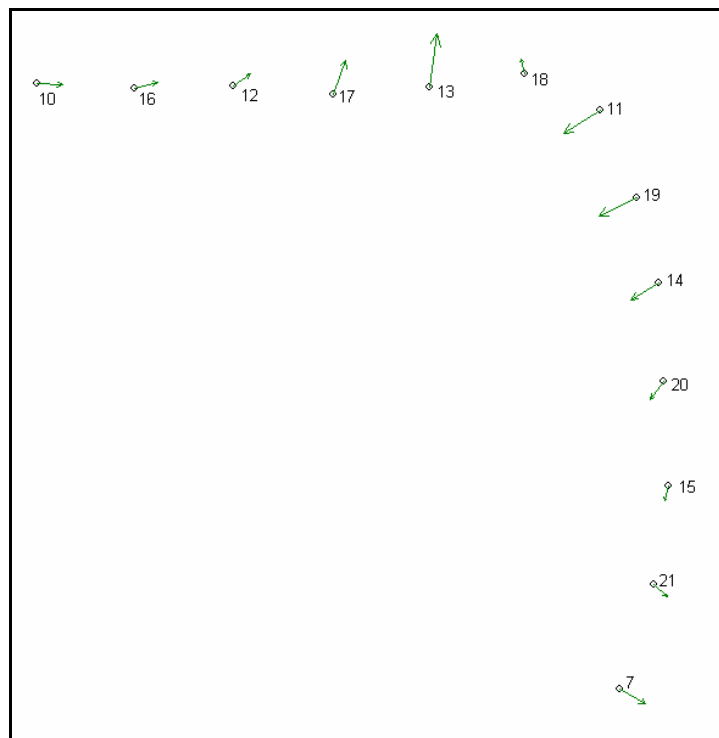


Figure 4.169: Relative Warp Analysis for the supraspinous border of four (green) and six (blue) year old juveniles

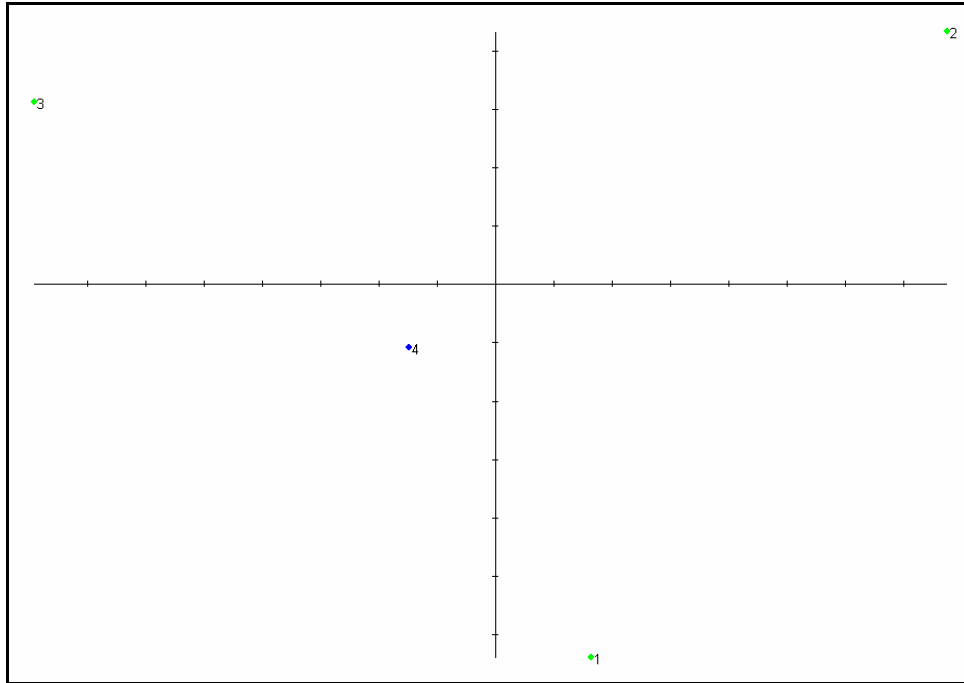


Figure 4.170: Consensus thin-plate spline (in vector mode) to show the separation of six year old juveniles (green arrow points) from four year old juveniles (black circles) along the supraspinous border

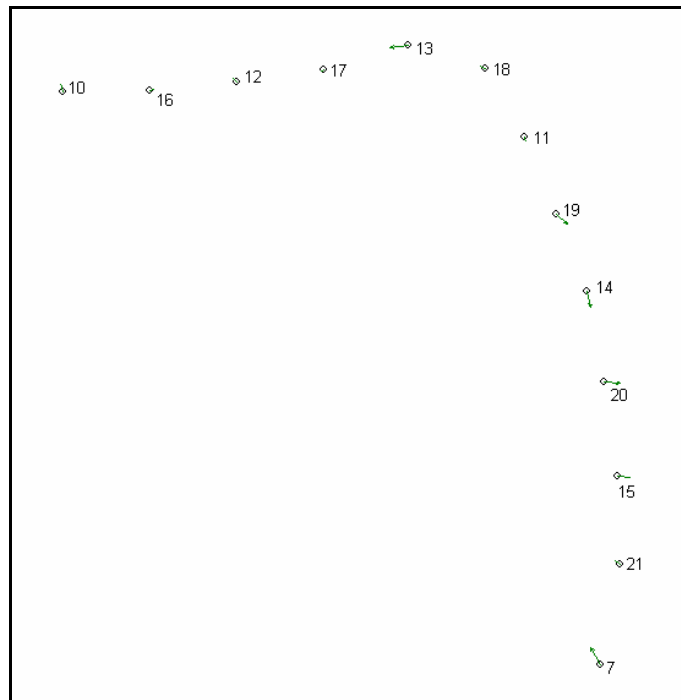


Figure 4.171: Consensus thin- plate spline (in vector mode) to show the separation of seven year old juveniles (green arrow points) from six year old juveniles (black circles) along the suprascapular border

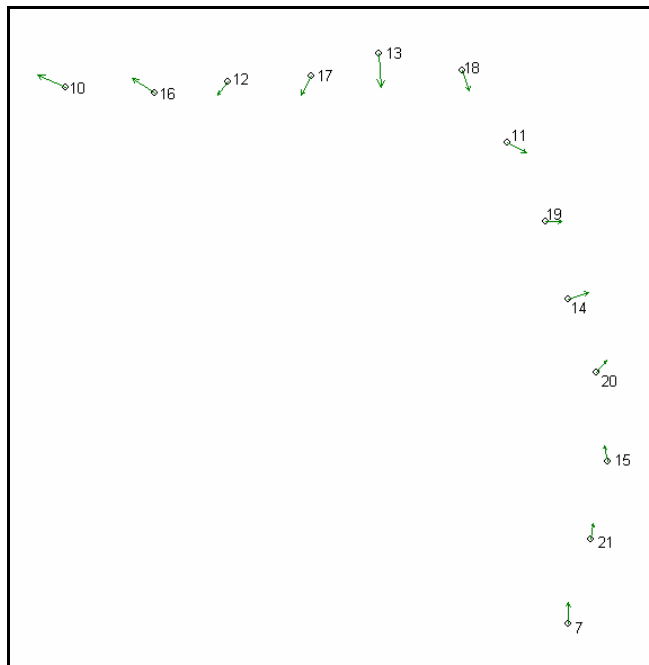


Figure 4.172: Consensus thin- plate spline (in vector mode) to show the separation of eight year old juveniles (green arrow points) from seven year old juveniles (black circles) along the suprascapular border

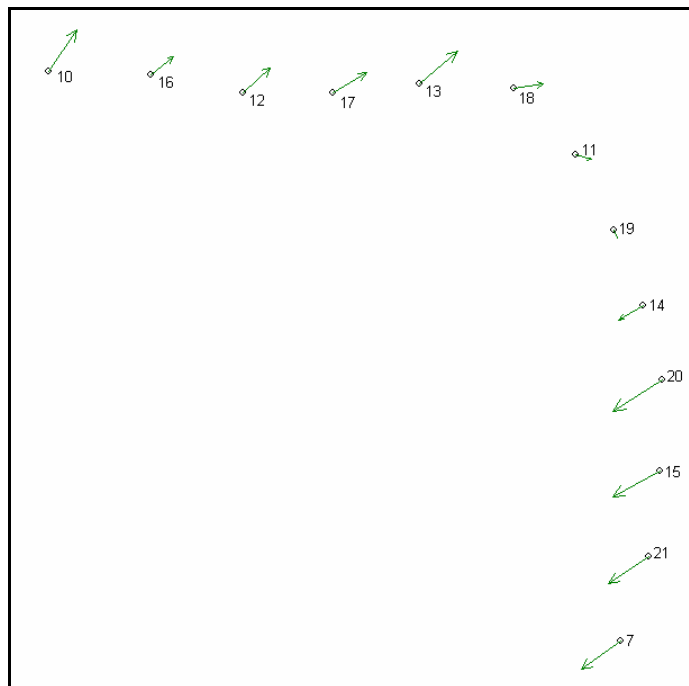


Figure 4.173: Consensus thin- plate spline (in vector mode) to show the separation of nine year old juveniles (green arrow points) from eight year old juveniles (black circles) along the suprascapular border

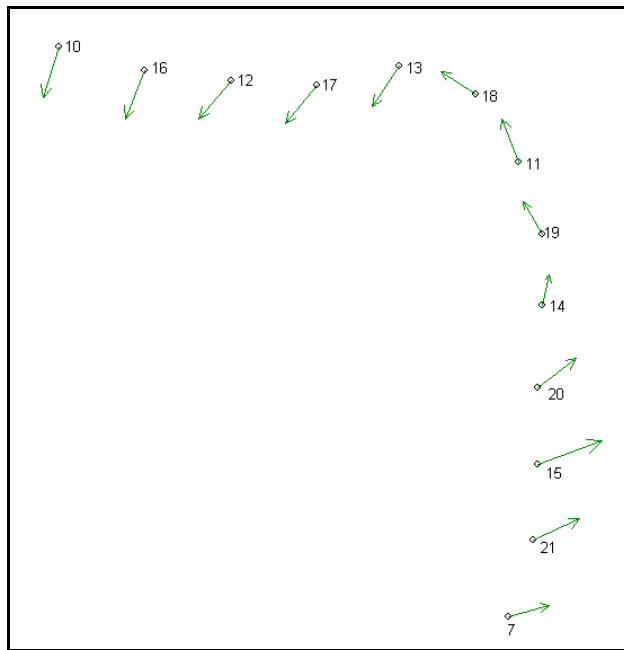


Figure 4.174: Consensus thin- plate spline (in vector mode) to show the separation of 10 year old juveniles (green arrow points) from nine year old juveniles (black circles) along the suprascapular border

