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Genetic Evaluation for Australian Ostriches

A report for the Rural Industries Research and Development Corporation

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Foreword

In recent years the Australian Ostrich Industry has changed from a fledgling Industry relying on the sale of high value breeding stock, to an Industry facing the realities of producing commercial end products efficiently from slaughter birds. In order to survive this transition within the Industry it is necessary for producers to overcome major limitations to production, which include poor reproductive success and slow weight gains in slaughter birds. Research into factors affecting productivity in farmed ostriches has been carried out in many areas to address these issues (eg. incubation management, nutrition, disease epidemiology etc). However, a notable exception has been in the area of genetic improvement.

The success of genetic improvement as a tool for improved productivity has been well illustrated in other livestock species, particularly in the intensive livestock industries. Genetic improvement in poultry is often used as a model for illustrating the gains that could be made in ostrich production through appropriate selection strategies, although the production systems and physiology of these species differ. Limited information has been available to date that indicates how successful selection may be for improving current and future gains of economically important traits in farmed Ostriches.

The aim of this project was to examine the potential role of genetic improvement in ostrich farming, through data analysis and estimation of genetic parameters. Results could then be applied to developing an Industry based genetic evaluation system. This publication examines the degree to which genetic variation influences performance in a range of ostrich traits, and subsequently the future role of genetic improvement in this Industry. The relationships between a range of reproduction and live weight traits are also examined. Further, analysis of data for genetic studies also provides an excellent opportunity to evaluate non-genetic influences on performance. Current limitations to the application of these results in the Australian Ostrich Industry are discussed.

The majority of results are presented from data generated by a large pair breeding flock located at the Little Karoo Agricultural Development Centre in South Africa, without whose cooperation this project would not have been possible. The value of their assistance in this study should be recognised by the Australian Ostrich Industry.

This project was funded from RIRDC Core Funds, which are provided by the Federal Government of Australia.

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Peter Core
Managing Director
Rural Industries Research and Development Corporation

Acknowledgments

The outcomes reported in this project would not have been possible without the development of a collaborative effort between Australian and South African researchers. Schalk Cloete, from the Elsenburg Agricultural Development Centre (ADC), was the principal researcher involved from South Africa, and I would like to ensure that special recognition is made of Schalk's efforts. Without Schalk's willingness to collaborate, this project would not have been completed. His constant contact, discussions, and encouragement have provided great benefits to myself and to the Australian and South African Ostrich Industries.

This collaboration was also achieved through efforts made by Dr Michael Bradfield, now located at the ARC-Animal Improvement Institute, Irene in South Africa. Dr Paul King (Assistant Director, Agricultural Sciences, ADC) has also actively encouraged and supported collaboration for this project. Thanks also must go to all staff at the Little Karoo Agricultural Development Centre, who have collected data over many years, which was subsequently used for our analyses. Particular thanks to Helet Lambrechts and Koot van Schalkwyk for their help, hospitality and discussions during my stay in South Africa, and Zanell Brand with data retrieval.

The successful response rate achieved from the Internet based reproductive questionnaire can also be largely attributed to the assistance of some key figures. They include Steve Warrington (Ostriches On Line), Fiona Benson (Blue Mountain International), and Daryl Holle (Blue Mountain Feeds) who provided enormous assistance in advertising the Questionnaire to members of their respective Ostrich Industries. Assistance was also provided by Alan Stables in Spain (Iberstruz), and Craig Culley (British Domesticated Ostrich Association). I would also like to thank the ostrich Internet community and survey respondents for supporting the reproductive questionnaire. Thanks also to Dr Doug Black for his comments on the analysis of questionnaire data.

Special thanks also to Dr Peter M^{c}Innes, who continued to support this project when it initially appeared as if it would never get off the ground.

Although their data subsequently could not be used, I would like to also thank those ostrich producers in the Australian Industry who provided data.

Finally, I would also like to acknowledge the assistance provided by Arthur Gilmour and Ron Crump with ASREML software.

Kim Bunter

Abbreviations

A large number of traits were analysed during the course of this study, and abbreviations have been used to minimise repetitive word content in this document.

Egg, Chick and Live Weight Traits

EGGWT	Egg weight: individual egg weight at lay (in grams).
CHICKWT	Chick weight: individual chick weight at hatch (in grams).
LW3	Live weight at three months: live weight at approximately three months (in kilograms).
LW6	Live weight at six months: live weight at approximately six months (in kilograms).
LW10	Live weight at ten months: live weight at approximately ten months (in kilograms).
SLWT	Live weight at slaughter: live weight at approximately 14 months (in kilograms).

Hen Traits

TTL	Time to lay: defined as the number of days between the formation of a breeding pair and the first recorded egg.
DUL	Duration of lay: number of days between first and last egg.
NCL	Number of clutches laid: where each clutch is defined as a group of eggs where each set of consecutive eggs are laid within 4 days of each other.
NLAID	the number of eggs laid.
NINC	the number of eggs incubated.
NINF	Number of incubated eggs that were infertile.
NHATCH	Number of incubated eggs that hatched.
AEWT	Average egg weight: the sum of egg weights divided by the number of eggs weighed.
ACWT	Average chick weight: the sum of chick weights divided by the number of chicks weighed.
AWTR	Average ratio of chick weight to egg weight: the ratio ACWT/AEWT.
TEWT	Total weight of eggs produced: sum of egg weights.
TCWT	Total weight of chicks produced: sum of chick weights.
PINF1	Percentage of infertile eggs: the number of infertile eggs as a percentage of the total number of eggs laid.
PINF2	the number of infertile eggs as a percentage of the total number of eggs incubated.
HPERC1	Hatching percentage: the number of chicks hatched as a percentage of the total number of eggs laid.
HPERC2	the number of chicks hatched as a percentage of the total number of eggs incubated.
HPERC3	the number of chicks hatched as a percentage of the total number of fertile eggs.
EPP	Egg production performance: NLAID / (0.5*the season length for that pair).
CPROD	Productivity: NHATCH / (0.5*the season length for that pair).

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Executive Summary

Background

In established livestock industries, genetic evaluation is routinely performed to enable the selection of superior livestock for breeding purposes. Selection based on genetic merit has led to substantial improvements in productivity, particularly in intensive livestock species, which contributes towards the economic viability of our livestock industries overall. However, for species like the ostrich which have a short domestic history, little is known about the genetic basis of observed variation in recorded traits, and effective breeding programs are yet to be developed.

Use of selection to improve productivity implies that selected traits are under some degree of genetic control. However, genetic parameters for many traits recorded for ostriches have either not been estimated previously, or have been restricted to considering repeatabilities for a limited number of traits. Although, estimates of parameters for comparable traits in poultry provide a general guide to potential improvements in ostrich production through selection, use of these parameters is not ideal given basic physiological differences between the species, and the very different management conditions under which they perform.

In 1997, the Rural Industries Research and Development Corporation funded a two-year research program aimed at implementing genetic evaluation procedures in the Australian Ostrich Industry. This report covers work conducted towards meeting this objective.

Research

Data were obtained from a large pair breeding flock located at the Little Karoo Agricultural Development Centre (LKADC) in South Africa. A series of analyses were performed to establish the relative importance of genetic and non-genetic influences on a range of reproductive and production traits recorded or generated from this data. These traits included individual egg, chick and live weights, along with a number of other traits that represent a range of indicators of reproductive performance in breeding adults. A questionnaire was also developed in order to benchmark reproductive performance commonly achieved in farmed ostriches, thereby establishing the scope for improvements in productivity from slaughter offspring in this Industry.

Outcomes

Key outcomes from analyses of performance and survey data were:

- **Individual egg, chick and live weight traits (except three-month weight) are moderately heritable and will respond to selection. Effects of individual hens on egg and subsequent chick weights are substantial, but of significantly less importance for later weights. Seasonal effects influence individual egg, chick and live weights, the latter of which are also influenced by the age at recording. In addition, hen age, egg position in the complete laying sequence, and some dietary treatments will affect egg and subsequently chick weights to varying degrees.**

  Given the substantial maternal influence on individual egg and chick weights, these are best considered as traits of the hen. Results for hen averages of egg and chick weights indicate that successful selection will also occur for these traits. The carry over effect of the hen on later live weights may also reduce the accuracy of selection based on individual weights recorded at later ages, and ideally should be accounted for in genetic evaluation procedures.

- **Genetic correlations between individual egg or chick weights and later weights are not significant, suggesting that weights recorded at very young ages are poor indicators of the potential for growth at later ages. Weights recorded from six months onwards have high genetic correlations with later weights.**

These results indicate that selection for changes in egg size are not expected to have a large impact on slaughter weights through genetic causes, and any desired changes in egg weight will be for meeting other objectives (eg. for influencing hatchability). Consequently, weights at later ages should be recorded for selection purposes. There was also no evidence for a genetic influence on weight at three months, suggesting environmental factors (in addition to hen related effects) contribute much to observed performance at this age. Weight at three months can also be considered a poor indicator of the genetic potential for future growth, although overall it is positively correlated with later growth.

- **Moderate to high repeatabilities of hen reproductive traits indicates that for many traits the current flock performance can be improved through culling based on previous performances. These traits include actual measures of egg and chick production, and to a lesser extent duration of lay. Low heritabilities for some reproductive traits do not necessarily indicate lack of genetic variation, and future gains can also be expected, but in small progressions given small flock sizes and a low accuracy of selection.**

  Ideally previous performance should encompass results from at least one complete breeding season. Partial season results may inaccurately reflect total production over the complete season if the commencement of laying is delayed for individual hens. Results indicated that duration of lay after the commencement of breeding was strongly associated with reproductive success, reducing the value of early season results for predicting total egg and chick production. In addition, substantial age of hen effects will influence appropriate selection and culling regimes. A relatively late age at which peak egg production occurs for hens (8-9 years) conflicts with shorter generation intervals desired to increase rates of genetic gain.

- **Fertility traits can be considered predominantly as traits of the service sire. Inexperienced or sexually immature males (<4 years) and older males (>11 years) have reduced fertility. Substantial variation between individual service sires for fertility remains apparent even after age effects are accounted for.**

  Given the wide variation between individual service sires in their fertility, factors influencing male fertility need to be identified and methods for assessing male fertility developed. This is necessary for both pair mating and colony breeding structures. Unless contra-indicated by other observations (eg. mate incompatibility, female) infertility of eggs should probably be considered to be a male related problem. Results also suggest that the development of fertility in at least some males is delayed until after the commencement of egg laying by their mates. Development of methods to increase synchronicity of male and female fertility may be warranted, particularly where separate sex flocks are maintained in the non-breeding season.

- **Hatchability traits are initially limited by variation in egg fertility. However, results for hatchability of fertile eggs indicates that hen related effects are also important.**

  Known variation in egg weight, along with other unrecorded egg and shell quality characteristics, are thought to contribute to variation between hens in the hatchability of their eggs. There is also a tendency for hatching percentage to decline with hen age. However, changes to incubation strategies may modify the significance of these effects, and continued investigation of alternative incubation strategies that allow for mixed flock age structures and variation in egg characteristics is strongly indicated for this species.

- **Survey results indicate that a high percentage of producers achieve relatively poor levels of fertility, hatchability and chick survival, in at least one season's results. Median values indicate levels of approximately 20% infertility, 64% hatchability and 26% chick mortality at three months. Realistic targets at the Industry level (based on 25% quantiles) are at least**

10% or less infertility, 75% or better hatchability, and 10% or less chick mortality at three months. Significantly, some individual producers achieve better results than this, and should aim towards increased egg production and increased efficiencies at incubation (eg. 85% hatchability). However, increasing scale of operation, young flock ages and producer inexperience (amongst other factors) will make these targets more difficult to achieve.

Implications

Results from this project clearly indicate that selection and culling can play a significant role in improving the current and future performance in reproductive and slaughter traits recorded in farmed ostriches. Further, survey results indicate that substantial scope for improvement exists within ostrich producing countries, including Australia. Producers who implement relatively simple strategies that result in the retention of superior breeding stock can expect improved economic viability.

However, a primary objective of this project was to implement a genetic evaluation system within the Australian Ostrich Industry, and this was not achieved within the project time frame. Poor performance recording within the Industry, along with commonly used breeding structures, currently hinder the implementation of advanced genetic evaluation systems at both the individual and Industry levels. Results from the Internet survey suggest that this problem is not isolated to the Australian Industry, but occurs worldwide.

The second objective of this project was to provide guidelines within the Industry for performance recording and genetic evaluation. This objective has been achieved as much as possible through written articles, workshops or meetings and publications, and many producers subsequently have increased awareness of performance recording and genetic evaluation issues. However, widespread dissemination of information to date has been limited by Industry difficulties over recent years. A significant extension effort is still required to educate producers as to the possible benefits of performance recording, and to encourage this activity within the Industry, in order to increase the impact of results from this study within the Australian Ostrich Industry.

Future Research

Poor levels of fertility and hatchability remain issues for ostrich producers. Consequently, research aimed at identifying causes of and strategies to deal with male and female infertility are required. For example, the effects of different breeding structures (eg. groups size and mating ratios) and pre-season and breeding season management of breeding adults on fertility are poorly quantified in this species. In addition, considerable scope exists for the development of incubation strategies which optimise hatchability of high quality chicks. This is of increased importance relative to other domestic poultry species due to significant levels of variation between individual hens, mixed flock age structures, and laying sequence effects on egg weight (and probably egg composition). An additional area in which knowledge is clearly lacking relates to chick mortality. High mortality levels are ultimately detrimental in a species where income is derived from slaughter progeny. Survey results indicated relatively high levels of chick mortality for the majority of farmers. However, details on chick mortality were not available for the South African data set, and factors affecting this could not be examined.

Continued collaboration with South African researchers is expected, and may provide the opportunity to address some of the above issues.

Conclusions

Significant additions to current knowledge of the genetic and non-genetic basis of performance in farmed ostriches have been achieved, and Australian ostrich producers are now in a better position to implement selection and culling strategies that will increase productivity. However, poor levels of performance recording within the Australian Industry, and lack of commitment by some key Industry figures, almost critically hindered the project initially, and has subsequently limited our ability to implement advanced genetic evaluation systems within this Industry. A substantial extension effort is required if results from this research are to be satisfactorily implemented in order to achieve a significant impact.

Publications

Publications to date include:

Bunter, K.L., Cloete, S.W.P. and van Schalkwyk, S.J. (1999). Significant genetic parameters for egg, chick and juvenile weight traits in ostriches. Proceedings of the 13th Conference of the Association for the Advancement of Animal Breeding and Genetics. pp476-479.

Hans-Ulrich Graser (1996). Performance recording for a genetic evaluation of ostriches. Australian Ostrich Association Journal, October/November 1996, pp 80-81.

Hans-Ulrich Graser (1997). Performance recording and estimated breeding values. Proceedings of the Australian Ostrich Convebtion, 6-10 August, 1997, Perth, Australia (session A6).

Schalk Cloete, Kim Bunter, Koot van Schalkwyk and Zanell Brand (2000). Seleksiemoontlikhede by Volstruise – Onlangse Vordering (Possibilities for selection in ostriches). Landbouweekblad, 10 March 2000, pp 40-42.

Material contained in this report will also contribute towards a thesis (in preparation) to be submitted for the degree of Doctor of Philosophy, University of New England, Armidale, Australia.

1 Introduction

The Australian Ostrich Industry is in the process of transition from a new or emerging industry status towards a more mature established Industry. This change in status corresponds with a reduction in the value of breeding stock, and increased commercial pressure to produce slaughter end products efficiently. Prior to this point in a new Industries development, livestock prices bear little resemblance to commercial performance and there is only a small incentive for genetic improvement (Amer and Fennessy, 1998). However, several members of the Australian Ostrich Industry recognised that efficient production was necessary if the Industry was to remain viable in the future. Further, it was also recognised that although strong expansion in the breeding stock sector had occurred in the Industry, very little formal evaluation of performance had occurred, and this has probably contributed to the relatively poor productivity of this species in the farming environment.

A more recent survey (Stables, 2000) of producers in Ostrich Industries around the world has indicated that production problems remain the primary cause of concern for producers in many countries, particularly those countries where the Industry is relatively new. Significantly, as this project has progressed the commercial reality of the need for efficient production has resulted in the exit of many producers from the Australian Industry. The remaining producers tend to be larger in their scale of operation, have more experience in ostrich production, are well organised and more co-operative, and should recognise the value of performance recording. They are subsequently becoming better placed to develop breeding objectives, organise breeding structures at industry and flock levels, and make use of advanced genetic evaluation procedures.

The Australian Ostrich Association (AOA) and the Rural Industries Research and Development Corporation (RIRDC) pre-empted this stage in the Industry by funding research in the area of genetic improvement. The overall objectives of this project were to:

- Develop and implement a genetic evaluation system for the Australian Ostrich Industry that will allow it to select breeding stock efficiently for improved genetic performance.
- Provide guidelines for quality performance recording and genetic selection to the Ostrich Industry through Industry workshops and individual consultations.

In order to develop and implement a genetic evaluation system within the Australian Industry, several sub-objectives needed to be met within the two years for which the project was funded. These included:

1. The identification of sources of suitable pedigree and performance data (Australian producers).
2. Data extraction and the development of a performance database.
3. Analysis of data and estimation of genetic parameters.
4. Development of estimated breeding values.
5. Field operation of a genetic evaluation system in place.
6. Dissemination of workshop materials

The success that could be achieved in later points was in part determined by success or otherwise higher up the list. For example, obtaining reliable estimates of genetic parameters is totally dependent on obtaining large and well-structured performance and pedigree recorded data sets. The methodology described below indicates the approach taken to meet the sub-objectives regarding data collection and analyses, whereas results are presented in detail only from the data analyses and benchmark studies. Overall discussion of the above points and their implications to the success of this project occurs in the General Discussion and Implications sections.

2 Methodology

2.1 Identification of Sources of Performance Data

A number of strategies were employed to identify and acquire suitable data for the project from the Australian Industry. These included:

1. Ascertaining data availability and key producer support prior to the commencement of the project.
2. Contacting each Branch of the AOA to notify their members of the project and obtain a shortlist of potentially suitable producers. This was accompanied by the mail out of information in Branches 2 and 3.
3. Direct contact of producers in person, or by phone or mail, after recommendation by other Industry members.
4. Approaching software providers (eg. "Birdtrak") to identify producers who had purchased performance recording software.
5. Delivery of talks at the 1997 Australasian Ostrich convention and a Branch 2 meeting (11/10/97) were used as opportunities to notify conference attendants of the project, and the type of data required.
6. Pyramid Hill abattoir management were contacted to provide information on the type and sourcing of abattoir data collected.
7. Analysis if the ABRI registration database was used to identify producers registering large numbers of birds, for approach regarding their performance recording.
8. Researchers organised to visit farms and help with data extraction where possible.

These steps resulted in significant exposure of the project and its researchers to producers in the Industry. However, the acquisition of Australian data was largely unsuccessful as the majority of producers:

1. did not adequately record performance for some or all traits which could be considered important
2. had not recorded or did not know pedigree information (often due to colony breeding strategies)
3. had not been operating sufficiently long enough to have significant numbers of records or sufficient pedigree depth
4. recorded data manually in books, and/or had problems with their performance recording software, making data extraction difficult
5. were not interested in providing data when it was available
6. promised data, but failed to deliver it.

Part of the original difficulty in obtaining data for the project was related to timing. The project commenced full-time in 1997 at the tail end of the peak prices received for breeding stock, coinciding with dramatic price reductions for individual birds and the suspension of operations of the AOC, and then continued throughout the Industry restructuring that has occurred between 1998-2000. Over this time period the Industry was relatively unstable, with several longer-term operators exiting the Industry and some larger scale operations failing to develop. Moreover, established operations appeared reticent to share their data. The failure of some key figures in the Industry to provide data subsequently reduced progress in the first year of the projects operation.

The remaining difficulties were associated with Industry immaturity and the lack of widespread performance recording. At the time, some software commonly used in the Industry performed poorly, making performance recording and particularly data extraction difficult (see below). In addition, no significant quantities of performance data were held at the Agricultural Business and Research Institute (ABRI) at this time. Further, registration of birds at ABRI for the AOA had declined significantly by 1997/1998, and this registration site has since seen relatively little activity.

Several deficiencies were also evident in the registration database for the purposes of genetic evaluation.

By the end of 1997 it was clear that the project would not be able to obtain suitable data from within Australia. Consequently, a collaborative effort was set up between Australian and South African researchers, who provided access to data from a large pair breeding flock in South Africa. Details of this data are provided in the section for estimation of genetic parameters.

2.2 Data Extraction

Data from three Australian farms (held using three different types of performance recording software) was obtained during 1997, and extraction from a fourth (held in "Ostrich Farmer") failed. On-farm software included an in-house system based around Microsoft Access, along with the more common "Ostrich Farmer" and "Birdtrak" software systems. Programs to enable data extraction from these systems were written, given that the ability to download performance data to external sources was not available in any of these programs at the time. Computer disks enabling automatic file copying were also provided directly for users of "Ostrich Farmer", and simple file copying directions for "Birdtrak" users were made available. Unfortunately, "Ostrich Farmer" was developed using Superbase programming tools, and data extraction required additional access to programmers with expertise and access to Superbase, who were difficult to locate.

Preliminary analyses of the farm data showed several problems with the data received. However, experience with the above-mentioned software, and the data obtainable from this software, was used to develop guidelines for performance recording in the Australian Ostrich Industry, along with guidelines for selecting performance recording software (see Appendix A). These guidelines were provided to producers participating in the project directly, and to the AOA for inclusion in their journal.

A fourth series of programs was developed for manipulating and analysing data received (via email) from South Africa. Details of data obtained, along with the methodology used for estimating genetic parameters, are presented below.

2.3 Estimation of Genetic Parameters

2.3.1 The Data

Records for all eggs produced in the 1991 to 1998 breeding seasons were obtained from a large pair breeding flock maintained at the Little Karoo Agricultural Development Centre (LKADC), near Oudtshoorn, South Africa. This flock was developed as an experimental resource in the 1980's through donation of commercial adult breeding birds. Further introductions were made in the 1990's giving rise to two predominant strains of founder parents in the flock. These were designated as 'commercial' or 'feather' strains according to the selection history of the flocks of origin, although the distinction of these two strains may be somewhat arbitrary (Koot van Schalkwyk, 1999, pers. comm.). The research flock gradually expanded over time, increasing from 63 pairs in 1991 to 117 pairs in 1998, with new breeders selected mostly from within flock. Eggs recorded over this time represented the total output of 195 hens and 191 males comprising 242 different breeding pairs, or approximately 36000 eggs. This equated to a total of 708 hen years (reproductive records for hens) in the data, and up to four generations of hens with reproductive records.

Information contained in each egg record included egg weight and date at collection, day old chick weights for all eggs which hatched, and live weights at 6, 10 and/or 14 months of age for a limited number of birds reared to slaughter age at the LKADC. A small percentage of eggs (<0.05%) were excluded from the data if laid more than one day before or four days after the breeding season started or finished. All remaining egg records were retained in the data set after correction of obvious errors. No specific incubation details for eggs, or management details for birds reared to slaughter, were available in the data. However, dates of hatching and weighing were present for birds with live weights recorded. Additionally, parents of all eggs were known along with their age (in years) at the start of the breeding season. For parents hatched within the flock a more precise calculation of their age was possible. The location of pairs during a given breeding season (ie their breeding paddock) was also recorded.

Management of breeding pairs and eggs were as described in van Schalkwyk *et al.* (1996) and Cloete *et al.* (1998), and as described here. Considerable detail on management for the flock is provided in this report, given that parameters are estimated for data recorded under the prevailing management strategy.

2.3.1.1 Management of Breeding Pairs

During the non-breeding season (approx. 3-4 months: February to May) adult birds were maintained in single sex flocks on sex specific diets of *ad-libitum* rations of hammer-milled lucerne with mineral-vitamin premix, and with access to lucerne pastures. Routine management consisted of harvesting white plumage (clipping and plucking) and treatment for external and internal parasites post breeding. Prior to the new breeding season birds were again treated for parasites and vaccinated against Newcastle disease and avian influenza. Birds were routinely flushed two weeks prior to the breeding season with strategic dietary supplements (van Schalkwyk *et al.*, 1996). The breeding season start and end dates for the flock, breeding group or specific pairs (where different) were defined by the date on which males were placed in (the start) or removed from (the end) their breeding paddocks.

At the commencement of the breeding season (May or June) females were allocated to single 0.25ha breeding paddocks according to their previous breeding location and mate, and replacement requirements of the flock, and males were introduced a few days later. A limited number of paddocks were 0.5ha in area. During flock expansion groups of inexperienced young pairs were generally introduced to their paddocks later in the breeding season (July, August or September). Hence, length of the breeding season was variable across years and for different breeding groups, but generally consistent within group and year for all hens. For several years preference for reforming the same pairs in the same breeding paddock occurred – a practice that is common for this livestock species. Consequently, only ~20% of breeders had more than one mate over time, and many returned annually to the same breeding paddock. However, in 1997 and 1998 several established pairs with records from previous seasons were deliberately moved to reduce confounding between breeding paddock and other pair mediated effects. Consequently, the hen records represent 276 hen-year-paddock combinations, with ~30% hens having moved paddock during the period of data collection.

Replacement parents were preferentially selected offspring from pairs with a good breeding history, and with adequate own live weight gains. However, no formal evaluation system was in place for selecting breeding replacements, and the flock may be considered as representing a relatively unselected population. Additionally, no systematic strategy regarding age of replacement for males or females was followed until the end of the 1997 season. Consequently, young birds entering the flock generally did so because of flock expansion or through death or injury of existing breeders. After the 1997 season breeding birds older than 11 years of age were removed from the flock. This followed prior analyses that provided some evidence of a decline in chick production after 11 years of age in the LKADC flock.

From 1991 to 1996 all breeding pairs were fed *ad-libitum* with a complete diet containing 14% crude protein and 9 MJ of metabolisable energy throughout the +/- 8-month breeding season. In the 1997 season the usual breeders diet was supplemented with 1 ml / bird / day of L-carnitine-magnesium in drinking water for 43 pairs, with the remaining 74 pairs un-supplemented. In the 1998 season 90 pairs were subjected to dietary trials for protein and energy combinations in a complete randomised block design. Codes for these treatments were present in the data and could be accounted for in analyses.

2.3.1.2 Management of Eggs

Eggs were collected daily in the early morning (1991-1997) or late afternoon (1998) and identified by paddock of origin. Paddock identity was used to connect an egg identity with the pedigree information. Immediately following collection eggs were transferred to the incubation facility in specially designed crates fitted with shaped sponges to cradle eggs separately (minimising transport and shock damage). Eggs were dry wiped to remove loose debris before being weighed on electronic scales. Eggs weighing less than 1kg were generally not incubated. Between 1991-1996 eggs were washed and disinfected in lukewarm (40°C) water containing Virkon-S® solution. After 1996 eggs were disinfected through exposure to ultra-violet radiation for 20 minutes (Van Schalkwyk *et al.*, 1998). Following sanitation eggs were permanently identified according to paddock and collection date before being stored for a maximum of 6 days in a cool room at 17 degrees C and 75% relative humidity (RH) (Van Schalkwyk *et al.*, 2000b). Eggs were stored in a vertical position with the airsac uppermost and turned through an angle of 90° daily, 45° either side of the vertical axis.

Prior to setting eggs on Tuesdays, eggs were transferred to the setter room by 15:00 on Mondays and placed in one of three multiphase electronic incubators to acclimatise. The incubators used were Buckeye® (1000 egg capacity), Prohatch® (340 egg capacity) and Natureform® (180 egg capacity) machines which differ in their setting positions and turning angles. However, all incubators were operated at 36°C and 28% RH. These settings resulted in an evaporative water loss of between 13-14% over the first 35 days of incubation (Blood *et al.*, 1998). Unfortunately, the incubator used for specific eggs was not captured in the database, but eggs were allocated randomly amongst incubators. In addition, a number of experiments involving the storage and incubation of eggs were undertaken during the experimental period (see Van Schalkwyk et al., 1998; 1999; 2000a, b; Brand et al, 1998). Treatments were applied to batches of eggs, but the identification of treatments on specific eggs was also not captured in the central database. Eggs were again allocated to treatments at random. Consequently, the introduction of any bias in favour of specific breeding pairs at this stage should be limited.

During incubation eggs were fogged weekly with Virkon-S®. All eggs were candled at 21 days of incubation (1991-1996) or after 14 days of incubation (1997-1998), using a 150 watt candling lamp, to assess infertility and embryonic development. Eggs not fitting the appropriate developmental stage (schedule according to Van Schalkwyk *et al.*, 1994) were broken out and inspected for embryonic development. Eggs showing no development were considered infertile, while those with ceased embryonic development were classified as embryonic deaths. Subsequent shell deaths and failures to hatch were also recorded.

At 35 days of incubation eggs were transferred to the hatching unit, operating at 38.5°C and 28%RH. Eggs were held vertically with no turning. From the 38th day eggs were inspected daily, using a portable candling lamp, for evidence of chick malpositioning and pipping. Eggs with suspected malpositioning of the chick were subsequently inspected more frequently to facilitate hatching assistance if required. Internal pipping generally commenced late on the 41st day of incubation, with external pipping some 6-12 hours later. After external pipping eggs were transferred to separate compartments to prevent loss of identity. Embryonic deaths and the hatching of live chicks was recorded at this stage, although whether the chicks were assisted at hatching was not noted in the data (Schalk Cloete, pers. comm.).

2.3.1.3 Management of Chicks and Juveniles

After hatching chicks were allowed to dry off for a maximum of 24 hours before being weighed, manually sexed (1997 onwards) and temporarily wing tagged for identification. Chicks were then transferred to an intensive chick rearing facility where they were brooded in groups of between 80-150 chicks at a constant temperature of 25 °C. Initially chicks were fed on a crumbed pre-starter diet (12.5mJ ME and 23% crude protein). After one week (depending on climatic conditions) chicks were allowed access to fresh, short lucerne pasture (*Medicago sativa*) together with the pre-starter diet. According to live weights chicks were gradually transferred to a crumbed starter diet at around 1 month of age (11.5 mJ ME and 19% crude protein). Batches of chicks were subdivided according to weight at this stage, retaining access to lucerne pastures, but were returned to shelters (with food and lighting available) in the evenings. External heating was withdrawn when live weights approached 20-25 kg.