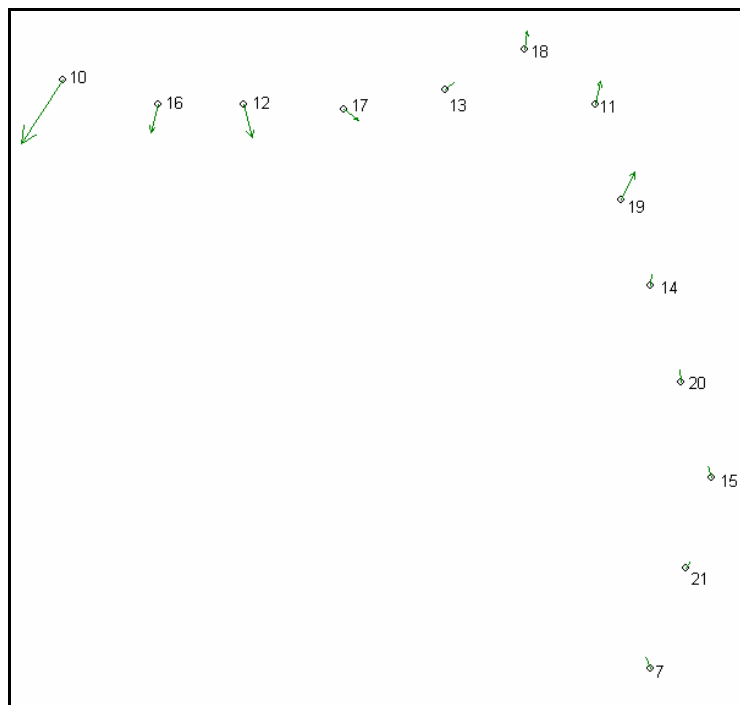


Figure 4.175: Relative Warp Analysis for the supraspinous border of 10 (green) and 12 (blue) year old juveniles

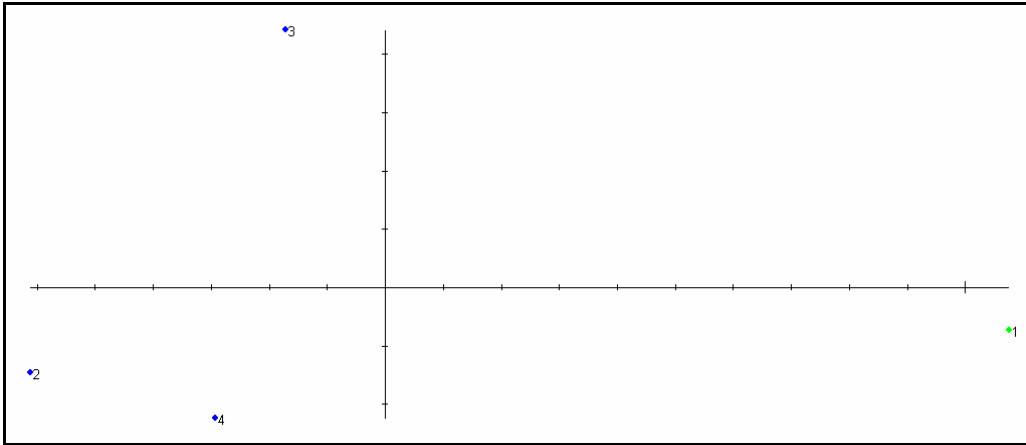


Figure 4.176: Consensus thin-plate spline (in vector mode) to show the separation of 12 year old juveniles (green arrow points) from 10 year old juveniles (black circles) along the supraspinous border

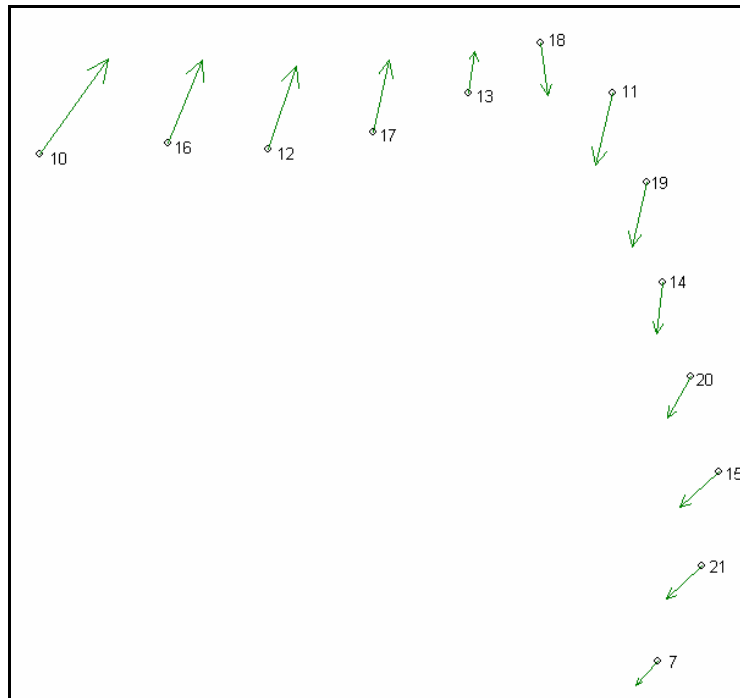


Figure 4.177: Relative Warp Analysis for the supraspinous border of 12 (green) and 13 (blue) year old juveniles

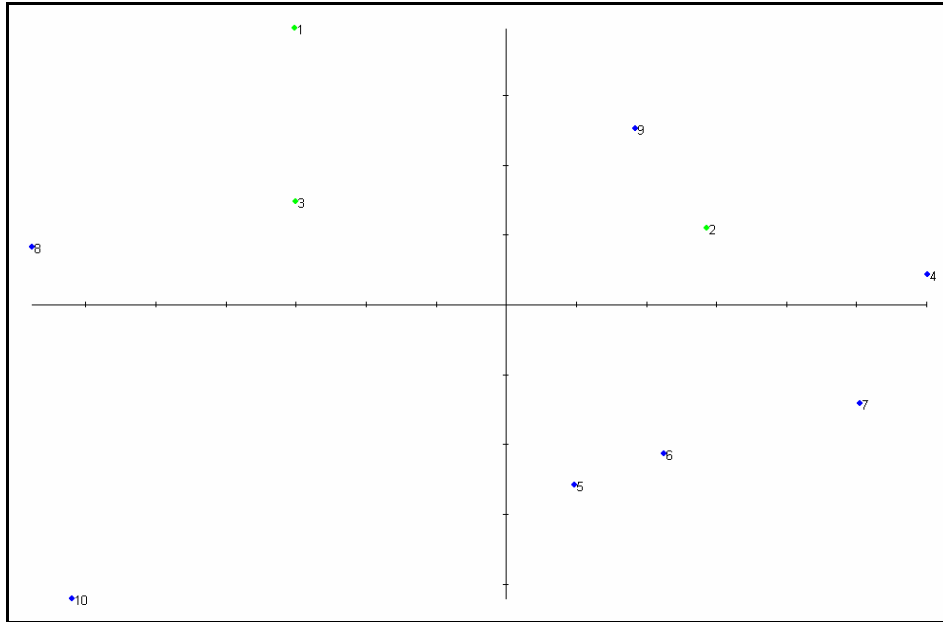


Figure 4.178: Consensus thin-plate spline (in vector mode) to show the separation of 13 year old juveniles (green arrow points) from 12 year old juveniles (black circles) along the supraspinous border

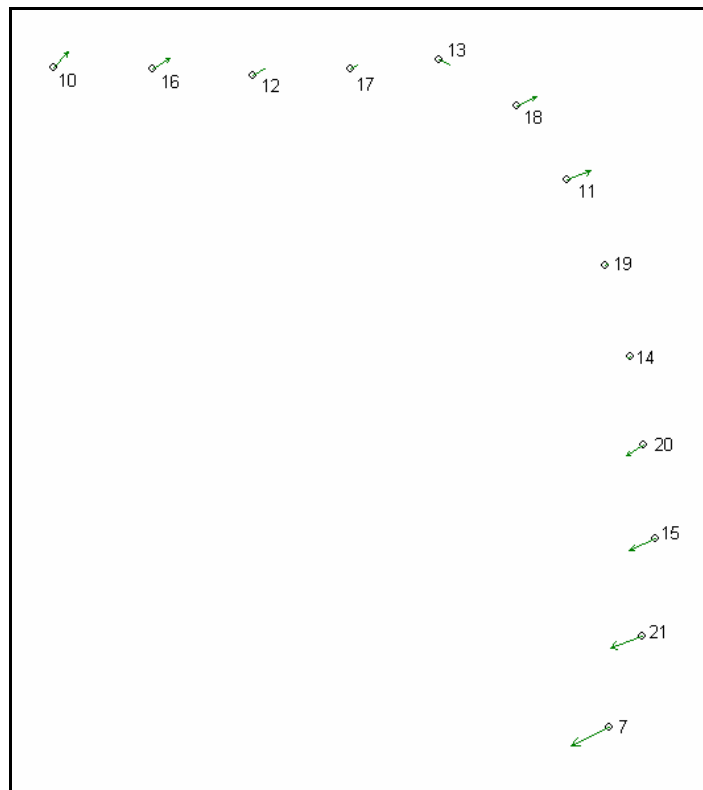


Figure 4.179: Relative Warp Analysis for the supraspinous border of 13 (green) and 14 (blue) year old juveniles

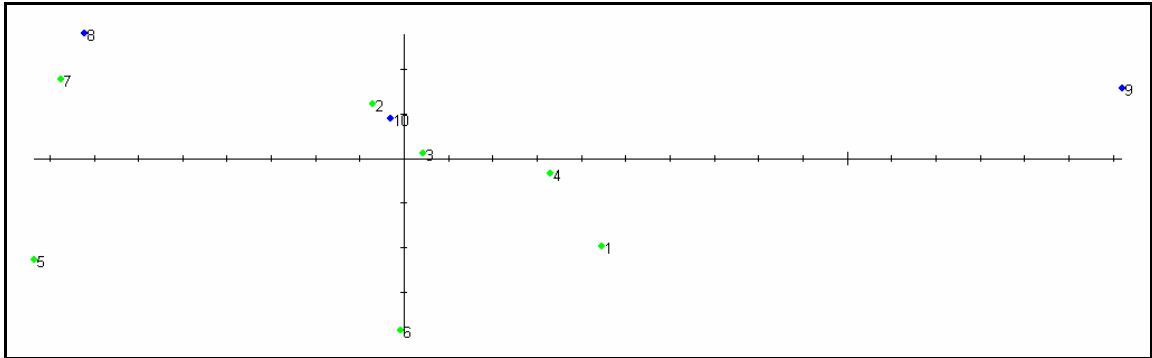


Figure 4.180: Consensus thin-plate spline (in vector mode) to show the separation of 14 year old juveniles (green arrow points) from 13 year old juveniles (black circles) along the supraspinous border