At three months of age (or at 30-35 kg live weight) chicks were permanently identified with neck tags and transferred to feedlots to be grown out. Diets were altered to a grower diet (10.5 mJ ME and 15.5% crude protein), with no further access available to lucerne or other forages. Chick densities were initially 75-100 birds/0.5 *ha*, which was decreased to 100 birds/*ha* by slaughter age. Before entering the feedlot chicks were routinely inoculated against Clostridium and Newcastle Disease. Treatments for internal or external parasites and Airsac Disease were also applied when required, although no note of treatments to individual birds are available. Around 9-10 months of age birds were placed on a complete finisher diet (9.2 mJ ME and 14% crude protein) until slaughter at 12-14 months. Diets are as described by Smith *et al.* (1995).

During the entire growth period birds were weighed on a regular basis. Live weights were recorded at approximately three, six, ten and 12-14 months of age. Birds were vaccinated against Newcastle disease, treated for external and internal parasites, and quarantined for a month prior to the expected slaughter date. No trials were performed on birds with weight data.

2.3.2 Development of Models for Analyses

Data were analysed treating eggs and/or the corresponding chicks as individual records. From this data reproductive records were also generated for individual hens. Each group of traits analysed in this study is as described below.

2.3.2.1 Individual Egg, Chick and Live Weight Traits

Records uniquely associated with each egg can be analysed as records of an individual or unit, even if they do not hatch. Consequently, data were analysed from the perspective of the individual egg, and for any resulting records on chicks or juveniles. Analysis of individual records has the advantage of maximising the pedigree depth in the data. However, for this data, individual records included in this study were limited to weights.

2.3.2.2 Hen Reproductive Traits

The ostrich industry does not have traits that are considered as "standard" for comparing reproductive performance of individuals. Consequently, several hen traits were developed for investigation. These traits were based on information available in the data along with traits defined in available avian or ostrich literature. Hen traits included:

- Measures of laying behaviour
    1. Time to lay (TTL): defined as the no. days between formation of breeding pair and the first recorded egg.
    2. Duration of lay (DUL): no. days between first and last egg.
    3. Number of clutches laid (NCL): where each clutch is defined as a group of eggs where each set of consecutive eggs are laid within 4 days of each other.

- Measures of total egg and chick production
    1. Number of eggs laid (NLAID) and incubated (NINC).
    2. Number of incubated eggs that were infertile (NINF).
    3. Number of incubated eggs that hatched (NHATCH).

- Measures of average performances
    1. Average egg weight (AEWT): the sum of egg weights divided by the number of eggs weighed.
    2. Average chick weight (ACWT): the sum of chick weights divided by the number of chicks weighed.

3. Average ratio of chick weight to egg weight (AWTR): the ratio ACWT/AEWT.

- Measures of total weight of output
  1. Total weight of eggs produced (TEWT): sum of egg weights.
  2. Total weight of chicks produced (TCWT): sum of chick weights.

- Measures of percentage performances
  1. The percentage of infertile eggs: the number of infertile eggs as a percentage of the total number of eggs laid (PINF1) or incubated (PINF2).
  2. Hatching percentages: the number of chicks hatched as a percentage of the total number of eggs laid (HPERC1), incubated (HPERC2), or fertile (HPERC3).

  Percentages of infertile or hatching eggs are expressed relative to total egg production (1), total eggs incubated (2), and total number of eggs identified as fertile (3) to illustrate potential differences between hens in egg suitability for incubation (1 vs 2) and egg fertility (1 or 2 vs 3).

- Measures of expected performance (as defined by Van Schalkwyk et al., 1996).
  1. Egg production performance (EPP): NLAID / (0.5*the season length for that pair).
  2. Productivity (CPROD): NHATCH / (0.5*the season length for that pair).

  For these measures season length was halved by Van Schalkwyk *et al.* (1996) to account for the expectation that hens will lay eggs on alternate days.

Hen reproductive traits were generated for each season in which the hen was exposed to breeding, and the majority of hens had repeated records. Data collection at LKADC included identification of breeding pairs that produced no eggs, providing a total inventory for breeding adults each season. Consequently, pairs with known zero production in each season were included in the data with zero records for each hen trait, with the exception of behavioural and fertility traits which were treated as missing. As noted above, eggs that were laid outside the defined breeding season were excluded from the data and did not contribute to hen reproductive records. The start and end of season dates were defined for each hen as the day in which their mate was introduced to the breeding paddock and the date on which pairs were split up.

2.3.2.3 Systematic Effects

A series of analyses were performed to investigate systematic effects for egg, chick, live weight and hen traits. Factors that were present in the data included:

- **Seasonal indicators**

  - were generated from season start and end dates, and dates eggs were laid. For individual egg or chick weights, year and month of production (and their interaction) were the main seasonal effects evaluated. For hen traits, production year and length of the breeding season were considered seasonal effects. Length of season was defined as the difference between the start and end dates of the breeding season (in days) and treated as a covariate.
- **Categories for strain of egg or parent**

  - eggs were predominantly purebred feather (F), purebred commercial (C), crossbred (CB=F5C), backcross (CB5F or CB5C) or F2 cross (CB5CB) genotypes. Additional genotypes involving various third generation crosses were of low frequency in the data, and generally represented eggs from very few individual parents.

  - parents of eggs were predominantly purebred feather (F) or commercial (C) birds, or first cross (CB) genotypes. Four ‘Blue neck’ pairs (B) of unknown parentage entered the breeding data in 1998.
- **Sex of chick, juvenile or adult**

  - was absent for chicks and juveniles between 1991-1996, but available from manual sexing of chicks commencing in the 1997 season. Sex was also known for birds recorded at LKADC hatched prior to 1997 that had developed adult plumage.
- **Age of male and female at the start of the breeding season**
  - recorded in years only for founder parents, but known accurately for replacement parents bred within the flock.
  - the range of age in months for each year age category were for 2yo: 16-28 months; 3yo: 29-38 months; 4yo: 41-47 months; 5yo: 53-58 months; 6yo: 65-69 months; 7yo: 77-81 months; and 8yo: 89 months.
  - age classes were arbitrarily constructed to ensure that each class contained at least 10 different individuals (where possible).
- **The effect of a new mate or a different number of mates**
  - for hens with more than one mate it was possible to determine whether a hen was bred to the same mate or a different mate from the previous season. Very few hens were presented with a new mate within a season. Each record was coded to indicate that the current seasons mate was the same (code=0) or different (code=1) to the previous seasons mate. In addition, the number of different mates a hen had been allocated throughout her productive life was also generated from the data. These effects were tested as class effects.
- **Location of breeding pair**
  - as defined by paddock number.

For egg and/or hen traits seasonal factors examined were production year and length of breeding season (fit across years) where appropriate. Heterotic effects for crossbred eggs, hens or service sires were examined by fitting these terms as fixed effect classes, where the proportion of heterosis expected of a particular mating type (0, 50% or 100%) defined the class level. Additionally, founder parents were allocated to separate genetic groups for ‘commercial’, ‘feather’ and ‘blue-neck’ strains, according to the procedures of Westell *et al.* (1988), to estimate strain differences under an animal model. Finally, parental age categories were arbitrarily constructed to examine age effects, and to reduce confounding between age in years and strain of parent. The impact of age differences between mates and a change in mates between seasons on hen performance were also evaluated.

2.3.2.4 Random Effects

A series of analyses were performed to identify the most appropriate random effects models given prior knowledge that several factors (ie hen, breeding paddock and service sire) were moderately confounded in the data, and that repeated records were available for the majority of hens. The basic assumption was that all reproductive traits evaluated were primarily traits of the hen. Thus, breeding paddock and service sires were treated as additional random effects which could potentially influence hen traits. Further, effects due to the hen could consist of both additive genetic and permanent environmental effects (amongst others). Assumed variance structures for each effect are as follows. Consider the full model:

$$y_i = \mu + u_i + pe_i + pad_i + ssire_i + e_i$$

where y_i is an observation on hen i, μ is the overall mean, and $u, pe, pad, ssire$ and e are vectors of additive genetic, permanent environmental, breeding paddock, service sire and residual (error) effects. Under an animal model $\mathrm{Var}(u) = A\sigma_u^2 = G$, where A is a matrix describing the relationships between animals (ie., the Numerator Relationship Matrix, or NRM), $\mathrm{Var}(pe) = I\sigma_{pe}^2$ (where I is an identity matrix), $\mathrm{Var}(pad) = I\sigma_{pad}^2$, $\mathrm{Var}(ssire) = I\sigma_{ssire}^2$ and $\mathrm{Var}(e) = I\sigma_e^2 = R$. It was assumed that random factors were uncorrelated, and that no bias was introduced through the allocation of mates to each other or to particular breeding paddocks. In particular, the confounding of hen with breeding paddock in early years of production made it undesirable to fit paddock as a fixed effect for evaluating the influence of individual paddocks on production.

Separate analyses fitting a single random effect were performed for each trait to identify which random factor contributed most towards maximising the Log-likelihood. Further hen effects were fit with variance structures proportional to I only (the basic hen model accounting for repeated records, but not relationships between hens), proportional to A only (which accounts for relationships between hens but not repeated records), or with separation of additive from permanent environmental effects (as in the full model above). Additional random effects were then added sequentially to the basic hen model to assess their ability to improve the Log-likelihood. Likelihood Ratio Tests (LRT) were performed to identify whether models were significantly improved through the addition of random effects, or under alternative variance structures.

2.3.2.5 Statistical Methods

Appropriate fixed and random effect models were developed, and parameter estimates obtained, using both ASREML (Gilmour *et al.*, 1999) and base SAS software (SAS Institute). The ASREML program estimates variance components for mixed models by restricted maximum likelihood, employing an average information algorithm which concurrently provides estimates of standard errors for parameter estimates (Gilmour *et al.*, 1995). Models treating each egg or hen as an individual were used to estimate variance components for all traits, with alternative variance structures for random effects (noted above) all evaluated in ASREML. Base SAS software used included the procedures MEAN, FREQ, and UNIVARIATE to characterise the data, along with PROC GLM, a procedure for Generalised Linear Models.

Preliminary fixed effect models were developed using ASREML. For egg and hen traits the strategy employed was to identify significant fixed effects at $P<0.05$ while fitting hen as a random effect in the model (proportional to I) to account for the presence of repeated records in the data. Approximate F tests were conducted for fixed effects, with numerator DF generally of n-1 levels of the factor, and denominator DF taken as infinity. Wald statistic F ratios were available for incremental testing (adjusting for preceding model terms only) and adjusted for all other terms in the model.

Additional random effects such a breeding paddock or service sire were then added to the model sequentially, with Likelihood Ratio Tests (LRT) performed to assess their significance. The LRT is based on testing twice the increase in Log-likelihood resulting from adding *n* random terms to the model of analysis as a χ_n^2 statistic. Alternatively, for two models with the same number of parameters, and assuming identical fixed effects models, the one with the higher likelihood fits the data better (Gilmour *et al.*, 1999, p117). Upon identifying significant paddock or service sire effects the fixed effects models were re-evaluated, but were generally consistent to the fixed effect models developed using ASREML or PROC GLM in SAS (SAS Institute) without these additional effects.

Relationships between 19 reproductive traits developed for ostrich hens were estimated from a series of 171 bivariate analyses, also conducted using ASREML software (Gilmour *et al.*, 1999). Traits were modelled according to univariate analyses, with any significant changes made to these noted in the following Results section. Starting values for variances were those obtained from univariate analyses, and values for covariances were initially set at a low to moderate magnitude for all traits, with the initial sign according to relationships between similar traits recorded in poultry.

For the majority of trait combinations convergence was quickly achieved without needing to fix or constrain variance components in any way. However, for specific trait combinations it was necessary to fix variances (at their univariate values) while estimating covariances. Estimation could then continue, releasing constrained parameters one at a time to achieve fully unconstrained parameter estimates for random effects. For a limited number of trait combinations it was necessary to respecify models for one trait. This is also noted where appropriate below.

Of particular relevance to this study was the poor separation of additive from permanent environmental effects of the hen for several traits in the available data (see Results section 3.4.2.1). This indicated that random effects due to the hen were most accurately estimated as a sum of its components. Thus, with the exception of combinations involving five specific traits, no attempt was made to separate genetic correlations from correlations between permanent environmental effects of the hen under bivariate analyses.

3 Results

3.1 Characteristics of the Data

3.1.1 Egg Traits

Characteristics of the data for egg, chick and live weights are shown in Table 1. From a mean egg weight of 1430 grams, a mean hatched chick weight of 856 grams resulted. Although variable, both egg and chick weights had low coefficients of variation (CV). In contrast, CVs for live weight traits were higher, particularly at early measurement ages. Distributions for all weight traits were approximately normal, and Shapiro-Wilk statistics ranged between 0.96 and 0.98 for live weight traits.

Table 1: Number of records (N), trait mean (Mean), median value (Median), range of values (Range), mode, standard deviation (STD), coefficient of variation (CV), skewness (SKEW) and kurtosis (KURT) for egg, chick, juvenile and slaughter weight data

Trait	N	Mean	Median	Range	Mode	STD	CV	SKEW	KURT
EGGWT	35822	1429.6	1428	864-1956	1440	141.0	9.86	0.02	0.39
CHICKWT	16739	855.6	853	505-1247	842	99.9	11.7	0.15	0.25
LW3	1235	22.2	21	4-44	20	7.84	35.3	0.36	-0.47
LW6	1248	56.7	56	22-98	52	14.4	25.5	0.26	-0.37
LW10	862	82.7	84	46-120	84	12.3	14.9	-0.26	-0.02
SLWT	1046	111.1	112	68-150	110	12.7	11.5	-0.22	0.27

EGGWT: Egg weight at lay (in grams)
CHICKWT: Chick weight at hatch (in grams)
LW3: Live weight at 3 months (kg)
LW6: Live weight at 6 months (kg)
LW10: Live weight at 10 months (kg)
SLWT: Live weight prior to slaughter (kg)

Trait acronyms represent more recent ‘standard’ ages at weighing. However, the mean ages at weighing were 82, 180, 288 and 447 days for LW3, LW6, LW10 and SLWT. Variation in the mean age at weighing for each trait occurred both across years and across hatches within year. The least variation in age at weighing occurred for LW10. Records for animals with extreme ages within each date of weighing were removed from the data. After editing, the ranges in age at weighing were 46-119, 126-225, 266-315, and 357-648 days. Given the mean values reported in Table 1, average rates of growth were 260, 310, 284 and 247 g/day from hatch to approximately 2.5, 6, 9.4 and 14.7 months of age. Growth rates within each time period were approximately 352 g/day (2.5 to 6 months), 279 g/day (6 to 9.4 months) and 215 g/day (9.4 to 14.7 months). Thus, peak rates of growth occurred before 6 months of age and declined thereafter. For convenience, weights are hereafter portrayed as being taken at 3, 6, 10 and 14 months of age.