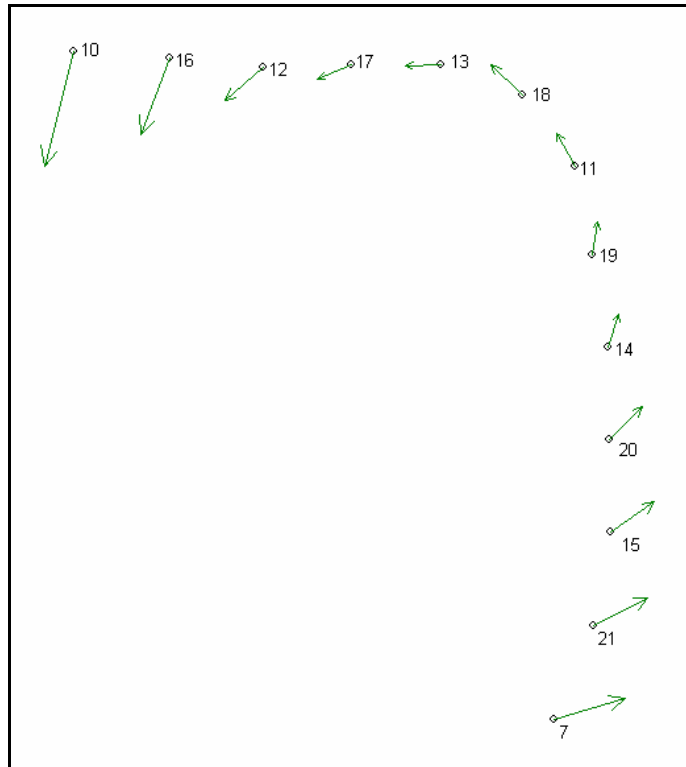


Figure 4.181: Relative Warp Analysis for the supraspinous border of 14 (green) and 15 (blue) year old juveniles

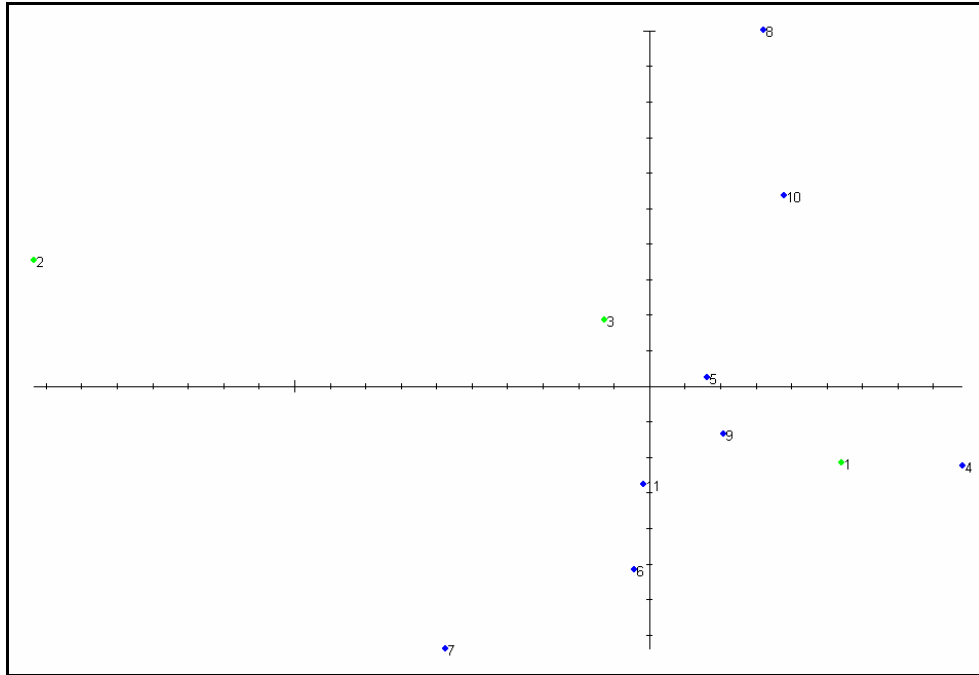


Figure 4.182: Consensus thin-plate spline (in vector mode) to show the separation of 15 year old juveniles (green arrow points) from 14 year old juveniles (black circles) along the supraspinous border

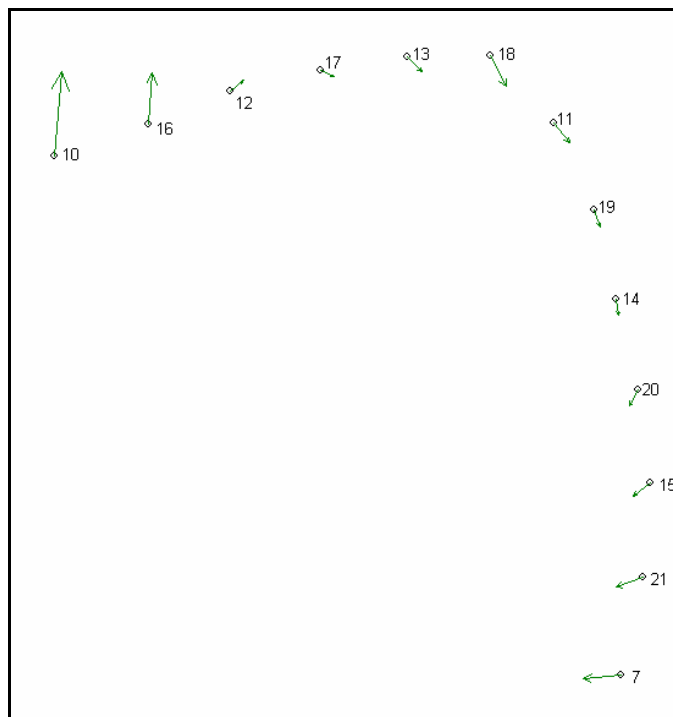


Figure 4.183: Relative Warp Analysis of the supraspinous border of 15 (green) and 16 (blue) year old juveniles

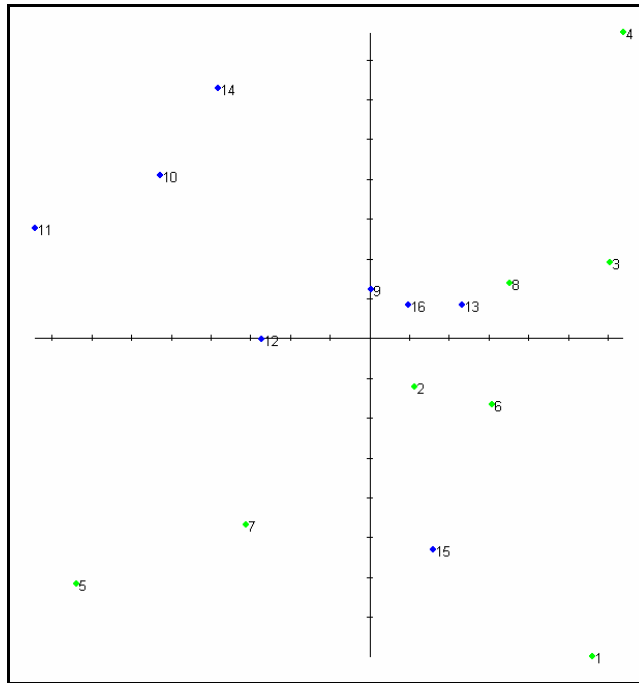


Figure 4.184: Consensus thin- plate spline (in vector mode) to show the separation of 16 year old juveniles (green arrow points) from 15 year old juveniles (black circles) along the supraspinous border

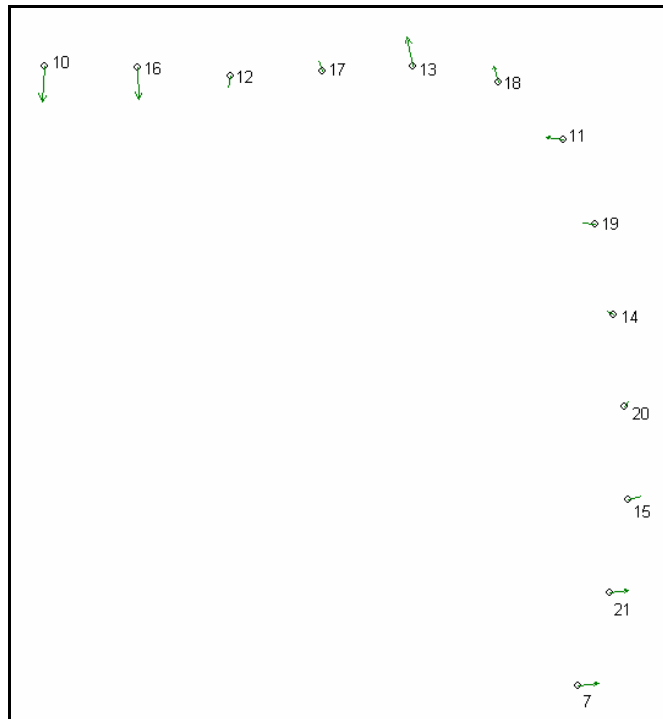


Figure 4.185: Relative Warp Analysis for the supraspinous border of 16 (green) and 17 (blue) year old juveniles

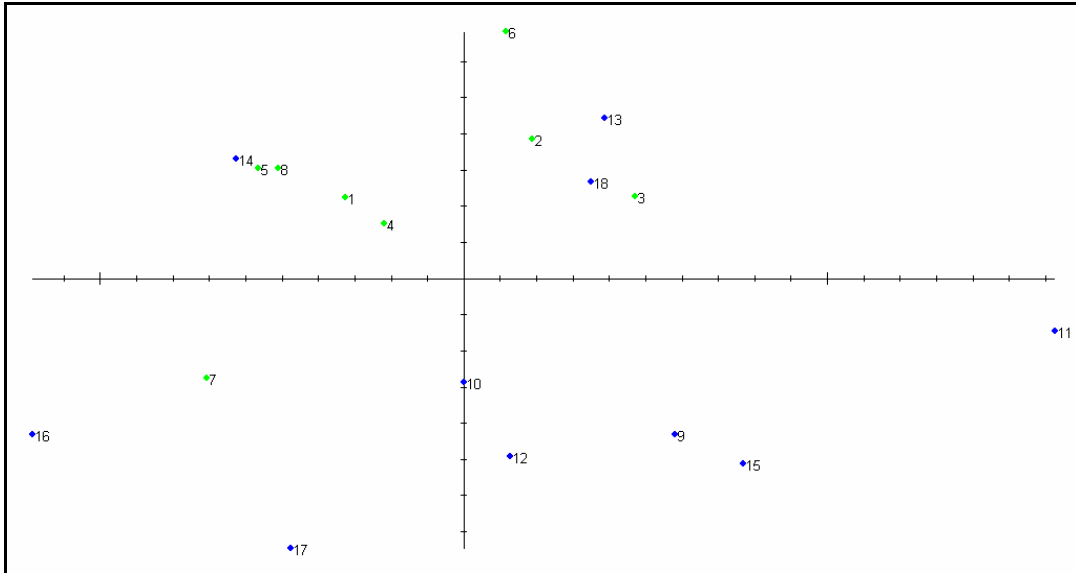


Figure 4.186: Consensus thin-plate spline (in vector mode) to show the separation of 17 year old juveniles (green arrow points) from 16 year old juveniles (black circles) along the supraspinous border