3.1.2 Hen Traits

Characteristics of the hen reproductive traits constructed from the egg data are shown in Table 2. Records for TTL, DUL, NINC, AEWT, ACWT, AWTR, TEWT and TCWT were not calculated for non-productive hens. Similarly percent infertile and hatched of eggs incubated (or fertile) were not calculated for hens with no eggs incubated (or fertile) within a breeding season. Finally, NCL was only calculated for hens that laid more than one egg in a season. Differences between means for egg and chick weights shown in Tables 1 and 2 reflect unequal numbers of records contributing to the average values for each hen, and a negative relationship between the average value for these traits and the number of contributing records.

Table 2: Number of records (N), trait mean (Mean), median value (Median), range of values (Range), mode, standard deviation (STD), coefficient of variation (CV), skewness (SKEW) and kurtosis (KURT) for hen reproductive traits.

Trait	N	Mean	Median	Range	Mode	STD	CV	SKEW	KURT
TTL[‡] (days)	689	35.9	25	-1-230	11	35.1	98.0	2.04	5.83
DUL (days)	689	173.2	187	0-272	203	59.1	34.1	-1.04	0.64
NCL	681	6.26	6	1-19	6	3.13	50.0	0.72	0.45
NLAID	708	51.1	52	0-121	64	26.5	51.8	-0.06	-0.71
NINC	689	48.6	48	0-108	53	24.8	51.0	0.05	-0.72
NINF	689	10.4	5	0-96	3	14.2	137.1	2.61	8.03
NHATCH	708	23.8	21	0-90	0	19.2	80.6	0.74	0.12
AEWT (gm)	689	1415.9	1412.6	963-1827.8	1353.6	127.7	9.02	0.06	0.55
ACWT (gm)	624	848.5	848.5	607-1137.3	745	86.3	10.2	0.23	0.36
AWTR	624	0.596	0.598	0.46-0.78	0.612	0.03	5.29	-0.05	2.78
TEWT (kg)	689	75.0	74.7	0.963-173.9	0.963	37.4	49.9	0.065	-0.66
TCWT (kg)	624	23.1	20.8	0.611-84.22	0.761	15.9	70.0	0.832	0.54
PINF1[†] (%)	689	22.0	10.4	0-100	0.0	26.5	120.5	1.61	1.53
PINF2[†] (%)	685	24.5	11.8	0-100	0.0	29.3	119.6	1.52	1.11
HPERC1[†] (%)	708	41.9	46.7	0-100	0.0	24.7	59.0	-0.27	-0.86
HPERC2[†] (%)	704	45.8	50.0	0-100	0.0	26.2	57.2	-0.33	-0.81
HPERC3[†] (%)	674	58.9	63.2	0-100	0.0	25.5	43.3	-0.80	0.08
EPP (%)	708	43.7	45.0	0-92	0.0	21.7	49.7	-0.18	-0.75
CPROD (%)	708	20.3	18.7	0-78.2	0.0	16.1	79.4	0.70	0.08

[†] (1) of number laid; (2) of number incubated; (3) of number incubated and fertile
[‡] hens that commenced laying prior to the introduction of their mate had negative values

TTL: Time to lay (days)
DUL: Duration of lay (days)
NCL: No. clutches laid
NLAID: No. eggs laid
NINC: No. eggs incubated
NINF: No. eggs infertile
NHATCH: No. eggs hatched
AEWT: Average egg weight (grams)
ACWT: Average chick weight (grams)
AWTR: Average ratio chick/egg weight
TEWT: Total weight of eggs produced
TCWT: Total weight of chicks produced
PINF1: Percent infertile[=] (1)
PINF2: Percent infertile[=] (2)
HPERC1: Hatching percentage[=] (1)
HPERC2: Hatching percentage[=] (2)
HPERC3: Hatching percentage[=] (3)
EPP: Egg production percentage
CPROD: Chick production percentage

With the exception of average egg or chick weights and their ratio, which had low coefficients of variation (CV), all hen traits were extremely variable and had large CV. Distributions for egg and chick weights (and their ratio) satisfied the null hypothesis that data values were a random sample drawn from a normal distribution, with Shapiro-Wilk statistics between 0.98 and 0.99. In contrast, distributions for the remaining traits deviated from normality. Shapiro-Wilk statistics ranged between 0.68 for NINF and 0.97 for NLAID, NINC and TEWT. Relatively high frequencies of records with zero value were apparent for NLAID, NINC, NHATCH, HPERC1, HPERC2, HPERC3, EPP and CPROD, disrupting the appearance otherwise of normality for these trait distributions (skewness and kurtosis remained close to zero). Similar distribution characteristics were apparent for

TEWT and TCWT. However, although NINF, PINF1 and PINF2 had relatively high frequencies of zero values, these traits were positively skewed. No simple normalising transformation exists for these types of trait distributions.

Approximately 2.5% of all records were zero for NLAID, 4.8% were zero for the number of fertile eggs, and 11.8% were zero for CPROD. These figures represented at least one season with a zero value for ~9% (mostly first season records), 14.8% and 32% of all hens respectively. However, removal of records from the data of hens that laid no eggs within a season had little impact on descriptive statistics for the remaining traits. Median values for hen traits indicated that 50% of hens laid up to 52 eggs annually, had less than 10-12% infertile eggs, but ultimately had low levels of production relative to their expected potential, as indicated by the low mean EPP and CPROD. The difference between the mean and median values for fertility and hatchability traits indicates that some hens had eggs with very high levels of infertility, increasing mean percentage infertility and reducing mean hatching percentages.

3.2 Significant Systematic Effects

3.2.1 Egg Traits

Significant systematic effects are presented for each trait in Table 3. Factors with significance level P>0.05 were not included in models for parameter estimation.

Identifiable systematic effects alone explained relatively little variation in egg or chick weight traits. However, variation in live weights at three or six months was well described by factors such as production year and month, along with date and age at recording. Notably, variation in live weights between years was mostly accounted for by month of hatch and age at weighing. Significantly less variation was attributed to these factors for weights recorded at later ages. However, birds reared to later ages were generally taken only from the first three to four months of chicks produced within any given year's production, reducing the opportunity for hatch and seasonal effects to be expressed.

Date at weighing was a significant effect for juvenile weights taken at each stage of growth. In addition to effects related to procedures on the date of weighing, weighing date also approximately described groups of birds reared together. Each days difference in the age at weighing accounted for 360, 179, 272 and 120 grams of weight at 3, 6, 10 and 14 months of age.

The age of the hen and the position of the egg in the laying sequence significantly influenced egg and subsequently chick weights. These effects are illustrated in Figure 1 and Figure 2. Significant increases in individual egg weights occurred for hens between 2 to 6 years of age. Peak egg and chick weights occurred for six-year-old hens, after which a gradual decline occurred. Trends in egg and chick weights with hen age were close to parallel.

Table 3: Significant[B] (P<0.10) systematic effects influencing egg, chick and live weights, along with the coefficient of determination (R^2) under a fully fixed model.

Trait	Year	Month	Year × Month	Hen Age Class	Egg Sequence Class	Carnitine supplement	Diet	Weight date	Age	R^2
EGGWT	****	****	****	****	****	****	****	-	na	.17
CHICKWT	****	****	****	****	****	-	****	-	na	.11
LW3	****	****	****	-	-	-	-	****	****	.72
LW6	****	***	****	-	-	-	-	****	***	.66
LW10	****	*	*	-	-	-	-	****	***	.15
SLWT	****	**	****	-	-	-	-	****	**	.27

See Table 1 for trait names and definitions.

na: not applicable; * P<.10; ** P<.05; *** P<.01; ****P<.0001: ^{B} Models for parameter estimation included only effects with significance level P<.05.

Year: production year (class effect: levels 1991-1998)

Hen Age Class: class 1: 2 year old (yo); class 2: 3yo; class 3: 4yo; class 4: 5yo; class 5: 6yo; class 6: 7yo; class 7: 8-9yo; class 8: 10-11yo; class 9: 12-13yo; class 10: 14-15yo; class 11: 16-21yo.

Egg Sequence Class: classes 1-5 for eggs 1-5; classes 6 to 18: next groups of five eggs; classes 19 and 20: next groups of 15 eggs; and class 21: remaining eggs (100-121).

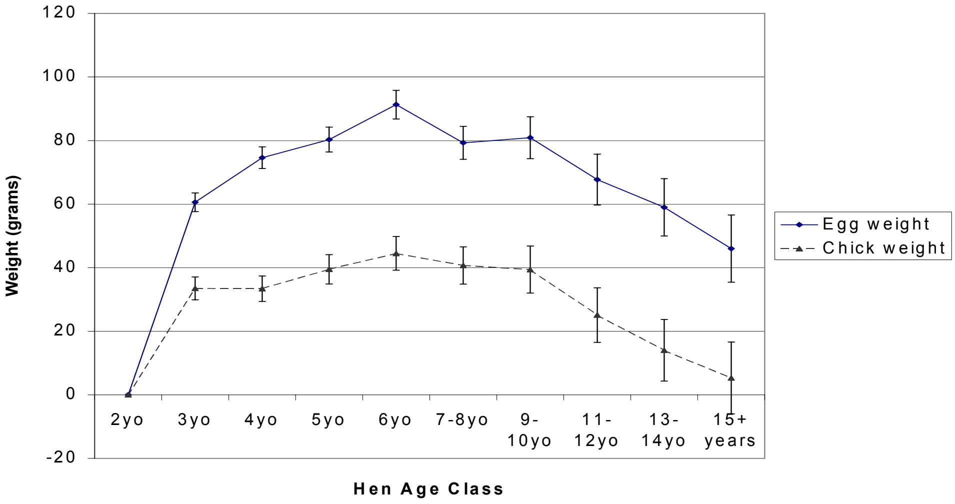
Carnitine supplement: dietary supplement tested in 1997 only (0=control, 1=treatment)

Diet: energy x protein level (3*3) factorial + control (10 levels)

Weight date: date on which the bird as weighed.

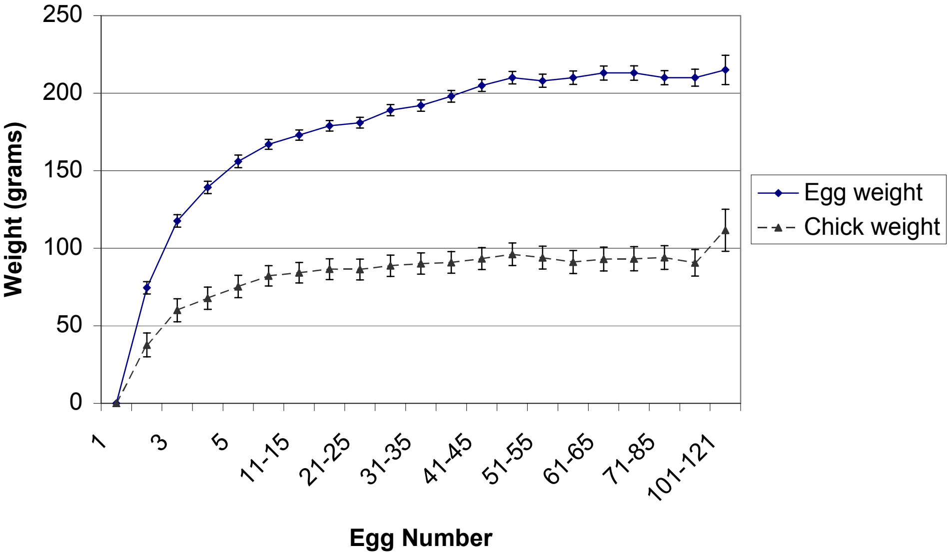
Age: age at weighing (in days)

Figure 1: Hen age effects on egg and chick weights.



Rapid increases in egg weight occurred for the first five eggs within the complete laying sequence, after which a more gradual increase was apparent. Although egg weight continued to increase throughout the laying cycle, trends in egg and chick weight curves diverged. Increases in chick weight with egg position in the laying cycle were less than would be predicted assuming a relatively constant ratio of chick to egg weight mass occurs throughout the entire laying season.

Figure 2: Egg position in the laying sequence affects egg and chick weights.



Dietary treatments involving a 3x3 factorial design for protein and energy levels, about which the meaning of treatment codes is currently unknown, significantly influenced egg and chick weights. Moreover, the use of Carnitine supplements significantly increased egg and chick weights to varying degrees, depending on whether the treatment was administered directly into water troughs or remotely through the water reticulation system. Although statistically significant, treatment with this supplement was of little practical significance given that the maximum gain in chick weight was less than 10 grams. There also appeared to be no significant carry over of these treatments (applied to the parents) on live weights of progeny recorded. However, relatively few progeny with live weights recorded were hatched from eggs laid during the course of dietary trials.

3.2.2 Reproductive Traits of Hens

Significant factors ($P<0.10$) affecting hen traits are shown in Table 4, along with their coefficients of determination. Factors with significance level $P>0.05$ were not included in models thereafter for parameter estimation.

Fixed effects alone explained very little ($R^2<0.10$) of the variation in the number of infertile or hatched eggs, percent infertile or hatching eggs, productivity as measured by CPROD, and average egg weight or AWTR. Of the remaining traits, year and/or length of season along with age class of the hen explained between 11-29% of the observed variation in hen traits. Substantial improvements in coefficients of determination for most traits were achieved with the addition of significant random effects identified in the following section.

As would be expected, year of recording significantly affected performance in the majority of hen traits, where differences between years reflect seasonal and management influences common to all hens recorded. Exceptions were hatching percentages for eggs laid (HPERC1) and incubated (HPERC2), and average egg weight (AEWT) upon which year had relatively little impact ($P<0.10$).

Total length of the breeding season (in days) affected actual duration of lay (DUL) and consequently total output and percentage measures. An increase of one day in the season length increased the duration of lay by 0.80 ± 0.09 days, NLAID and NINC by 0.21 ± 0.03 and 0.20 ± 0.04 eggs, and NHATCH by 0.12 ± 0.03 chicks. The percentages of eggs laid (PINF1) or incubated (PINF2) which were infertile decreased in the order of -0.13 ± 0.04 and –0.16 ± 0.04 percent per each days increase, whereas corresponding values for hatchability were 0.08 ± 0.03 and 0.11 ± 0.03 percent. Length of season also affected productivity with respect to the number of chicks hatched (CPROD) even though this trait is already defined as NHATCH/(0.5×length of season in days). CPROD increased by 0.04 ± 0.02 for each days increase in season length. Thus, for all of the above traits, increasing the number of days in the season resulted in favourable reproductive outcomes. In contrast, length of season had no impact on the time taken to commence breeding (TTL), the total number of infertile eggs reported (NINF), expected egg production (EPP), measures of egg and chick weights or their ratio (AEWT, ACWT, AWTR), and the hatching percentage of fertile eggs incubated (HPERC3).

Table 4: Significant^{B} (P<.10) systematic effects for hen traits along with the coefficient of determination (R^{2}) under a fully fixed model.

Trait	Year	Length of breeding season	Hen Age Class	Sire Age Class	Carnitine supplement	Diet	R^{2}
TTL‡ (days)	****	-	****	-	-	-	.22
DUL (days)	****	****	****	-	-	-	.29
NCL	****	****	**	-	-	-	.11
NLAID	****	****	****	-	*	-	.22
NINC	****	****	****	-	*	-	.20
NINF	****	-	-	***	-	-	.04
NHATCH	****	****	****	-	*	-	.09
AEWT (gm)	*	-	****	-	-	-	.07
ACWT (gm)	****	-	****	-	*	-	.13
AWTR	****	-	****	-	-	-	.07
TEWT (kg)	****	****	****	-	**	-	.16
TCWT (kg)	****	****	**	-	-	-	.06
PINF1† (%)	****	****	-	****	*	***	.09
PINF2† (%)	****	****	-	***	-	***	.09
HPERC1† (%)	-	****	****	-	-	-	.04
HPERC2† (%)	-	****	****	-	-	-	.05
HPERC3† (%)	****	-	***	-	-	-	.07
EPP (%)	****	-	****	-	*	-	.13
CPROD (%)	****	**	****	-	*	-	.05

See Table 2 for trait names and definitions.

* P<.10; ** P<.05; *** P<.01; ****P<.0001: ^{B} Models for parameter estimation included only effects with significance level P<.05.

Year: production year (class effect: levels 1991-1998)

Length of breeding season: number of days in the breeding season (linear covariate)

Hen or Sire Age Class: class 1: 2 year old (yo); class 2: 3yo; class 3: 4yo; class 4: 5yo; class 5: 6yo; class 6: 7yo; class 7: 8-9yo; class 8: 10-11yo; class 9: 12-13yo; class 10: 14-15yo; class 11: 16-21yo.

Carnitine supplement: dietary supplement tested in 1997 only (0=control, 1=treatment)

Diet: energy x protein level (3*3) factorial + control (10 levels)

Hen age class also affected the expression of most hen traits, with the exception of the fertility traits NINF, and percentages of eggs infertile (PINF1 & PINF2). For these three traits, age class of the hens' mate (or service sire) explained more variation in performance than hen age. The effect of hen age on measures of reproductive performance is presented in Table 5. Fitting average age group of the pair, as an alternative to fitting either hen or service sire age class, provided similar model fit for DUL, NINF, ACWT and PINF2 compared to the models used (see in Table 4). For no traits were hen and sire age class effects simultaneously significant. However, age class of the hen was moderately associated with the age class of her mate, making complete separation of these effects more difficult.

Table 5: The influence of hen age on reproductive performance, presented as deviations from results for two year old hens, as estimated under the full animal model.

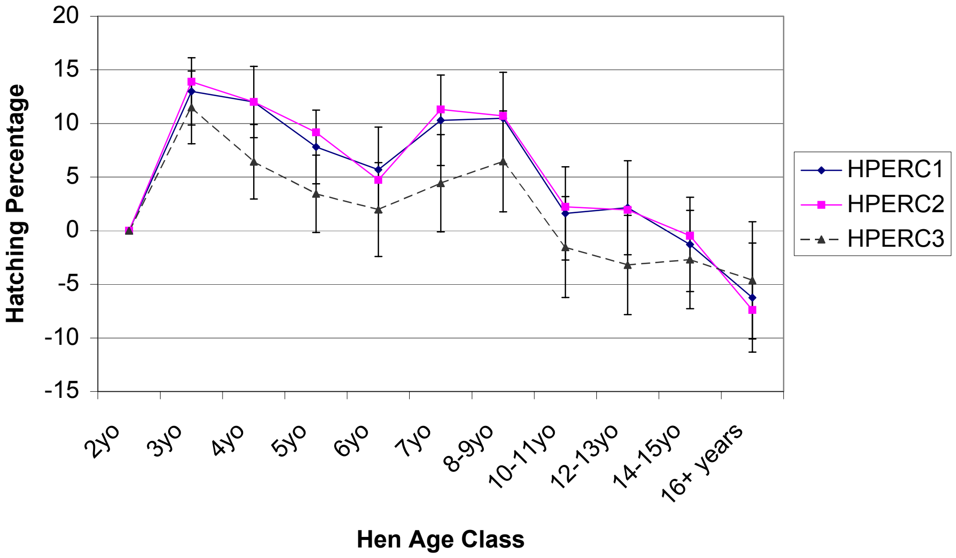
Hen Age Trait	3yo	4yo	5yo	6yo	7yo	8-9yo	10-11yo	12-13yo	14-15yo	16+ years
TTL[‡] (days)	-18.0	-20.1	-16.3	-11.5	-22.8	-34.4	-30.9	-31.1	-35.7	-33.8
DUL (days)	21.3	27.1	23.5	17.9	26.5	51.1	53.3	45.1	41.7	37.3
NCL	0.33	0.64	0.62	-.21	-.05	0.41	1.0	1.4	1.4	1.9
NLAID	11.5	11.1	9.0	8.4	15.6	23.3	21.9	19.0	11.3	10.3
NINC	8.9	8.0	5.6	7.2	12.2	20.3	17.0	16.4	9.9	9.0
NHATCH	8.8	7.3	6.3	5.3	9.1	13.9	8.4	6.4	1.8	-2.7
AEWT (gm)	64.8	75.1	63.6	58.2	57.2	47.4	40.3	10.2	-7.9	-36.7
ACWT (gm)	27.6	20.9	26.5	21.5	10.0	11.2	-4.33	-23.0	-21.3	-45.0
AWTR	-.21	-1.36	-0.72	-1.00	-1.34	-0.88	-2.08	-1.73	-0.71	-1.44
TEWT (kg)	15.3	13.3	10.7	13.2	19.9	31.6	29.1	24.6	14.9	10.3
TCWT (kg)	5.00	3.84	2.91	3.38	5.05	9.30	5.32	4.78	0.69	-4.3
HPERC1[†] (%)	13.0	12.0	7.81	5.69	10.3	10.5	1.62	2.15	-1.28	-6.24
HPERC2[†] (%)	13.9	12.0	9.18	4.74	11.3	10.7	2.23	1.94	-0.47	-7.40
HPERC3[†] (%)	11.5	6.44	3.44	1.98	4.43	6.47	-1.53	-3.20	-2.69	-4.63
EPP (%)	12.7	12.6	9.91	9.47	15.2	21.7	20.0	17.9	12.4	11.5
CPROD (%)	7.97	6.35	5.39	4.57	7.73	11.7	6.96	5.01	1.70	-1.87

See Table 2 for trait names and definitions.

Figure 3: The influence of hen age on egg and chick production.

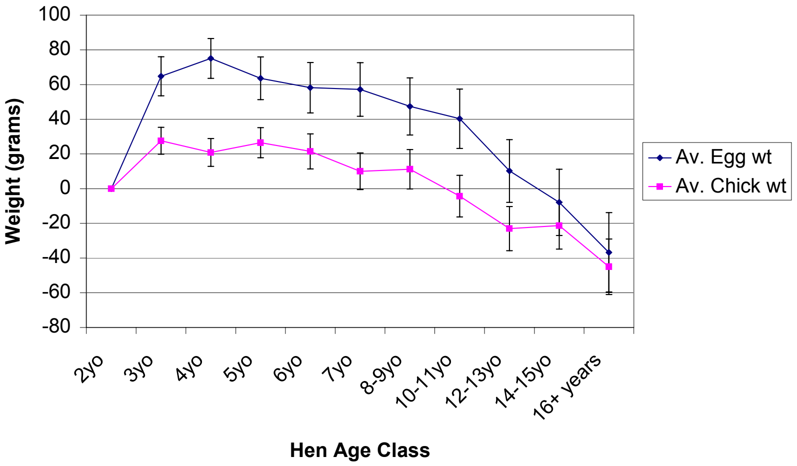
Two-year-old hens took significantly longer to commence laying than older hens, and had a significantly shorter duration of lay. Hens 3 years or older took increasingly less time to commence laying with increasing age, with peak duration of lay occurring between 8 and 11 years of age. This peak also corresponded with the highest number of eggs laid or incubated, and the highest levels for EPP. However, the maximum number of chicks hatching occurred for hens between the ages of 7-11 years inclusive (for standard errors see Figure 3). Consequently, although hens retained relatively high egg production after 11 years of age, this was not translated to a corresponding increase in chick production. Peak CPROD was associated with 8-9 year old hens, along with peak TEWT and TCWT.

Figure 4: Hen age influences the hatching percentage of eggs laid (HPERC1), incubated (HPERC2) or fertile eggs (HPERC3).



Changes in chick production were accompanied by differences in hatching percentages of hens in different age groups. Hatchability of all eggs laid or incubated was highest for hens between the ages of 3 and 9 years of age (inclusive), with two year old hens and 10+ year old hens achieving similar and lower hatching percentages. In contrast, hatchability of fertile eggs was significantly better for three-year-old hens than those in other age classes, which had similar hatching percentages (for standard errors see Figure 4).

Figure 5: Average egg and chick weights are influenced by hen age.



Hen age was also associated with significant changes in other traits. The number of clutches recorded for hens 10 years or older was significantly increased, suggesting a greater number of pauses occurred between egg laying sequences. Average egg weight (and therefore average chick weights) also had a curvilinear association with hen age, with peak egg weights occurring for 3-5 year old hens, diminishing thereafter. In comparison, the highest chick weights came from eggs laid by hens between 3-6 years inclusive, and diminished thereafter. After 11years of age, hens had similar average egg and chick weights to two-year-old hens, but both weights continued to decline with increasing hen age (for standard errors see Figure 5).

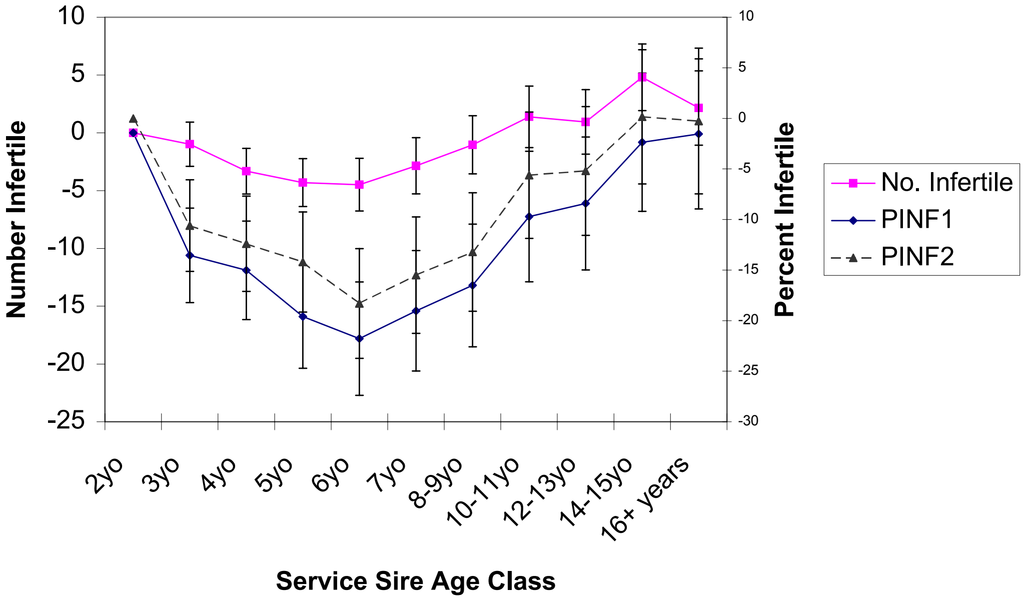
The effects of service sire age on measures of reproductive performance are shown in Table 6. Service sire age influenced female reproductive performance predominantly through egg fertility. The number of infertile eggs was significantly lower for hens paired with 4-6 year old service sires, higher for three-year-old service sires, and gradually increased for service sires older than six. However, females in different age groups also lay different numbers of eggs. Thus, the percentage of infertile eggs laid was significantly lower for hens whose service sires were between the ages of 3 and 9 years (inclusive) compared to younger (2 year old) or older (10-20 year old) service sires. Trends in fertility with service sire age (along with standard errors) are illustrated in Figure 6. It should be noted that a moderate proportion of service sires were similar ages to their mates.

Table 6: The influence of service sire age on reproductive performance, presented as deviations from results for two year old hens, as estimated under a full animal model.

Service Sire Age Trait	3yo	4yo	5yo	6yo	7yo	8-9yo	10-11yo	12-13yo	14-15yo	16+ years
NINF	-0.98	-3.31	-4.31	-4.49	-2.85	-1.03	1.39	0.95	4.81	2.15
PINF1† (%)	-10.6	-11.9	-15.9	-17.8	-15.4	-13.2	-7.24	-6.11	-0.81	-0.09
PINF2† (%)	-10.6	-12.4	-14.2	-18.3	-15.5	-13.2	-5.62	-5.19	0.16	-0.26

See Table 2 for trait names and definitions.

Figure 6: Service sire age affects egg fertility and the percentage of eggs laid (PINF1) or incubated (PINF2) which are infertile.



Age differences between mates did not significantly affect any hen traits, although results from previous analyses on a subset of this data (1991-1996 data) had suggested that hens with older mates had reduced numbers of infertile eggs and improved hatchability (HPERC1). Post 1996 data had a reduction in average hen and service sire age, which also corresponded with a reduced frequency of any age differences between mates, particularly with respect to the use of older males.

Dietary supplements added to the normal breeder diet in 1997 were not significant for the majority of hen traits, although supplementation significantly ($P<0.05$) increased TEWT produced. There was a weak suggestion ($P<0.10$) that supplementation of breeding pairs with L-carnitine-magnesium enhanced performance in NLAID, NINC, NHATCH, ACWT, PINF1, and EPP% or CPROD%. These results differ from results published by Davis *et al.* (1998), who also used data from this flock and experiment. Finally, the effects of differing protein and energy levels in the breeder diet were assessed in 1998 by applying dietary treatments in a 3 x 3 factorial design. Preliminary results by Brand *et al.* (1998) indicated no energy or protein level effects on egg production or the percentages of live chicks that hatched. However, in this study diet was found to significantly affect ($P<0.05$) the percentages of infertile eggs (PINF1 & PINF2). Differences in use of the data, models applied and statistical methodology were apparent between these studies and the current analyses. Moreover, although dietary codes were present in the data, information on dietary treatments has not been provided.

Of the remaining factors examined, no significant differences between genetic groups (commercial vs feather vs blue necks) were found for any hen traits, and tests for significant heterotic effects on reproductive performance in hens or their mates were also not significant. Additionally, allocation of a new mate to hens from season to season had no significant impact on their reproductive performance.

3.3 Significant Random Effects

3.3.1 Egg Traits

Development of random effects models for egg, chick and live weight traits is straight forward (as described in Section 2.3.2.4) and results for alternative models are not presented in further detail here.

3.3.2 Hen Traits

Testing of alternative random effects models was complicated for hen traits by a moderate level of confounding between effects. Log-likelihood's from different random effects models for hen traits are subsequently presented in Table 7. The appropriate model comparisons are as described with the Table.