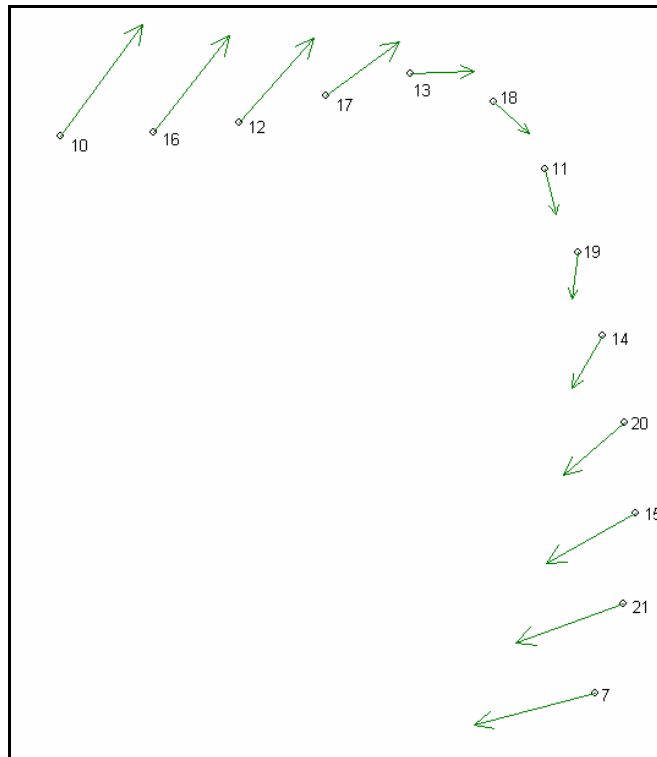


Figure 4.187: Relative Warp Analysis for the supraspinous border of 17 (green) and 18 (blue) year old juveniles

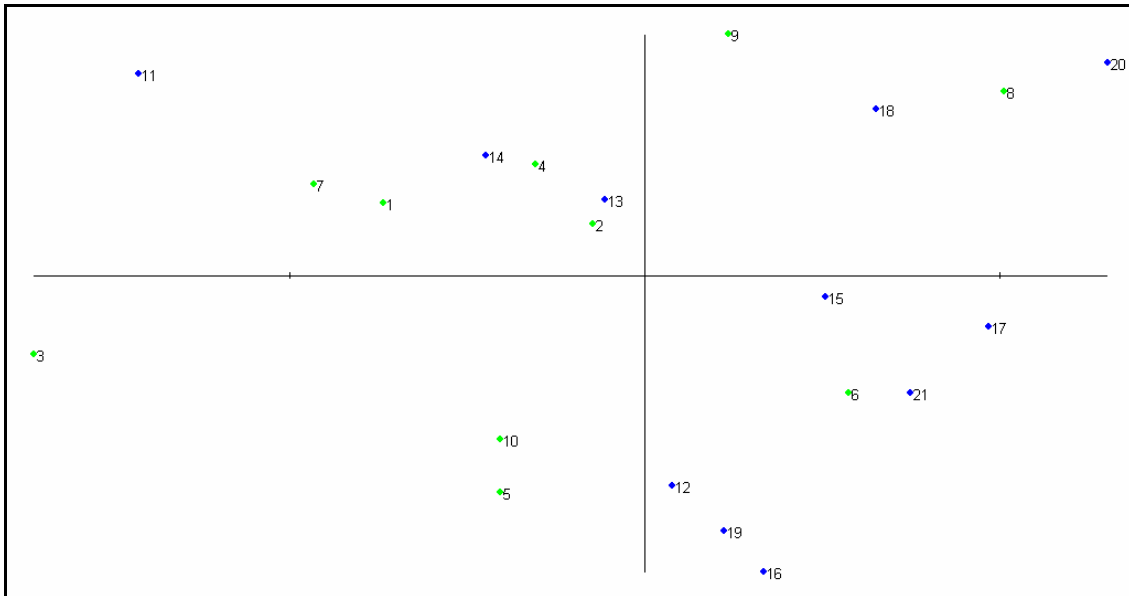


Figure 4.188: Consensus thin-plate spline (in vector mode) to show the separation of 18 year old juveniles (green arrow points) from 17 year old juveniles (black circles) along the supraspinous border

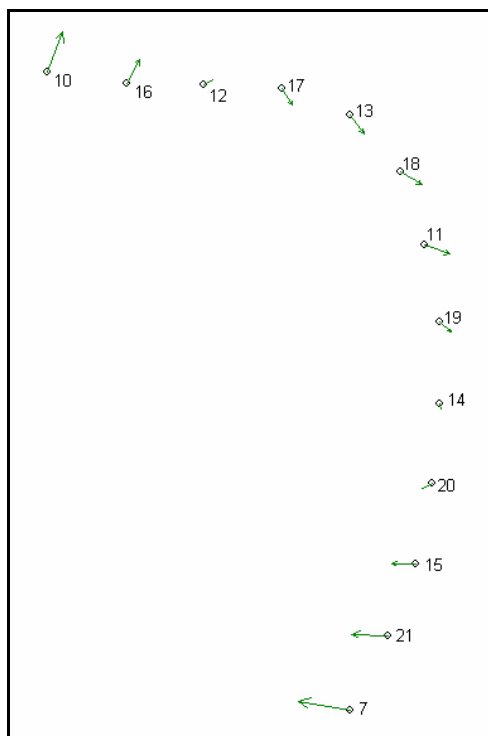


Figure 4.189: Relative Warp Analysis for the supraspinous border of 18 (green) and 19 (blue) year old juveniles

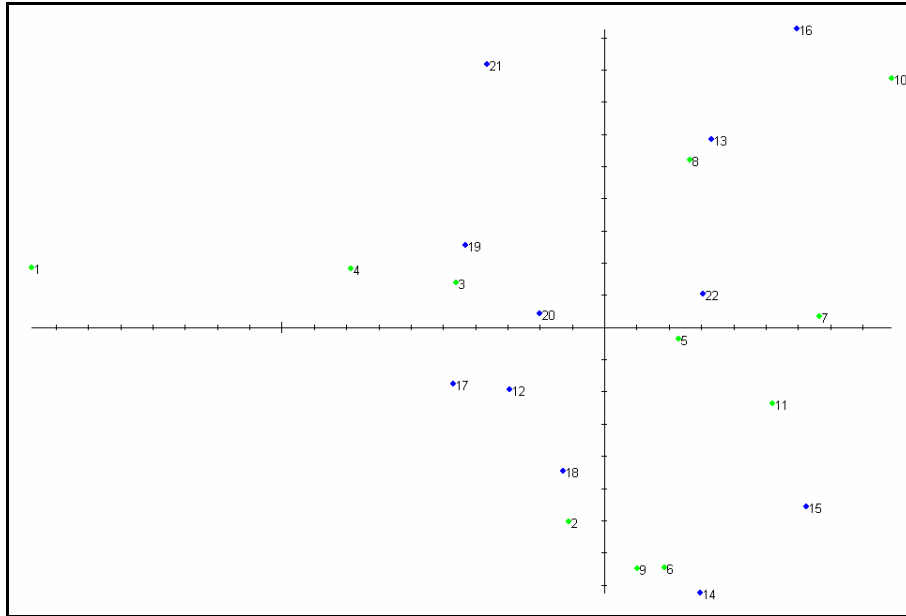


Figure 4.190: Consensus thin-plate spline (in vector mode) to show the separation of 19 year old juveniles (green arrow points) from 18 year old juveniles (black circles) along the supraspinous border

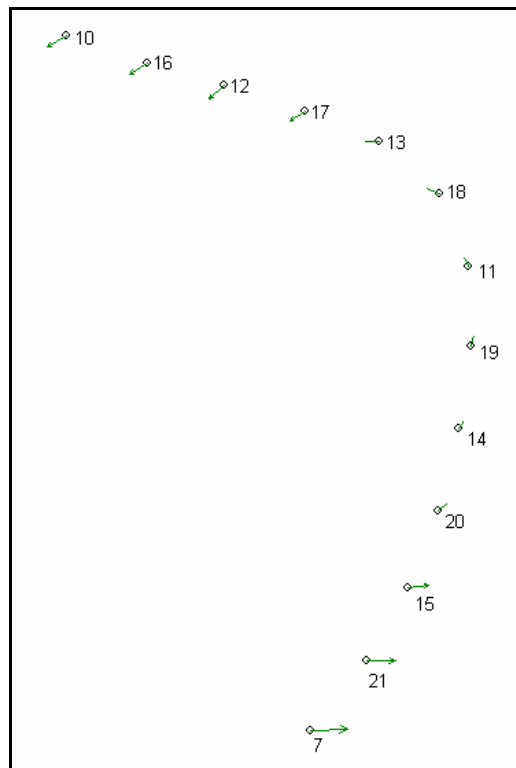


Figure 4.191: Relative Warp Analysis for the supraspinous borders of 1 – 10 (green) and 12 – 19 (blue) year old juveniles