For all traits, significant improvement in Log-likelihoods (according to LRT) indicated that the models for analyses were superior relative to basic fixed effect models through the inclusion of one, or more, random effects. Models were significantly improved for all hen traits through fitting permanent environment of the hen (Hen_I) to allow for repeated records. However, DUL was best described by fitting hen effects proportional to the NRM only, and no significant permanent environmental effects were identified for this trait in subsequent analyses. AEWT, ACWT and AWTR were best modelled through including both additive and permanent environmental hen effects in the analyses. For the remaining traits, models fitting both additive and permanent environmental effects explicitly provided no improvement over the basic (fitting Hen_I) model. For NLAID, HPERC3 and AWTR fitting the additional random effects of either paddock or service sire resulted in no significant improvements to models for analyses.

Table 7: Log- likelihood values for models fitting different random effects for hen traits. Models with significantly improved Log Likelihoods (P<0.05), tested over preceding models (to the left hand side), are in bold.

Model Trait	Fixed effects (FE) only	Fixed + Paddock	Fixed + Service Sire	Fixed + Hen$_I$	Fixed + Hen$_A$	Fixed + Hen$_I$ + Hen$_A$†	FE + Hen$_I$ + Breeding paddock†	FE + Hen$_I$ + Service Sire†
TTL‡ (days)	-2687.1	-2676.3	-2675.2	**-2675.9**	-2676.3	-2675.6	-2674.4 (P<.10)	-2674.9
DUL (days)	-3006.3	-2997.6	-2994.2	-2992.3	**-2990.7**	-2990.7 (P<.10)	-2992.3	-2991.6
NCL	-1097.5	-1065.9	-1074.6	**-1066.7**	-1073.5	-1066.7	**-1063.5 (P<.025)**	-1066.7
NLAID	-2566.9	-2530.0	-2513.7	**-2497.6**	-2500.8	-2496.9	-2497.6	-2495.7 (P<.10)
NINC	-2462.4	-2411.4	-2404.9	**-2392.1**	-2395.0	-2391.3	-2391.2	**-2390.0 (P<.05)**
NINF	-2149.5	-2130.3	-2091.8	**-2099.1**	-2109.3	-2099.1	-2099.1	**-2078.2 (P<.005)**
NHATCH	-2398.4	-2342.9	-2331.6	**-2293.7**	-2299.5	-2293.2	-2293.7	**-2290.8 (P<.025)**
AEWT (gm)	-3629.4	-3462.6	-3424.8	-3348.1	**-3345.6**	**-3343.7 (P<.005)**	**-3317.1 (P<.005)**	-3320.7
ACWT (gm)	-3008.0	-2879.2	-2847.2	-2750.6	**-2747.4**	**-2745.8 (P<.005)**	-2745.2	**-2743.3 (P<.05)**
AWTR	-1019.7	-954.6	-947.3	-883.8	**-882.3**	**-880.6 (P<.025)**	-880.6	-880.7
TEWT (kg)	-7370.8	-7311.4	-7303.0	**-7294.9**	-7299.1	-7294.4	**-7292.4 (P<.05)**	**-7291.2 (P<.01)**
TCWT (kg)	-6187.6	-6126.0	-6104.2	**-6094.0**	-6096.9	-6092.6 (P<.10)	-6093.6	**-6088.7 (P<.005)**
PINF1† (%)	-2532.2	-2505.7	-2478.2	**-2472.0**	-2478.9	-2472.0	-2471.4	**-2458.3 (P<.005)**
PINF2† (%)	-2581.7	-2556.4	-2527.9	**-2523.6**	-2529.6	-2523.6	-2522.9	**-2509.2 (P<.005)**
HPERC1† (%)	-2602.3	-2578.9	-2566.6	**-2538.7**	-2549.1	-2538.7	-2537.7	**-2535.7 (P<.025)**
HPERC2† (%)	-2624.5	-2603.7	-2591.9	**-2565.3**	-2574.2	-2565.2	-2564.5	**-2562.0 (P<.025)**
HPERC3† (%)	-2474.1	-2462.4	-2456.4	**-2428.2**	-2436.5	-2428.2	-2427.9	-2428.1
EPP (%)	-2464.5	-2426.5	-2409.7	**-2394.7**	-2398.6	-2393.9	-2394.0	**-2391.7 (P<.025)**
CPROD (%)	-2293.2	-2237.5	-2225.2	**-2189.0**	-2195.0	-2188.4	-2188.9	**-2186.2 (P<.025)**

See Table 2 for trait names and definitions.
Column 1: fixed effects model only, held constant across columns within trait.
Columns 2 and 3: adding a single additional random component to the underlying fixed effect models.
Columns 4 and 5: comparison of alternative variance structures (I vs A) for hen effects. The variance structure with best fit is in bold.
Column 6: separation of additive genetic from permanent environmental hen effects. Significant improvement over the model of best fit from columns 4 and 5 is indicated by bold font.
Column 7: addition of breeding paddock to the model of best fit from columns 4 to 6, with significant improvements over previous best model in bold.
Column 8: addition of service sire to the model of best fit from columns 4 to 7, with significant improvements over previous best model in bold.

Likelihood ratio tests identified that breeding paddock was a significant factor affecting the traits number of clutches laid (NCL), and average (AEWT) or total egg weights (TEWT). However, overall TEWT was best described through inclusion of Hen_I and service sire effects in the model for analysis. There was a suggestion ($P<0.10$) that breeding paddock affected the time taken to commence laying (TTL). Fitting breeding paddock alone produced the model of best fit for NCL when models containing one random effect are compared.

LRT showed that service sire effects in addition to Hen_I were significant ($P<0.05$) for a large number of the remaining hen traits (refer Table 7). However, models for traits reflecting laying behaviour (TTL, DUL and NCL) were not improved through fitting additional service sire effects. Similarly traits reflecting average egg weights (AEWT and AWTR) were uninfluenced by service sire effects. Of note also is that accounting for service sire significantly improved models for NINC and hatchability traits (HPERC1 or HPERC2), but did not for NLAID or HPERC3. Fitting service sire alone produced the model of best fit for TTL and NINF when models containing only one random effect are compared. There was only a suggestion ($P<0.10$) that service sire may influence NLAID. Relative to models containing two significant effects, the inclusion of all three effects (hen, breeding paddock and service sire) did not significantly improve the Log-likelihood for any trait.

3.4 Estimates of Genetic Parameters

3.4.1 Egg Traits

3.4.1.1 Heritability Estimates and Additional Random Effects

Estimates of genetic parameters from univariate analyses are presented in Table 8. Several differences were apparent between results from this study and that from previous analyses conducted using a subset of the current data (Bunter *et al*, 1999). For comparison, the increase in data for each trait examined was by approximately 50% between the previous and current analyses, and all data for LW3. Moreover, additional parameters were estimated for each trait which, in combination with aspects of data structure, resulted in relatively large standard errors for heritability estimates.

Table 8: Genetic parameters for egg, chick and live weight traits as estimated under single trait analyses.

Parameter Trait	h^2	m^2_{Hen}	c^2_{Hen}	$m^2_{\text{Hen}} + c^2_{\text{Hen}}$	c^2_{Paddock}	σ^2_p
EGGWT	0.19 ± 0.04	0.31 ± 0.13	0.24 ± 0.12	0.55 ± 0.04	0.13 ± 0.03	23937
CHICKWT	0.16 ± 0.05	0.26 ± 0.12	0.26 ± 0.11	0.52 ± 0.04	0.05 ± 0.02	11291
LW3	0.02 ± 0.06	-	0.08 ± 0.04	-	-	18.3
LW6	0.21 ± 0.10	-	0.09 ± 0.04	-	-	74.3
LW10	0.11 ± 0.15	-	0.17 ± 0.08	-	-	132.7
SLWT	0.17 ± 0.11	-	0.13 ± 0.05	-	-	122.2

Parameters are h^2: heritability (σ^2_a/σ^2_p); m^2_{Hen}: heritable maternal effect of the hen ($\sigma^2 m_{\text{Hen}} / \sigma^2_p$); c^2_{Hen}: permanent effect due to the hen ($\sigma^2 c_{\text{Hen}} / \sigma^2_p$); c^2_{Paddock}: permanent effect due to the breeding paddock ($\sigma^2 c_{\text{Paddock}} / \sigma^2_p$), where σ^2_a is variance due to additive effects, $\sigma^2 m_{\text{Hen}}$ is variation due to maternal effects, $\sigma^2 c_{\text{Hen}}$ is variation due to permanent environmental hen effects, $\sigma^2 c_{\text{Paddock}}$ is variation explained by breeding paddock and σ^2_p is the phenotypic variance.

With the exception of results for LW3, low to moderate heritabilities were estimated for each trait analysed. These estimates were consistent with previous results for egg and chick weights, but were considerably reduced (from approximately 0.4 to 0.2) for later live weights when compared to those from the previous study (Bunter *et al*, 1999).

Significant moderate maternal and permanent environmental effects of the hen were estimated for egg and chick weights, contributing to a large overall hen effect for these traits. Additional breeding paddock effects were also estimated for egg weight, which was subsequently reduced in magnitude for chick weights. Low to moderate (<0.20) additional random effects due to the hen were also present for juvenile and later live weight traits. These effects were not significant in previous analyses and were clearly partitioned towards the higher additive variances estimated for these traits in the previous study (see Bunter *et al*, 1999).

3.4.1.2 Relationships between Traits

Estimates of genetic parameters from multi-trait analyses are presented in Table 9. Correlations between LW3 and later weights are not presented due to the negligible additive variance that was estimated for this trait.

Table 9: Estimates of heritabilities (diagonal), correlations (phenotypic below the diagonal) between egg, chick and live weight traits under multi-trait analyses.

Trait	**EGGWT**	**CHICKWT**	**LW6**	**LW10**	**SLWT**	σ^2_p	Correlation
EGGWT		0.95 ± 0.03	-0.13 ± 0.27	-0.13 ± 0.42	0.30 ± 0.31	23650	Genetic
	0.20 ± 0.04	0.97 ± 0.04	na	na	na		**Hen (m2)**
		0.86 ± 0.08	0.25 ± 0.27	0.14 ± 0.25	0.21 ± 0.25		Hen (c2)
		0.87 ± 0.05	na	na	na		Paddock
		0.56 ± 0.04	0.12 ± 0.09	0.07 ± 0.11	0.00 ± 0.10		**Residual**
CHICKWT			0.09 ± 0.33	0.30 ± 0.70	0.56 ± 0.38	13274	Genetic
	0.84 ± 0.01	**0.16 ± 0.04**	na	na	na		**Hen (m2)**
			0.42 ± 0.26	0.35 ± 0.22	0.40 ± 0.22		Hen (c2)
			na	na	na		Paddock
			0.10 ± 0.07	0.01 ± 0.08	0.0 ± 0.07		**Residual**
LW6				0.91 ± 0.08	0.90 ± 0.12	75.2	Genetic
	0.06 ± 0.06	0.15 ± 0.05	**0.20 ± 0.09**	1.02 ± 0.07	0.89 ± 0.15		Hen (c2)
				0.65 ± 0.04	0.43 ± 0.05		**Residual**
LW10					1.06 ± 0.07	134.4	Genetic
	0.04 ± 0.08	0.14 ± 0.06	0.74 ± 0.02	**0.24 ± 0.12**	0.77 ± 0.13		Hen (c2)
					0.68 ± 0.04		**Residual**
SLWT						127.1	Genetic
	0.12 ± 0.07	0.19 ± 0.06	0.58 ± 0.03	0.78 ± 0.02	**0.26 ± 0.11**		Hen (c2)
							Residual

na: parameter not applicable
Correlations (and phenotypic variance) between egg and chick weights are from a bivariate analysis.
Correlations (and phenotypic variance) between live weight traits are from a trivariate analysis.
Correlations between egg, or chick, and live weight traits are from a series of bivariate analyses.

Heritability estimates for egg and chick weights were consistent with those obtained from univariate analyses. Correlations between all random effects influencing these traits were high to very high, contributing to a phenotypic correlation of 0.84. Therefore, hatched chick weight is largely determined by the weight of the egg in which the embryo developed.

In contrast, phenotypic correlations between egg weight and live weights at 6, 10 or 14 months were low and not significantly different from zero. Environmental correlations between egg weight and later weights were low, not significantly different from zero, and diminishing with temporal separation to zero by slaughter. Correlations between egg and live weight traits for additive and permanent environmental effects were variable in sign and not significantly different from zero due to large standard errors. Correlations between chick weights and later weights were broadly similar to results obtained for egg weights, although phenotypic correlations between these traits were slightly stronger.

In comparison with results from univariate analyses, heritability estimates from the trivariate analysis were higher for all live weight traits, particularly those recorded at 10 and 14 months. Thus moderate estimates of heritability would appear more likely for these traits than the lower estimates obtained under univariate analyses. In contrast to univariate analyses, the trivariate analysis allows for the potentially negative effects of prior selection on live weight on the heritability estimates for later traits.

High to very high correlations between random effects were present between live weight traits, with estimates of greater magnitude apparent between traits measured temporally closer together. Correlations exceeding unity were estimated between additive effects for LW10 and SLWT, and between permanent environmental effects of the hen between LW6 and LW10. However, these estimates are not different to unity, and in a constrained analysis are considered unity.

In a multi-trait analysis containing all weights except the three-month weight (ie five traits), which allows for selection based on weights recorded at earlier stages, the following changes occurred:

1. Additive genetic correlations reduced in magnitude between egg or chick weights and later weights.
2. Phenotypic correlations reduced between chick and later weights, and
3. permanent environmental effects of the hen reduced to <0.10 for all live weight traits recorded post hatching (ie., LW6, LW10 and LWSL)

3.4.2 Reproductive Traits of Hens

3.4.2.1 Heritability Estimates and Additional Random Effects

Genetic parameters for each trait, estimated under models including both additive and permanent environmental effects, are presented in Table 10. Zero values for h^2 estimates indicate fixation of additive variances in ASREML to a very small positive value (<0.00001), which may introduce additional bias to estimates of other variance components. However, this was not apparent when parameter estimates from the complete model were compared with those estimated under models not fitting additive effects, and would suggest that the estimates of heritability for these traits were close to zero.

In particular, no or very little additive variance appeared to be present for any of the fertility related traits (NBAD, PINF1, PINF2, HPERC1, HPERC2, or HPERC3). Variation between hens in fertility traits does not have a significant additive component. For the majority of remaining traits estimates of heritability were also very low (around 0.1) and not significantly different to zero. Exceptions were estimates for DUL and TCWT ($h^2 \sim 0.20$), and AEWT, ACWT and AWTR which were moderately heritable (h^2 between 0.33 and 0.51) and significantly different to zero. Estimates of permanent environmental effects of hens were low for the behavioural traits TTL, DUL and NCL ($c^2_{Hen} \sim 0.10$), and moderate for the remaining traits. Corresponding estimates of trait repeatabilities ranged from 0.12 for NCL to 0.75 for AEWT.

Estimates of paddock effects were low for NCL and AEWT ($c^2_{Paddock}$ from 0.11 to 0.14). Estimates of service sire effects were very low for ACWT ($c^2_{SSire} = 0.06$), low for NINC, NHATCH, HPERC1, HPERC2, TEWT, TCWT, EPP and CPROD (0.11 to 0.18), but moderate (0.27 to 0.31) for the fertility traits NINF, PINF1 and PINF2. Fitting Hen_A as the only variance structure associated with hen generally resulted in both altered repeatability values and increased variance due to service sire. However, these changes were not significant and are not presented.

Standard errors were large for the estimates of both heritability (h^2) and permanent environmental effects of the hen (c^2_{Hen}), but lower for paddock and service sire effects where the number of levels was fewer. Standard errors of repeatability estimates were significantly lower, showing that the sum of additive and permanent environmental effects was estimated more accurately than each effect separately. High sampling correlations were evident between these two parameters for the majority of traits. However, sampling correlations between two parameters were often reduced when a third parameter was added to the model.

Table 10 : Genetic parameters for hen traits, estimated under models fitting additive and permanent environmental effects of the hen.

Parameter	h^2	c^2_{Hen}	r	$c^2_{Paddock}$	c^2_{SSire}	σ^2_p
Trait						
TTL[‡] (days)	.07 ± .08	.11 ± .08	.18 ± .04			1004
DUL (days)	.19 ± .10	.01 ± .08	.20 ± .05			2633
NCL	0	.12 ± .06	.12 ± .06	.14 ± .06		8.806
NLAID	.12 ± .11	.32 ± .10	.44 ± .04			580.1
NINC	.14 ± .11	.21 ± .12	.35 ± .07		.12 ± .06	516.7
NINF	0	.23 ± .06	.23 ± .06		.31 ± .06	222.9
NHATCH	.11 ± .11	.33 ± .12	.44 ± .06		.11 ± .06	352.9
AEWT (grams)	**.43 ± 16**	.25 ± .15	.68 ± .06	.11 ± .05		15273
ACWT (grams)	**.51 ± .17**	.25 ± .16	.75 ± .04		.06 ± .04	7162
AWTR	**.33 ± .14**	.26 ± .13	.59 ± .04			9.193
TEWT (kg)	.12 ± .11	.20 ± .12	.31 ± .07		.16 ± .07	1217
TCWT (kg)	.19 ± .12	.19 ± .13	.36 ± .08		.18 ± .07	247.7
PINF1[†] (%)	0	.30 ± .07	.30 ± .07		.27 ± .07	770.0
PINF2[†] (%)	.01 ± .08	.28 ± .10	.28 ± .07		.29 ± .07	941.2
HPERC1[†] (%)	0	.37 ± .06	.37 ± .06		.12 ± .06	652.0
HPERC2[†] (%)	.01 ± .08	.35 ± .10	.36 ± .06		.13 ± .06	730.2
HPERC3[†] (%)	0	.42 ± .05	.42 ± .05			667.4
EPP (%)	.12 ± .10	.24 ± .11	.36 ± .07		.13 ± .06	442.6
CPROD (%)	.12 ± .11	.33 ± .12	.45 ± .06		.11 ± .06	262.0

Parameters are h^2: heritability (σ^2_a/σ^2_p); c^2_{Hen}: permanent effect due to the hen ($\sigma^2 c_{Hen} /\sigma^2_p$); r: the repeatability of hen effects ($h^2+c^2_{Hen}$); $c^2_{Paddock}$: permanent effect due to the breeding paddock ($\sigma^2 c_{Paddock} /\sigma^2_p$); c^2_{SSire}: permanent effect due to the service sire ($\sigma^2 c_{Ssire} /\sigma^2_p$), where σ^2_a is variance due to additive effects, $\sigma^2 c_{Hen}$ is variation due to hen effects, $\sigma^2 c_{Paddock}$ is variation explained by breeding paddock and σ^2_p is the phenotypic variance.

Estimates for c^2_{Hen} for NCL increased from 0.12 ± 0.06 to 0.25 ± 0.04 when excluding paddock as an additional random effect from the model for analysis. The majority of paddock variance for AEWT was also re-partitioned into the estimate for c^2_{Hen}, although with only a slight increase in the estimate of heritability for this trait.

3.4.2.2 Relationships between Hen Traits

Estimates of correlations between random effects for all pairs of traits are presented in Table 11. Estimates of genetic correlations between bivariate combinations of the traits DUL, AEWT, ACWT, AWTR and TCWT are presented in Table 12. Results are presented for each trait group in detail below.

Overall, estimates of variance components were generally consistent with those obtained from univariate analyses. However, where significant changes occur, these are noted below. Further, the majority of bivariate analyses yielded estimates of correlations within the parameter space, although constraints were not applied to ensure this. Correlations greater than unity between random effects were estimated in five out of 171 (~3%) of bivariate analyses. In each of these cases correlations were not significantly different to unity, and the correlation estimated simply reflected an unconstrained parameter space and unity correlated traits.

Standard errors for non-unity phenotypic or environmental correlations were low, ranging between 0.02 to 0.07. Standard errors for additional random components contributing to the phenotypic correlations were between 0.02 to 0.23 for hen effects and between 0.05 to 0.47 for service sire effects. Phenotypic correlations were intermediate in value to estimates of correlations between contributing random components (ie. hen, breeding paddock, service sire or environment), although more similar to environmental correlations in general.

3.4.2.2.1 Correlations between Behavioural and Other Traits

3.4.2.2.1.1 Time to Lay

Phenotypic correlations between TTL and DUL were large and negative, particularly between hen effects. Correlations between TTL and NCL were also negative and moderate in magnitude, indicating a reduced number of clutches laid with increased TTL. Delayed commencement of laying reduced egg production as measured by the number of eggs laid (NLAID) or incubated (NINC), or the total mass of eggs produced (TEWT), as shown by moderate negative correlations between TTL and these traits. Correlations were low to moderate between TTL and the number of eggs that hatched (NHATCH) or the total mass of chicks hatched (TCWT). Overall, productivity as measured by EPP or CPROD was negatively correlated with TTL. Estimates of correlations between traits were generally consistent in sign and magnitude for both hen and environmental effects, thereby resulting in phenotypic correlations of a similar magnitude. However, correlations between hen effects, although moderate and negative, were not significantly different from zero between TTL and NCL, NHATCH or TCWT due to large standard errors.

In contrast, phenotypic correlations between TTL and NINF or AEWT were generally low and negative. Further, phenotypic correlations between TTL and ACWT, AWTR, PINF, HPERC and HPERC3 were generally not significantly different from zero. Correlations between hen effects were of greater magnitude than the corresponding environmental correlations between TTL and NINF or AWTR. These results suggest that hens with delayed TTL have reduced numbers of infertile eggs and hatch heavier chicks relative to their egg weights. This is consistent with the estimates of negative correlations for hen effects between TTL and PINF, and the positive correlations between TTL and HPERC or HPERC3, although none of these correlations were significantly different from zero. However, environmental correlations between TTL and fertility traits were opposite in sign, and of greater magnitude, than those estimated for hen effects. Thus, delayed time to laying had a detrimental effect on fertility and hatchability through environmental causes.

Including TTL in bivariate analyses with the traits NINC, TEWT or EPP resulted in substantially reduced estimates of service sire effects for these traits. Service sire effects were no longer significant for NINC and EPP, and were only significant at the $P<0.10$ level for TEWT, suggesting that significant service sire effects originally estimated for these traits were related to variation in the time taken before their mate commenced laying.

3.4.2.2.1.2 Duration of Lay

Given the large negative correlations between DUL and TTL for both hen and residual effects, it was expected that correlations between DUL and the remaining traits would be opposite in sign (and of similar magnitude) to those presented above. For all trait combinations where covariance estimates were estimated with small standard errors this was the case. However, correlations for all random effects were generally greater in magnitude between DUL and other traits compared to those for TTL trait combinations. Thus, duration of lay after commencement of laying was more strongly associated with productivity over the season than the time taken for laying to commence. Increased DUL was associated with increased levels of production, higher average and total egg and chick weights, decreased PINF and subsequently increased HPERC. Overall, DUL was highly correlated with NLAID and EPP, and moderately correlated with NHATCH and CPROD, but uncorrelated with the hatchability of fertile eggs.

Correlations between hen effects were either low or not significantly different from zero between the traits DUL and NCL, NINF, AEWT or ACWT, and fertility or hatchability traits. This is consistent with results presented for TTL above. However, there was a suggestion that increased DUL was associated with reduced AWTR at the hen level. That is, hens with longer DUL produced lighter chicks relative to egg weight on average.

In contrast to results for TTL, bivariate analyses containing DUL did not reduce the significance of service sire effects for NINC, EPP or TEWT.

3.4.2.2.1.3 Number of Clutches Laid

Significant negative phenotypic correlations were estimated between NCL and NHATCH, TCWT, hatching percentage traits or CPROD. Although low, these correlations indicate that increased numbers of clutches were associated with reduced hatching percentages, a reduction in the number of chicks hatched or the total weight of chicks produced, and subsequently reduced chick production. Phenotypic correlations between NCL and the remaining traits were not significantly different from zero. Further, estimates of correlations for both random components (hen or environment) were not significantly different from zero between NCL and NINF, AEWT, ACWT, AWTR, or PINF, suggesting no significant relationship exists between NCL and these traits.

For the majority of remaining trait combinations involving NCL, correlations between hen effects were inconsistent in magnitude and sign with estimates of environmental correlations. Strong negative correlations between hen effects were apparent between NCL and NLAID, NINC, NHATCH, TEWT, TCWT, hatching percentage traits, EPP or CPROD. Thus, increased numbers of clutches at the individual hen level had a detrimental impact on their reproductive performance, as measured by the above traits. In contrast, environmental correlations were low and positive between NCL and NLAID, NINC, TEWT or EPP, and not significant between NCL and NHATCH, TCWT, hatching percentages or CPROD. That is, at the environmental level more clutches were associated with increased output of eggs, but not with increased chick production.

The significance of service sire effects were reduced for NINC (to $P<0.10$) when this trait was included in a bivariate analysis with NCL, indicating that clutching behaviour or output of the service sires' mate contributed to the significance of this effect for NINC. Further, the significance of dam age group for NCL was reduced to $P<0.10$ in the bivariate analysis of NCL with NINF.

3.4.2.2.2 Correlations between Production and Other Traits

3.4.2.2.2.1 Number of Eggs Laid or Incubated

Correlations within each level of random components estimated between NLAID and NINC were not significantly different from unity, indicating that these two traits are, for practical purposes, identical. Correspondingly, correlations obtained from bivariate analyses of NLAID or NINC with the other traits were almost identical, and to avoid repetition will be presented in detail only for NLAID in this section.

Correlations between NLAID and other measures of productivity (TEWT, EPP) were not significantly different from unity. Thus, for this data set a difference in NLAID was the major component contributing to differences in TEWT and EPP. Phenotypic correlations between NLAID and chick production (NHATCH, TCWT and CPROD) were also very high, coupled particularly with large correlations between hen effects for these trait combinations, but were different from unity. Correlations between NLAID and HPERC1 or HPERC2 were moderate (between environmental effects) to high (between hen effects) but reducing in magnitude between NLAID and HPERC3. In contrast, correlations between NLAID and NINF (positive) or PINF1 (negative) were generally lower, moderate and significant between environmental effects but not significantly different from zero for hen effects. Thus, although NLAID was only moderately associated with fertility and hatchability traits overall, a high egg production was ultimately associated with high levels of chick production, particularly at the hen level.

NLAID was uncorrelated with ACWT, although moderately correlated with AEWT (positive) and AWTR (negative), at the phenotypic level. As average egg weight increased with an increasing number of eggs laid, average chick weight declined relative to egg weight. Environmental correlations were of greater magnitude between NLAID and AEWT or ACWT than correlations between hen effects. However, the reverse was observed between NLAID and AWTR. Thus, changes in AWTR with NLAID appear more highly related to characteristics of individual hens.

Significant service sire effects estimated from univariate analyses of NINC were reduced to insignificance under some bivariate analyses. For example, service sire was no longer a significant effect for NINC when this trait was included in bivariate analyses with the traits NLAID, NHATCH, AEWT, AWTR, TEWT, TCWT, EPP or CPROD. Similarly, service sire effects were not significant for TEWT when analysed concurrently with NLAID. Corresponding increases in trait repeatability were noted for NINC and TEWT in bivariate analyses. Increases from univariate to bivariate analyses were from 0.35 ± 0.07 to 0.46 ± 0.04 for NINC (with NLAID), and from 0.31 ± 0.07 to 0.46 ± 0.04 for TEWT (with NLAID). These increases were overall consistent with the repartitioning of service sire effects towards repeatability of the hen when service sire was removed from the model.

3.4.2.2.2.2 Number of Infertile Eggs

Phenotypic correlations between NINF and TEWT or EPP were low (~0.20) and positive, moderately negative between NINF and NHATCH, HPERC3, TCWT or CPROD, and very high between NINF and PINF (positive) or HPERC (negative). Thus, increased egg production was only associated to a small extent with an increased number of infertile eggs. More significantly, increased numbers of infertile eggs resulted in reduced chick production, particularly through increased percentage infertility and reduced hatching percentages. Relative to correlations between NINF and HPERC, phenotypic correlations between NINF and HPERC3 were still negative but much lower in magnitude. In particular, environmental correlations between NINF and HPERC3 were no longer significantly different from zero, and correlations between hen effects were of smaller magnitude. NINF was not significantly correlated with AEWT, ACWT, or AWTR, indicating that fertility or otherwise was not associated with average egg mass, and therefore potential chick mass.

Correlations between hen or service sire effects were generally inconsistent in magnitude and/or sign with estimates of environmental correlations. Environmental correlations between NINF and PINF or HPERC were significantly lower than correlations between hen or service sire effects for these trait combinations. Further, the magnitude of correlations between service sire effects was significantly larger between NINF and NHATCH, TCWT, HPERC or CPROD than correlations between hen or environmental effects, which were similar in magnitude, for these trait combinations. Of particular note, the correlation between hen or service sire effects was not significantly different from zero between NINF and EPP indicating that infertility was generally not worse for individual hens or service sires with high production, although environmental correlations were antagonistic.

The significance of service sire age on NINF was reduced to $P<0.10$ in the bivariate analyses of NINF with ACWT or EPP.

3.4.2.2.2.3 Number of Hatched Eggs

Correlations between NHATCH and other measures of chick productivity (TCWT, CPROD) were not significantly different from unity. Thus, for this data set a difference in NHATCH was the major component contributing to differences in TCWT and CPROD. Correlations between NHATCH and AEWT or ACWT were moderate and positive, to high and positive between NHATCH and TEWT, HPERC, HPERC3 and EPP. The number of chicks hatching was positively associated with average egg and chick weights and hatching percentages. However, NHATCH was uncorrelated with AWTR. In agreement with results for HPERC, correlations between NHATCH and PINF were high but negative.

With the exception of traits relating to fertility and hatchability, correlations between service sire effects had very large standard errors and were mostly uninformative. In contrast, correlations between service sire effects were large and negative between NHATCH and PINF, and of greater magnitude than corresponding hen or environmental correlations. Thus, a low number of chicks hatched was associated with an increased percentage of infertile eggs, especially for service sires. Correlations between hen effects were of greater magnitude compared to correlations between other random effects for bivariate analyses of NHATCH with TEWT, HPERC3 or EPP. This indicates that the number of chicks hatched was positively associated with both egg production and hatchability of fertile eggs at the hen level.