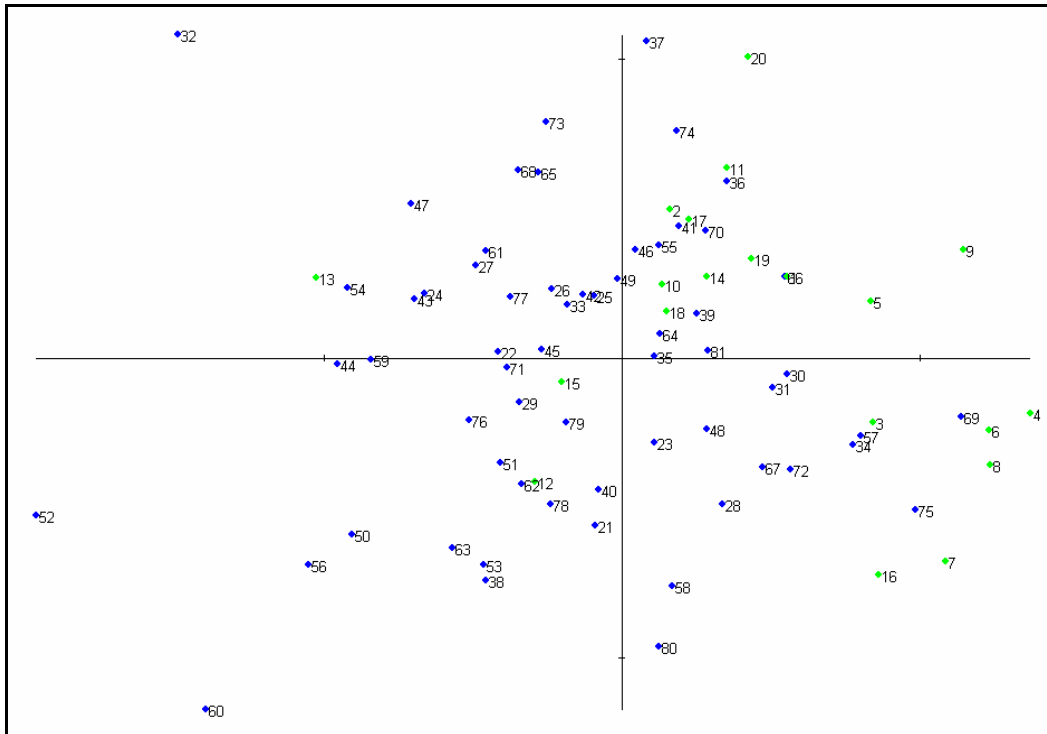


Figure 4.192: Consensus thin- plate spline for the supraspinous border of 1 – 10 year old juveniles

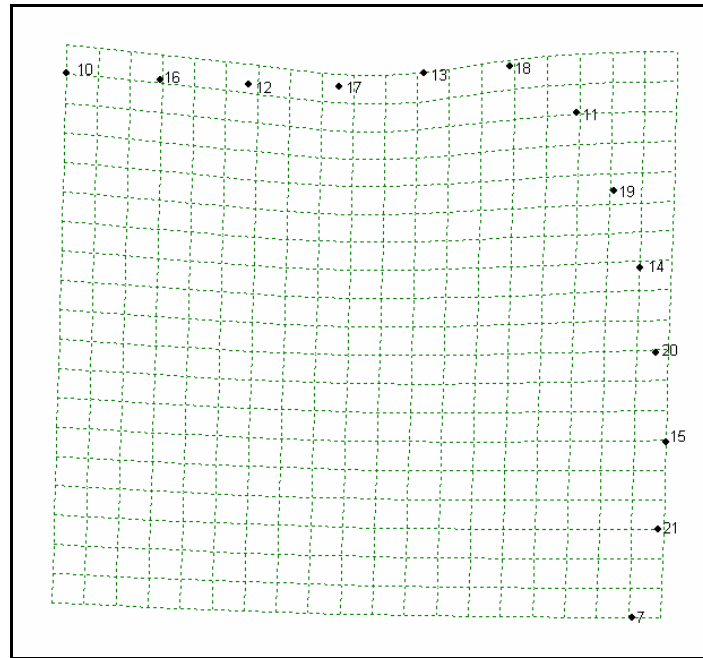


Figure 4.193: Consensus thin- plate spline for the supraspinous border of 12 – 19 year old juveniles

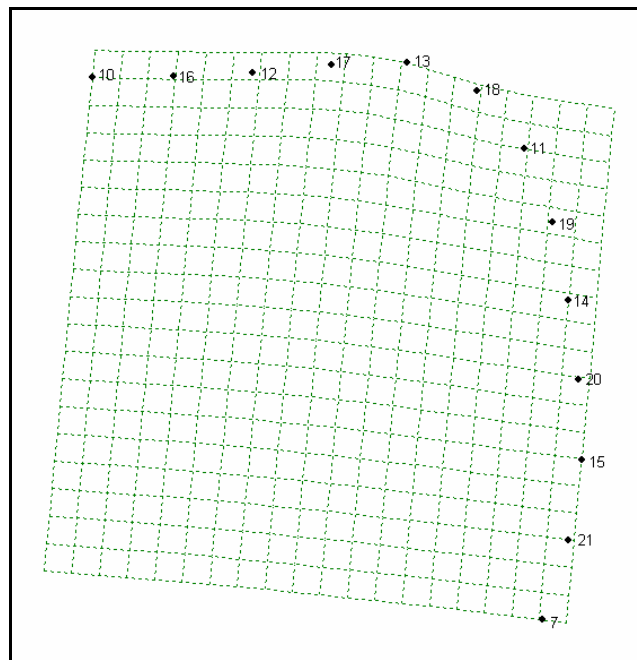


Figure 4.194: Consensus thin- plate spline (in vector mode) to show the separation of 12 – 19 year old juveniles (green arrow points) from 1 – 10 year old juveniles (black circles) along the suprascapular border

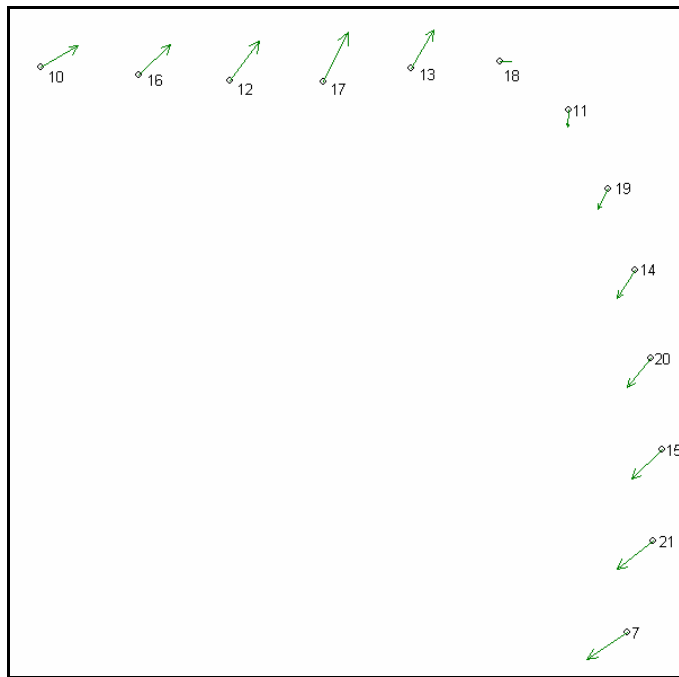


Figure 4.195: TwoGroup BC Superimposition plot for the suprascapular fossae of 1 – 10 and 12 – 19 year old individuals (○ = 1 – 10 year old; □ = 12 – 19 year old) . The suprascapular fossa border has been rotated so that landmark 7 is represented by the point (0,0) and landmark 10 by the point (0,1)

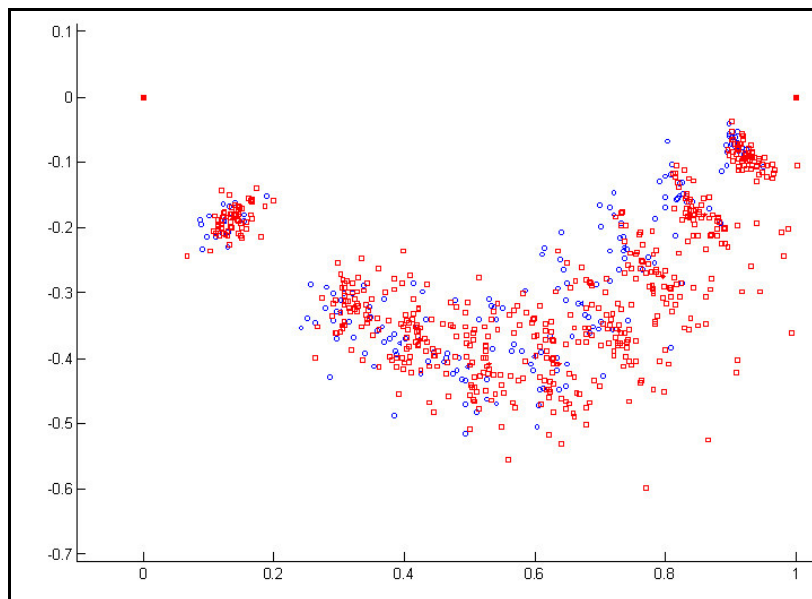


Figure 4.196: CVA plot for the superior border of 1 – 10 and 12 – 19 year old individuals (○ = 1 – 10 year old; x = 12 – 19 year old). The supraspinous fossa border has been rotated so that landmark 7 is closest to the vertical (y-) axis

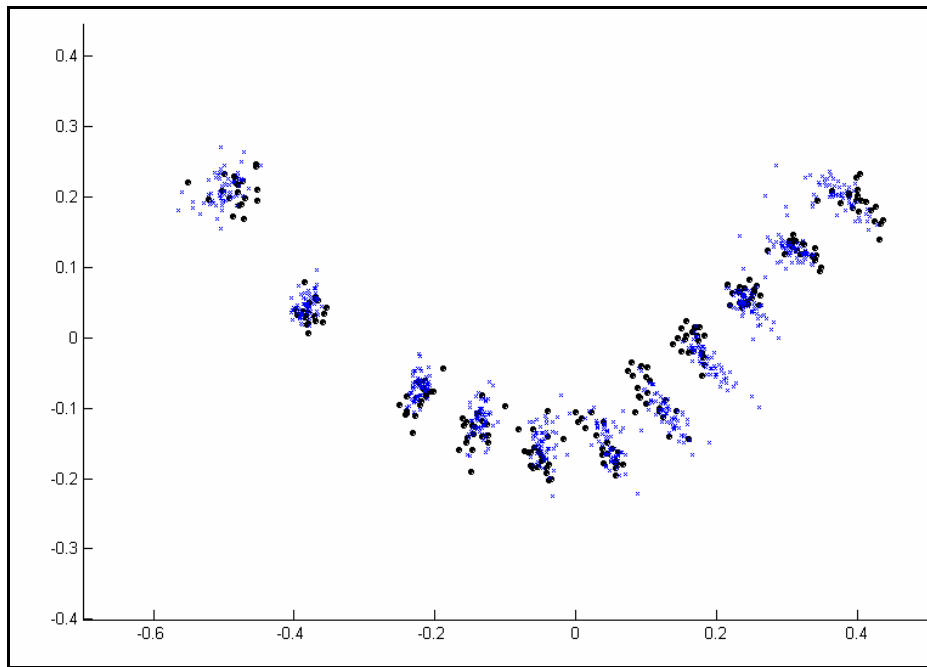


Figure 4.197: Mean of the CVA plot for the superior border of 1 – 10 and 12 – 19 year old individuals (○ = 1 – 10 year old; x = 12 – 19 year old). The larger black circle and blue cross represent the mean shape for adult females and males respectively

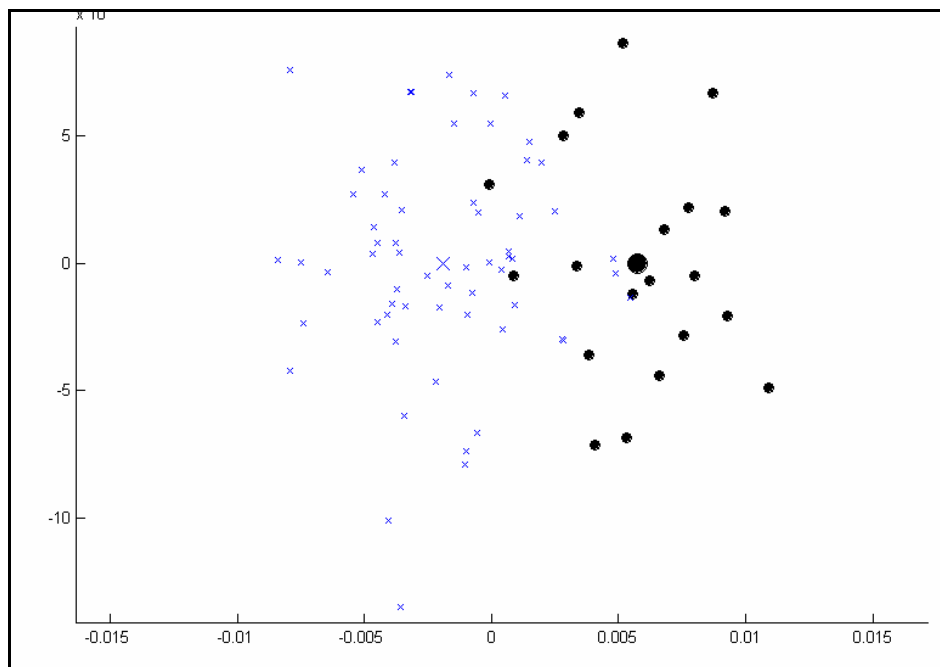


Table 4.1: Percentage of males and females correctly assigned using a canonical variates analysis. The number of individuals used is indicated in the left hand column

Sex as in Dataset	CVA assignment based on shape data		Percentage correctly assigned
	<i>Correctly assigned</i>	<i>Incorrectly assigned</i>	
Females (45)	41	4	91.11%
Males (45)	43	2	95.56%

Table 4.2: Percentage of juveniles correctly assigned into two age groups using a canonical variates analysis. The number of individuals used is indicated in the left hand column

Age as in dataset	CVA assignment based on shape data		Percentage correctly assigned
	<i>Correctly assigned</i>	<i>Incorrectly assigned</i>	
1-10 years (20)	20	0	100.00%
12-19 years (61)	60	1	98.36%

Table 4.3: Percentage of juveniles correctly assigned into two age groups based on the shape of the supraspinous fossa using a canonical variates analysis. The number of individuals used is indicated in the left hand column

Age as in dataset	CVA assignment based on shape data		Percentage correctly assigned
	<i>Correctly assigned</i>	<i>Incorrectly assigned</i>	
1-10 years (20)	18	2	90.00%
12-19 years (61)	54	7	88.52%

CHAPTER 5

DISCUSSION

5.1 SEXUAL DIMORPHISM IN THE ADULT SCAPULA

Figures 5.1 and 5.2 are examples of typical female and male scapulae. When looking at the complete female scapula, it is much narrower than the male scapula. The lateral border is straighter in the female, while being more curved in the male. The inferior angle is generally sharper in males than females and the medial border of the male is more curved than that of the female – broader towards the scapular spine, and narrower towards the inferior angle. The superior border of the supraspinous fossa is convexly curved in females, while in males it runs with a downward slope towards the superior angle. The medial border of the supraspinous fossa is straighter in females, while in males it curves toward the scapular spine. However, much variation and overlap exists.

As described in the results, one of the problems in this study was that it is difficult to assign homologous landmarks to the scapula (although the landmarks proved to be repeatable). There are no definite homogeneous landmarks along the borders of the scapula and the majority of the landmarks are to a large extent dependent upon the observer (except for landmarks 1, 2, 5 and to some extent 7 and 10 which remain constant). This may have influenced the results, although there is currently no way to bypass these problems.

In order to understand the observed differences between male and female scapulae better, the three borders (lateral, medial and superior) were studied separately. The same differences were seen when the three borders were studied separately as when the complete scapula was studied, with the superior border showing the most variation between the two sexes.

One of the drawbacks to studying the three borders separately was that the three borders on their own did not yield good results when using the Integrated Morphometrics Package (IMP). Neither the TwoGroup program's statistical analyses nor the CVA analysis could be used on the medial border as there were not enough landmarks (only four landmarks). Although the two programs were used on the lateral border and supraspinous fossa, the results obtained were not significant. The lateral border yielded non-significant p- values, with Goodall's F- test yielding a p- value of 0.342, while Hotelling's T^2 - test gave no result. A CVA plot for the mean shapes of the female and male lateral borders showed almost complete overlap.

The TwoGroup program was used with some success on the supraspinous fossa, with Goodall's F- test yielding a significant p- value of 0.038, while Hotelling's T^2 - test yielded a p- value of 0.063 which was significant at the 0.1 level. A CVA plot for the mean shapes of the female and male supraspinous fossae showed a large amount of overlap.

Based on the p- values obtained, as well as the CVA plots, the superior border of the scapula is a more accurate indicator of sexual dimorphism than the lateral border, as Goodall's F- test and Hotelling's T^2 - test both yielded statistically significant p- values, while the p- values for the lateral border were not statistically significant.

The complete scapula, however, yielded better results. Goodall's F- test yielded a non-significant p- value of 0.20014, while Hotelling's T^2 - test yielded a significant p- value of 0.00039. When the CVA analysis was performed on the complete scapula, 91.1% of the females were correctly classified as female, while 95.6% of the males were correctly classified as male. The CVA analysis also yielded a statistically significant p- value of 0.00015.

When the medial border of the scapula (pooled sexes) was compared with results obtained by Graves (1921), similarities were seen. Graves found that the convex shape of the medial border was most frequently seen with percentages of 61% and 54.3% seen in two different samples. The straight medial border was the second most frequent, with percentages of 26% and 27% seen in two different samples. The concave medial border was the least frequent, with percentages of 13% and 18.7% seen in two different samples. In the current study similar results were seen in the pooled sample group, with 53.3% of the sample showing a convex medial border, 34.4% showing the straight medial border and 12.2% a concave medial border ¹⁶.

The results obtained from this study are similar to the results from previous studies into the sexual dimorphism of the scapula, especially those of Hrdlička (1942), as well as Bainbridge and Genovés (1956) ^{17, 19, 20}.

In this study, the superior border of the scapula was found to be convexly curved in females, while in males it runs with a downward slope towards the superior angle. These results are supported by Hrdlička (1942), who found that the female superior border generally varies between horizontal or slightly rising, moderately oblique moderately rising and angular or deep saddle- shaped, while the male superior border generally varies between steep or markedly oblique, concave or semi- lunar and markedly concavo- convex or wavy. In this study the superior border of the scapula was found to be the most variable of all the borders ¹⁷.

The geometric morphometric analysis indicated that the medial border of the scapula was straighter in the female and more curved in the male (broader towards the scapular spine and narrower towards the inferior angle). These results are supported by Bainbridge and Genovés (1956), who assessed the scapulae from a collection of 17th – and 18th – century skeletons from St. Bride church in London. They recognised the three

main forms of the infrapinuous portion of the medial border as convex, straight and concave and found that the male scapula was convex in 37 of the 45 male scapulae, while the medial border of females was straight in seven of the 13 female samples²⁰.

The percentage accuracy as indicated by the CVA analysis, compare favourably with previous studies using geometric morphometric techniques to determine sexual dimorphism. These include studies of the greater sciatic notch, mandibular ramus flexure and orbital shape⁸⁻¹⁰.

Pretorius *et al.* (2006) investigated the usability of sexual dimorphism in South African Negroid populations. Orbital shape, mandibular ramus flexure (using data obtained by Oettlé *et al.* in 2005) and greater sciatic notch shape (using data obtained by Steyn *et al.* in 2004) were assessed and their accuracies compared. It was found that the shape of the sciatic notch was the most accurate feature, with 87.1% of females and 93.1% of males being correctly assigned. A p- value of 0.0 was obtained for sexual dimorphism of this feature, indicating a high degree of significance. Orbital shape was second best with 80.0% of the females and 73.3% of the males correctly assigned. A p- value of 0.00129 was obtained for the orbits. Overlap was present in the mandibular ramus with 67.8% of the females and 69.9% of the males correctly assigned, and a p- value of 0.031 being obtained²⁴. Hotelling's T²- test yielded a statistically significant p- value of 0.014⁸⁻¹⁰.

Compared to the above, the results obtained from the current study on the sexual dimorphism of the scapula are very accurate, indicating that the shape of the scapula can be used as an indicator of sexual dimorphism. These results indicate that geometric morphometric methods can be used to accurately determine sex from scapular shape. These methods can, however, only be used on the complete scapula, as the results

obtained from the three separate borders, except for the superior border, were not statistically significant.

Geometric morphometric techniques could be used, for example, if a complete scapula of unknown origin was found. The scapula could be photographed in the standardized position described in Chapter 3 and the landmarks could be assigned to the digitized photograph. The unknown scapula could then be added to a selection of known scapulae and thin-plate splines as well as vector thin-plate splines could be compared in order to determine the sex of the unknown scapula. It could also be pooled with a selection of known scapulae to determine into which group a CVA analysis classifies it. One problem that could be encountered during such an experiment is the problem of assigning the homologous landmarks as this needs some experience.

The differences between the male and female scapulae might be as a result of males being more active and doing more physical labour leading to better developed muscles. The influence of surrounding muscles on scapular shape is supported by Kuhns and Wolffson, both of whom stated that the attaching muscles of the vertebral border played a role in determining its shape^{34, 35}. Further research into this topic, however, is needed.

5.2 SEXUAL DIMORPHISM IN THE JUVENILE SCAPULA

The juvenile sample consisted of 81 scapulae of known age and sex. Seventy-nine of these scapulae were obtained from the Raymond Dart Collection at the University of the Witwatersrand, while a further two scapulae, that of a three year old male and an eight year old female from forensic cases of known individuals, were used. The scapulae obtained ranged from one to 19 years. All the specimens in the Raymond

Dart Collection were included in the sample, but due to the fact that juvenile scapulae are rare there was not necessarily a good representation of all age groups.

No five year old or 11 year old scapulae could be found. In some of the age groups only one scapula was available (six, eight, nine and ten year old juveniles). More scapulae were available in the older age groups (age 15 and up), while the younger scapulae were less numerous. The male scapulae were also more abundant than the female scapulae. In the whole sample only 30 individuals were female, while 51 were male.

Juvenile skeletal samples are very rare and the difficulties of finding a large enough sample is a problem all over the world. One of the drawbacks in this study into the sexual dimorphism of juvenile scapulae was thus the sample size. The juvenile sample was not large enough to reach a definitive conclusion. The results were also affected by the fact that more male than female scapulae were available and by the fact that the males and females were not equally distributed in all the age groups. Another drawback was once again the assignment of landmarks. Although the landmarks were repeatable, it was difficult to determine and assign homologous landmarks to the scapula. Results obtained thus remain tentative. A large amount of variation was seen and the trends between the different age groups were not always clearly seen. These are problems that could have been less if a larger sample had been available, thus eliminating the effect of “individual human variation”.

The juveniles were divided into three age groups in order to determine whether sexual dimorphism could be observed. This was done because of the small numbers of samples in each age group (including the fact that in some age groups one or even no samples were available), as well as the fact that scapular shape changes so much during

the growth period that it could not be compared over the large age range. The three age groups are: ages 1 – 6 (younger infants), 7 – 12 (older infants) and 13 – 19 (adolescents).

Differences could be seen in all three age groups, albeit small. In the Relative Warp Analyses for the three age groups, separation could be seen in the 1 – 6 and 7 – 12 year age groups, while the 13 – 19 year old age group showed overlap. This could be as a result of the number of males and females in each age group. In the 1 – 6 year old group there are seven females and eight males, five females and three males in the 7 – 12 year old group and 19 females and 39 males in the 13 – 19 year old group. The males and females in the two younger groups are thus more equally distributed, while there are almost twice as many males as females in the 13 – 19 year age group. This could have influenced the distribution on the Relative Warp Analysis.

In the 1 – 6 year age group, the female shape was shorter and broader than that of males. The inferior angle was slightly sharper in males than in females. The lateral and the medial borders were longer and straighter in males than in females. While the superior border of the supraspinous fossa was convex for both sexes, the female shape seemed slightly more convex. The medial border of the supraspinous fossa seems to be slightly more curved for females.

In the 7 – 12 year age group, the male scapula was more elongated than that of the female. The lateral border was more elongated in males than in females, while the inferior angle was sharper in males. The medial border was more curved in males than in females. The superior border of the supraspinous fossa seemed to be more concave in females and convex in males, while the medial border of the supraspinous fossa was straighter in females than in males.

In the 13 – 19 year age group, the male scapulae were more elongated and narrower than that of females. The lateral border was straighter in males, while the

medial border was straighter in females. The superior border of the supraspinous fossa was concave in males and slightly convex in females, while the medial border of the supraspinous fossa was straighter in females than in males.

In the 1 – 6 year age group, no CVA analysis could be performed due to the small sample size (15 individuals – 7 females and 8 males). Goodall's F- test was performed using the TwoGroup program and yielded a statistically significant p- value of 0.014.

No CVA analysis could be performed on the 7 – 12 year age group, due to the small number of individuals in the sample (8 individuals – 3 females, 5 males). Goodall's F- test was performed and was not significant, with a p- value of 0.609.

The CVA plot for the mean shape of 13 – 19 year old females and males showed clear separation between the sexes. Goodall's F- test yielded a statistically significant p- value of 0.003.

The differences observed between the juvenile males and females in all three age groups are consistent with the observations made by Hrdlička (1942), who found that sexual dimorphism was present in the scapular shape of juveniles, but that these differences were irregular. He concluded that a larger sample was necessary in order to reach a definite conclusion¹⁹.

Although the differences between juvenile male and female scapular shape are irregular, the scapular body of all three age groups was found to be shorter and broader in females while being longer and more elongated in males. The lateral border in all three age groups was found to be straighter in males than in females. This means that the lateral border of the scapula can be used to determine sex even if the age is not known. The differences between the other two borders can only be used to determine sex if the

age of the individual is known. However, the variation is so big that any conclusions will remain tentative at best. More research, with larger samples, is needed.

5.3 ONTOGENY OF THE SCAPULA

Problems that were encountered with this study include the assignment of landmarks (although the landmarks were repeatable), as well as the sample size. While landmarks 1, 2, 5, 7 and 10 were rather homogenous, the other landmarks were to a large extent dependent upon the observer. It is difficult, however, to identify homogenous landmarks on the scapula especially in juvenile bones. The sample size was also problematic, with no individuals in some of the age groups (five and eleven year old juveniles), while in other age groups only one or two individuals were available (the six, eight, nine and ten year age groups had only one individual each). Different results may have been obtained if a larger sample was available.

From the results it is clear that there are significant changes in the shape of the scapula as it grows. When the complete scapula observed, it seems that there are changes in the shapes of all the borders, but the area that shows the most consistent change is the supraspinous area. The superior border of the supraspinous fossa changes from concave in younger individuals to convex in older juveniles. This change seems to happen between the ages of 10 and 12, where after this part of the scapula takes on the typical convex shape seen in adult females. It is difficult to give an exact age when this shape change takes place, as no scapulae of 11 year old individuals could be found. It is not clear exactly what causes these changes. The medial border of the supraspinous fossa also changes with advancing age, but these changes are not constant and no directional trend could be observed.

The lateral border of the juvenile scapula remained constant with progressing age. It became slightly straighter and somewhat more elongated with progressing age in the younger juveniles, but after 12 years of age the lateral border showed little change.

The medial border of the juvenile scapula remained constant during early childhood up to the age of six. During older childhood and early adolescence (seven to 15 years old) the medial border became longer and varied between straight and curved. In the older adolescents (15 – 19 years old) the shape of the medial border remained constant showing little change.

The scapular body becomes more elongated and broader with advancing age in the young individuals (1 – 4 years old). This could be as a result of the methods of locomotion in young children. In babies who crawl, the arm is weight bearing, however, most children start walking from age one. The changes in scapular shape in juveniles might also be as a result of muscle development. From the age of six, the scapular body becomes narrower, while still becoming more elongated. From the ages of 12 – 16 the body once again becomes broader while still elongating. At the age of 17 the scapular body becomes narrower and remains constant from then on. From the results obtained it seems that scapular growth is complete at the age of 17 or 18 where after the shapes of all three borders as well as the scapular body remain constant.

The changes observed in the scapular body, as well as the three scapular borders coincide with the ossification of the scapula as described by Scheuer and Black²⁹. The changes that occur in the superior border of the supraspinous fossa, as well as the complete scapular body after 12 years of age coincide with the fusion of the coracoid and subcoracoid ossification centres to the scapular body (13 – 16 years). The fact that the shape of the scapular body remains constant from age 17 coincide with the fusion of the glenoid epiphyses which is complete at ages 17 – 18. According to Scheuer and

Black all the scapular epiphyses are fused and adult shape achieved by 23 years of age, although from the current shapes it seems to be earlier²⁸.

The results obtained, although varying somewhat from available research, seem to be supported by the literature especially that of Hrdlička, who found the superior border to be the most variable part of the scapula. He also found the most frequent superior border shape among juveniles to be concave, changing with age to a more straight or oblique border¹⁷.

Hrdlička classified juvenile scapulae into three main categories: triangular (type 1), concave (type 3) and convex (type 6). He found the type 6 scapula to be predominant in young juveniles from birth onward, with this shape diminishing towards adulthood. He also found that the frequency of type 1 scapulae increased from childhood to adulthood and that this form was thought to develop from type 6. He found that type 3 scapulae were the least frequent. The results obtained from the current study confirm the results obtained by Hrdlička. Up to age 12 the predominant shape of the scapular body in this sample is convex (type 6), with 73.9% of the 1 – 12 year old juveniles showing the type 6 scapula compared to 4.3% type 1 scapulae and 21.7% type 3 scapulae. In the older juveniles (ages 13 – 19) the triangular scapula (type 1) was found to be the most frequent, with 43.1% of the 13 – 19 year olds showing type 1 scapulae compared to 27.6% type 6 scapulae and 29.3% type 3 scapulae.

This study focused on the shape changes in the scapula during its growth employing geometric morphometric methods. While the size of the scapula does increase during the growth period and the shape changes seen in this study may be as a result of these changes, more research is needed.

When the growth of the juvenile scapula is compared with its sexual dimorphism, the scapular body shape is closer to that of the juvenile male. The juvenile male scapular body was found to be narrow and elongated in all three age groups used to study the sexual dimorphism of the juvenile scapula (1 – 6, 7 – 12 and 13 – 19). When the scapular shape of the whole sample was compared, it was found that the scapular body tended to be narrower and elongated in most of the age groups.

The lateral border of the scapula was found to be straight in the males of all three age groups and this was also the case when the lateral border of the whole sample was studied. The medial border of the 1 – 6 year old males was found to be more curved than that of the females, while in both the 7 – 12 and 13 – 19 year age groups, the female medial border was straighter than that of the males. When the medial border of the whole sample was compared, it was found to resemble mostly the female medial border shape – being mostly curved in 1 – 6 year olds and straight in 13 – 19 year olds. The only difference was found in the 7 – 12 year olds, where the medial border of the scapula was found to be more curved, only becoming straighter in the 12 year olds.

The superior border of the supraspinous fossa was found to be more convex in 1-6 as well as 13 – 19 year old females than in the males, while in the 7 – 12 year age group the superior border was found to be more convex than that of the females. When the superior border of the whole sample was compared, it was found that the superior border of the 1 – 6 year olds was concave, but became less concave and straighter with each passing year (thus initially resembling the male, but tending more towards the female shape). For the 7 – 12 year olds, the whole sample was concave, becoming straighter in the 12 year olds – once again resembling female shape. In the 13 – 19 year age group the whole sample once again resembled female shape by becoming more convex.

The medial border of the supraspinous fossa was found to be more curved in the 1 – 6 year old females than the males, but in both the 7 – 12 and 13 – 19 year age groups, the medial border of the supraspinous fossa was found to be more curved for males than females. When the whole sample was compared, the medial border of the supraspinous fossa tended to be more curved thus resembling the 1 – 6 year old females and the 7 – 19 year old males.

Therefore it can be said that while in some aspects the shape of the juvenile scapula resembles that of the male, it is closer to the eventual female shape during its growth period.

The study into the sexual dimorphism of the juvenile scapula can be improved if the sample size is increased and male and female scapulae are evenly distributed throughout the sample, as these were the two main drawbacks of the study into the sexual dimorphism of the juvenile scapula. If the sample size, as well as the distribution of the sexes can be improved, more definitive results regarding the sexual dimorphism of the juvenile scapula might be obtained.

Figure 5.1: Example of a typical female scapula. Note the narrow scapular body, the blunt inferior angle and straight medial border. Also note the convex superior border of the supraspinous fossa, as well as the straight medial border of the supraspinous fossa.



Figure 5.2: Example of a typical male scapula. Note the scapular body which is broader than that of the female and the lateral border which is more curved than that of the female. Also note the medial border which is more curved than that of the female. The superior border of the supraspinous fossa is straighter than that of the female.



CHAPTER 6

CONCLUSION

From this study it could be concluded that geometric morphometric techniques can be used in the study of scapular shape. These techniques were successfully used to study the sexual dimorphism of the adult scapula, as well as the ontogeny and sexual dimorphism of the juvenile scapula.

The largest amount of variation between the adult female and male scapulae were seen in the supraspinous fossa border with the superior border of the female supraspinous fossa being convex, while that of the male was found to run with a downward slope towards the scapular spine, with a more straight to concave shape.

The juvenile sample provided no statistically significant sex differences, although some differences were observed.

It was found that the juvenile scapulae also showed the most change at the supraspinous fossa border. The superior border of the supraspinous fossa was more concave in younger juveniles (aged 1 – 10 years), while in older juveniles (ages 12 – 19) the it displayed the convex shape also seen in adult females.

One problem encountered in this study was the fact that it is difficult to assign homologous landmarks to the scapula. Different results might be obtained of more homologous landmarks are assigned.

Another problem was the fact that juvenile skeletal material is very rare and as a result the sample used in this study, although containing all available juvenile scapulae, was not large enough for a definitive conclusion to be reached. Different results might be obtained if a larger juvenile sample could be acquired. The distribution of males and females in the juvenile sample was also problematic. If the males and females were more evenly distributed, the results might have been different.

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APPENDIX A: Adult scapulae used in the study

List of adult male scapulae

NUMBER	SKELETON NUMBER	AGE	COLLECTION
1	2019	20	Pretoria Bone Collection
2	1694	40	Pretoria Bone Collection
3	2786	50	Pretoria Bone Collection
4	2788	80	Pretoria Bone Collection
5	2855	55	Pretoria Bone Collection
6	2858	22	Pretoria Bone Collection
7	2865	60	Pretoria Bone Collection
8	2889	34	Pretoria Bone Collection
9	2906	50	Pretoria Bone Collection
10	2940	80	Pretoria Bone Collection
11	2949	72	Pretoria Bone Collection
12	2950	70	Pretoria Bone Collection
13	2978	60	Pretoria Bone Collection
14	3003	70	Pretoria Bone Collection
15	3004	46	Pretoria Bone Collection
16	3006	35	Pretoria Bone Collection
17	3023	48	Pretoria Bone Collection
18	3038	36	Pretoria Bone Collection
19	3066	70	Pretoria Bone Collection
20	3096	28	Pretoria Bone Collection
21	3441	47	Pretoria Bone Collection
22	3561	36	Pretoria Bone Collection
23	3670	62	Pretoria Bone Collection
24	3676	58	Pretoria Bone Collection
25	3718	30	Pretoria Bone Collection
26	4196	45	Pretoria Bone Collection
27	4200	59	Pretoria Bone Collection
28	4244	50	Pretoria Bone Collection
29	4258	55	Pretoria Bone Collection
30	4265	55	Pretoria Bone Collection
31	4405	69	Pretoria Bone Collection
32	4421	42	Pretoria Bone Collection
33	4500	55	Pretoria Bone Collection
34	4542	60	Pretoria Bone Collection
35	4602	60	Pretoria Bone Collection
36	4608	90	Pretoria Bone Collection
37	4773	60	Pretoria Bone Collection
38	4731	60	Pretoria Bone Collection
39	4927	84	Pretoria Bone Collection
40	4939	44	Pretoria Bone Collection
41	4942	75	Pretoria Bone Collection
42	4946	96	Pretoria Bone Collection
43	4961	66	Pretoria Bone Collection
44	4968	34	Pretoria Bone Collection
45	4979	55	Pretoria Bone Collection

List of adult female scapulae

NUMBER	SKELETON NUMBER	AGE	COLLECTION
1	4492	48	Pretoria Bone Collection
2	2632	50	Pretoria Bone Collection
3	4565	47	Pretoria Bone Collection
4	4998	63	Pretoria Bone Collection
5	5783	42	Pretoria Bone Collection
6	1543	40	Pretoria Bone Collection
7	3266	28	Pretoria Bone Collection
8	5013	55	Pretoria Bone Collection
9	2900	60	Pretoria Bone Collection
10	3854	40	Pretoria Bone Collection
11	4464	66	Pretoria Bone Collection
12	4598	32	Pretoria Bone Collection
13	4956	40	Pretoria Bone Collection
14	5108	68	Pretoria Bone Collection
15	3015	70	Pretoria Bone Collection
16	5342	57	Pretoria Bone Collection
17	4990	60	Pretoria Bone Collection
18	5079	45	Pretoria Bone Collection
19	5259	35	Pretoria Bone Collection
20	5708	71	Pretoria Bone Collection
21	5698	50	Pretoria Bone Collection
22	2980	49	Pretoria Bone Collection
23	3609	44	Pretoria Bone Collection
24	4240	50	Pretoria Bone Collection
25	4256	42	Pretoria Bone Collection
26	3843	40	Pretoria Bone Collection
27	1803	60	Pretoria Bone Collection
28	6177	23	Pretoria Bone Collection
29	6094	33	Pretoria Bone Collection
30	4605	38	Pretoria Bone Collection
31	5018	59	Pretoria Bone Collection
32	5511	65	Pretoria Bone Collection
33	1696	79	Pretoria Bone Collection
34	4436	37	Pretoria Bone Collection
35	5086	34	Pretoria Bone Collection
36	5717	55	Pretoria Bone Collection
37	2885	60	Pretoria Bone Collection
38	5878	32	Pretoria Bone Collection
39	4855	65	Pretoria Bone Collection
40	5148	54	Pretoria Bone Collection
41	5005	60	Pretoria Bone Collection
42	5602	55	Pretoria Bone Collection
43	5073	64	Pretoria Bone Collection
44	5033	70	Pretoria Bone Collection
45	5797	28	Pretoria Bone Collection

APPENDIX B: Juvenile scapulae used in this study

NUMBER	SKELETON NUMBER	SEX	AGE	COLLECTION
1a	472	Male	1	Raymond Dart (Wits)
1b	608	Female	1	Raymond Dart (Wits)
1c	713	Female	1	Raymond Dart (Wits)
1d	1572	Female	1	Raymond Dart (Wits)
1e	3014	Male	1	Raymond Dart (Wits)
1f	3018	Female	1	Raymond Dart (Wits)
2a	656	Female	2	Raymond Dart (Wits)
2b	1469	Female	2	Raymond Dart (Wits)
3a	854	Male	3	Raymond Dart (Wits)
3b	1327	Male	3	Raymond Dart (Wits)
3c		Male	3	UP (Forensic)
4a	712	Male	4	Raymond Dart (Wits)
4b	1247	Female	4	Raymond Dart (Wits)
4c	1320	Male	4	Raymond Dart (Wits)
6a	3019	Male	6	Raymond Dart (Wits)
7a	722	Male	7	Raymond Dart (Wits)
7b	3148	Female	7	Raymond Dart (Wits)
8a		Female	8	UP (Forensic)
9a	1439	Male	9	Raymond Dart (Wits)
10a	3015	Male	10	Raymond Dart (Wits)
12a	972	Female	12	Raymond Dart (Wits)
12b	1244	Female	12	Raymond Dart (Wits)
12c	1630	Female	12	Raymond Dart (Wits)
13a	680	Male	13	Raymond Dart (Wits)
13b	746	Female	13	Raymond Dart (Wits)
13c	769	Female	13	Raymond Dart (Wits)
13d	2940	Male	13	Raymond Dart (Wits)
13e	3013	Male	13	Raymond Dart (Wits)
13f	3671	Male	13	Raymond Dart (Wits)
13g	3963	Male	13	Raymond Dart (Wits)
14a	439	Male	14	Raymond Dart (Wits)
14b	1875	Female	14	Raymond Dart (Wits)
14c	3344	Female	14	Raymond Dart (Wits)
15a	27	Female	15	Raymond Dart (Wits)
15b	151	Male	15	Raymond Dart (Wits)
15c	154	Female	15	Raymond Dart (Wits)
15d	266	Male	15	Raymond Dart (Wits)
15e	508	Male	15	Raymond Dart (Wits)
15f	1666	Female	15	Raymond Dart (Wits)
15g	1893	Male	15	Raymond Dart (Wits)
15h	3109	Male	15	Raymond Dart (Wits)
16a	380	Male	16	Raymond Dart (Wits)
16b	592	Female	16	Raymond Dart (Wits)
16c	800	Male	16	Raymond Dart (Wits)
16d	1271	Male	16	Raymond Dart (Wits)
16e	1525	Male	16	Raymond Dart (Wits)
16f	1632	Male	16	Raymond Dart (Wits)
16g	2393	Male	16	Raymond Dart (Wits)

Appendix B (continued)

16h	3397	Male	16	Raymond Dart (Wits)
17a	174	Male	17	Raymond Dart (Wits)
17b	205	Male	17	Raymond Dart (Wits)
17c	280	Male	17	Raymond Dart (Wits)
17d	383	Male	17	Raymond Dart (Wits)
17e	398	Male	17	Raymond Dart (Wits)
17f	475	Male	17	Raymond Dart (Wits)
17g	496	Male	17	Raymond Dart (Wits)
17h	1280	Male	17	Raymond Dart (Wits)
17i	1586	Male	17	Raymond Dart (Wits)
17j	2178	Female	17	Raymond Dart (Wits)
18a	184	Male	18	Raymond Dart (Wits)
18b	432	Male	18	Raymond Dart (Wits)
18c	577	Female	18	Raymond Dart (Wits)
18d	602	Male	18	Raymond Dart (Wits)
18e	691	Male	18	Raymond Dart (Wits)
18f	742	Male	18	Raymond Dart (Wits)
18g	973	Male	18	Raymond Dart (Wits)
18h	1263	Female	18	Raymond Dart (Wits)
18i	1266	Male	18	Raymond Dart (Wits)
18j	1434	Male	18	Raymond Dart (Wits)
18k	1627	Male	18	Raymond Dart (Wits)
19a	164	Female	19	Raymond Dart (Wits)
19b	723	Male	19	Raymond Dart (Wits)
19c	1304	Male	19	Raymond Dart (Wits)
19d	1360	Female	19	Raymond Dart (Wits)
19e	1483	Female	19	Raymond Dart (Wits)
19f	1958	Female	19	Raymond Dart (Wits)
19g	2016	Male	19	Raymond Dart (Wits)
19h	2179	Female	19	Raymond Dart (Wits)
19i	2842	Female	19	Raymond Dart (Wits)
19j	3366	Female	19	Raymond Dart (Wits)
19k	3924	Female	19	Raymond Dart (Wits)