Repeatability estimates for TCWT increased from 0.36 ± 0.08 (univariate analysis) to 0.45 ± 0.06 obtained from the bivariate analysis of NHATCH with TCWT. The model for TCWT was the same as that presented under univariate analysis.

3.4.2.2.3 Correlations between Egg or Chick Weight Traits and Other Traits

3.4.2.2.3.1 Average Egg or Chick Weight

AEWT and ACWT were very highly correlated, particularly at the level of hen effects. In contrast, AEWT and AWTR were uncorrelated, whereas ACWT and AWTR were highly correlated, particularly at the environmental level. Thus, high average egg weight was associated with high average chick weight, but not differences in the ratio of average chick to egg weight. However, high average chick weight was positively associated with average chick to egg weight ratios, particularly at the environmental level. These results would appear somewhat inconsistent given the high correlations between AEWT and ACWT (at all levels). Correlations were moderate and positive between AEWT and TEWT, TCWT or CPROD, with hen and environmental effects consistent in magnitude and sign. High average egg weight was therefore associated with an increased total mass of eggs or chicks produced, and productivity as measured by CPROD.

Phenotypic correlations were low and negative between AEWT and PINF1, with environmental correlations not significantly different from zero. The magnitude of all correlations was increased in magnitude between AEWT and PINF2, with increasing average egg weight associated with reduced percentages of infertile eggs, particularly at the hen level. Correlations between AEWT and HPERC were positive and generally similar in magnitude across random factors, consistent with results for PINF. However, AEWT was uncorrelated with HPERC3, except for a low positive environmental correlation between these traits. Therefore, average egg weight was positively associated with improved hatching percentages of fertile eggs at the environmental level, or improved hatching percentages overall when hatchability was defined by the number of eggs either laid or incubated.

Correlations between ACWT and fertility traits, hatchability traits or CPROD were very similar to those obtained between AEWT and these traits. However, the magnitude of correlations between ACWT and TEWT or TCWT were reduced compared to those estimated between AEWT and these traits, but consistent in sign. Further, correlations between ACWT and the remaining traits differed somewhat to results reported above for AEWT. ACWT was moderately correlated with AWTR, with larger average chick weight associated with higher ratios of chick to egg weight, more so due to environmental causes but also at the hen level. In addition, ACWT was not significantly correlated with TEWT and EPP at the hen level, although moderate positive environmental correlations were apparent between these traits. Relationships between these latter traits would appear to be environmentally mediated.

For all bivariate combinations involving the trait ACWT, correlations between service sire effects (where fit) were associated with large standard errors, and were uninformative even for estimates of moderate to large magnitude. Further, service sire effects were no longer significant for ACWT in bivariate analyses with AEWT, AWTR or HPERC1. Moreover, breeding paddock effects and service sire effects were no longer significant for AEWT of TEWT respectively in the bivariate analysis containing these traits.

3.4.2.2.3.2 Average Ratio of Chick to Egg Weight

AWTR was uncorrelated with TCWT, PINF, HPERC and CPROD, suggesting no relationship between these traits. Moderate negative correlations were estimated between AWTR and TEWT or EPP at the hen level, although phenotypic correlations were reduced due to low environmental correlations between these traits. Thus, higher egg producing hens are associated with lower ratios of chick to egg weights, but environmental factors altering egg production appear to have no influence on AWTR. Low to moderate positive correlations between AWTR and HPERC3 indicates that an increased hatching percentage of fertile eggs is associated with chick weights which were heavier relative to egg weights.

Length of season was no longer a significant influence on HPERC3 when AWTR was included with this trait in a bivariate analysis.

3.4.2.2.3.3 Total Egg or Chick Weight

TEWT was very highly correlated with EPP, with correlations between all random effects close to unity. TEWT was also highly correlated with TCWT and CPROD, particularly at the hen level. However, phenotypic correlations between these traits were significantly lower than unity due to lower correlations between environmental and service sire effects. Correlations between service sire effects for TEWT and the remaining traits were generally low and not significantly different from zero.

Phenotypic correlations between TEWT and PINF were low to moderate and negative, and of greater magnitude between hen effects. Thus increased total egg weight was weakly associated with decreased percentages of infertile eggs, mostly at the hen level. Correlations between TEWT and HPERC were significantly larger compared to those estimated between TEWT and PINF, again more so at the hen level. However, environmental correlations were no longer significant between TEWT and HPERC3, and correlations between hen effects were also reduced compared to alternative HPERC traits.

With the exception of correlations between service sire effects, correlations between random effects for bivariate analyses of TCWT and fertility or hatchability traits were consistent with those reported for TEWT, but of significantly greater magnitude. Correlations between service sire effects were large and significant for bivariate analyses of TCWT and PINF (negative) or HPERC (positive), whereas they were small and non-significant for the same trait combinations involving TEWT instead of TCWT. Thus, TCWT was strongly associated with fertility and hatchability traits for all levels of random effects, whereas TEWT was mostly associated with these traits due to relationships between hen effects.

Relative to results between TCWT and PINF1, the significance of dam age group for total chick weight produced was reduced, but still significant, when TCWT was analysed with PINF2. Further, the repeatability of TCWT was increased from 0.36 ± 0.08 (univariate analysis) to 0.44 ± 0.06 when this trait was included in a bivariate analysis with CPROD, consistent with results from the bivariate analysis of TCWT with NHATCH.

3.4.2.2.4 Correlations between Fertility and Other Traits

3.4.2.2.4.1 Percent Infertile Eggs

For all random components, correlations between PINF1 and PINF2 were not significantly different from unity, indicating that the same effects controlled the percentage of infertile eggs when infertility was defined relative to either NLAID or NINC. Correlations between PINF and HPERC were large and negative, and were unity for service sire effects, but of lower magnitude for hen effects or environmental correlations. Thus, high levels of infertility were strongly associated with reduced overall hatching percentages, particularly with respect to service sire effects. Correlations between PINF and HPERC3 were negative and moderate (between environmental effects) to high (between hen effects), resulting in a moderate phenotypic correlation between these traits. Thus, differences in hatchability are only moderately explained by differences in the percentage of infertile eggs, with hen level effects of increasing significance once variation in fertility is accounted for.

Overall, low negative (~-0.20) environmental correlations were estimated between PINF and EPP, indicating that environmental factors associated with reduced rates of lay were also associated with an increased percentage of infertile eggs. Correlations between PINF and CPROD were moderate (between hen or environmental effects) to large (between service sire effects), suggesting that the limiting factors for CPROD differed for females compared to males.

3.4.2.2.5 Correlations between Hatchability and Productivity Traits

3.4.2.2.5.1 Hatching Percent

Correlations between HPERC1 and HPERC2 were not significantly different from unity for all random components, indicating that hatching percentage defined relative to either the number of eggs laid or incubated may be considered the same trait. However, correlations between HPERC1 or HPERC2 and HPERC3, although still high, were significantly lower than unity due mainly to the reduced magnitude of environmental correlations. Thus, factors affecting hatching percentages of all eggs were still highly associated with factors affecting the hatching percentages of fertile eggs only.

HPERC was positively correlated with EPP, with correlations between hen effects significantly larger than environmental correlations, resulting overall in moderate phenotypic correlations. Higher hatching percentages are therefore moderately associated with increased egg production. However, correlations between service sire effects were close to zero and not significant for these trait combinations, indicating that the relationships observed between these traits resulted from covariances between hen and environmental effects only. In contrast, correlations between hatching percentage traits and CPROD were very high and of significantly greater magnitude for all random components. Ultimately, higher hatching percentages are strongly associated with higher chick production. However, environmental correlations between HPERC and CPROD were generally lower than those estimated between hen or service sire effects, and were significantly reduced for HPERC3 relative to either HPERC1 or HPERC2. The influence of season length on CPROD was no longer significant when this trait was included in a bivariate analysis with HPERC3 (see results for AWTR).

Finally, estimates of correlations between EPP and CPROD were moderate (between service sire effects), high (between environmental effects) or very high (between hen effects). Thus, even at the level of the individual hen the ability to produce a large number of eggs was not fully correlated with the production of chicks, and corresponding phenotypic correlations were significantly different from unity.

Table 11: Estimates of correlations between reproductive traits for hen (Hen$_I$) or service sire (Ssire) effects, along with environmental (E: above diagonal) and phenotypic correlations (below diagonal).

	TTL	DUL	NCL	NLAID	NINC	NINF	NHATCH	AEWT	ACWT	AWTR	TEWT	TCWT	
TTL		-.81 (.08) -.64 (.03)	-.31 (.23) -.24 (.04)	-.48 (.11) -.51 (.03)	-.48 (.12) -.48 (.03)	-.32 (.18) -.10 (.05)	-.23 (.14) -.36 (.04)	-.13 (.13) -.34 (.04)	-.06 (.13) -.20 (.05)	.26 (.13) -.08 (.05)	-.49 (.12) -.49 (.03)	-.27 (.15) -.36 (.05)	Hen$_I$ E
DUL	-.67 (.02)		.27 (.23) .47 (.04)	.79 (.06) .72 (.02)	.69 (.02) .82 (.07)	.16 (.18) .21 (.04)	.48 (.04) .57 (.10)	.21 (.12) .41 (.04)	.08 (.12) .18 (.05)	-.30 (.12) -.07 (.05)	.85 (.07) .71 (.02)	.60 (.12) .48 (.04)	Hen$_I$ E
NCL	-.23 (.04)	.40 (.04)		-.52 (.18) .15 (.04)	-.60 (.18) .11 (.05)	-.03 (.23) .06 (.05)	-.58 (.16) .04 (.05)	-.09 (.16) .02 (.05)	-.09 (.16) .02 (.05)	-.16 (.17) .08 (.05)	-.55 (.20) .14 (.05)	-.60 (.17) -.03 (.05)	Hen$_I$ E
NLAID	-.48 (.03)	.72 (.02)	-.03 (.05)		0.99 (.001) 0.99 (.001)	.20 (.14) .30 (.04)	.86 (.04) .70 (.02)	.22 (.09) .46 (.04)	.05 (.10) .25 (.05)	-.31 (.09) -.11 (.05)	.98 (.005) .99 (.001)	.90 (.04) .70 (.03)	Hen$_I$ E
NINC	-.46 (.03)	.69 (.02)	-.06 (.05)	0.99 (.001)		.04 (.19) .39 (.24) .28 (.04)	.87 (.04) .50 (.28) .70 (.02)	.25 (.10) na .46 (.04)	.05 (.12) .14 (.41) .25 (.05)	-.31 (.11) na -.10 (.05)	.95 (.01) 1.002 (.01)† .98 (.001)	.90 (.05) .50 (.27) .71 (.03)	Hen$_I$ Ssire E
NINF	-.13 (.04)	.17 (.04)	.03 (.04)	.22 (.05)	.23 (.05)		-.37 (.15) -.68 (.22) -.30 (.04)	-.14 (.13) na .12 (.05)	-.24 (.15) .09 (.27) -.02 (.05)	-.18 (.14) na -.10 (.05)	.00 (.20) .31 (.21) .27 (.04)	-.26 (.17) -.65 (.21) -.36 (.05)	Hen$_I$ Ssire E
NHATCH	-.29 (.04)	.46 (.04)	-.12 (.04)	.74 (.02)	.74 (.02)	-.37 (.04)		.28 (.10) na .35 (.04)	.23 (.10) -.23 (.43) .27 (.05)	-.09 (.11) na .03 (.05)	.86 (.05) .53 (.23) .69 (.02)	.99 (.003) .99 (.008) .99 (.001)	Hen$_I$ Ssire E
AEWT	-.19 (.05)	.24 (.04)	-.02 (.05)	.29 (.05)	.29 (.05)	-.02 (.05)	.26 (.05)		.91 (.02) .78 (.02)	.11 (.10) -.09 (.05)	.47 (.08) .51 (.03)	.45 (.09) .41 (.04)	Hen$_I$ E
ACWT	-.10 (.05)	.10 (.05)	-.02 (.05)	.11 (.06)	.12 (.06)	-.09 (.06)	.19 (.06)	.87 (.02)		.51 (.07) na .66 (.03)	.23 (.12) .36 (.33) .30 (.05)	.33 (.11) .07 (.35) .31 (.05)	Hen$_I$ Ssire E
AWTR	.03 (.05)	-.14 (.05)	.00 (.05)	-.21 (.05)	-.19 (.05)	-.11 (.05)	-.03 (.06)	.04 (.06)	.53 (.04)		-.31 (.11) -.09 (.05)	-.05 (.12) .07 (.05)	Hen$_I$ E
TEWT	-.45 (.03)	.69 (.02)	-.03 (.05)	0.99 (.002)	0.97 (.003)	.20 (.05)	.73 (.02)	.43 (.05)	.24 (.05)	-.18 (.05)		.93 (.05) .57 (.21) .70 (.03)	Hen$_I$ Ssire E
TCWT	-.29 (.04)	.45 (.04)	-.16 (.05)	.75 (.02)	.75 (.02)	-.37 (.05)	.99 (.001)	.36 (.05)	.27 (.06)	.01 (.05)	.76 (.02)		

na = parameter not applicable; † parameter estimate outside the theoretical parameter space.

Table 11 (continued): Estimates of correlations between reproductive traits for hen (Hen$_I$) or service sire (Ssire) effects, along with environmental (E) and phenotypic (P) correlations.

	PINF1	PINF2	HPERC1	HPERC2	HPERC3	EPP	CPROD	
TTL	-.20 (.18)	-.13 (.18)	.12 (.16)	.16 (.16)	.18 (.15)	-.54 (.11)	-.23 (.14)	Hen$_I$
	.16 (.05)	.20 (.05)	-.20 (.04)	-.20 (.05)	-.14 (.05)	-.52 (.03)	-.38 (.04)	E
	.05 (.04)	.09 (.04)	-.10 (.04)	-.09 (.05)	-.05 (.05)	-.49 (.03)	-.29 (.04)	P
DUL	-.02 (.17)	-.10 (.17)	.15 (.15)	.14 (.15)	.08 (.15)	.87 (.05)	.58 (.10)	Hen$_I$
	-.17 (.05)	-.21 (.05)	.21 (.04)	.17 (.05)	.08 (.05)	.73 (.02)	.48 (.04)	E
	-.11 (.04)	-.15 (.04)	.17 (.04)	.15 (.04)	.08 (.05)	.72 (.02)	.46 (.04)	P
NCL	.24 (.21)	.28 (.21)	-.70 (.18)	-.65 (.19)	-.64 (.18)	-.55 (.20)	-.59 (.16)	Hen$_I$
	-.05 (.05)	-.06 (.05)	.06 (.05)	.06 (.05)	.01 (.05)	.16 (.05)	.04 (.05)	E
	.01 (.04)	.02 (.04)	-.12 (.04)	-.10 (.04)	-.14 (.05)	-.02 (.05)	-.12 (.05)	P
NLAID	-.20 (.13)	-.28 (.13)	.56 (.09)	.52 (.10)	.39 (.10)	1.005 (.001)	.86 (.04)	Hen$_I$
	-.18 (.05)	-.22 (.05)	.28 (.04)	.25 (.04)	.18 (.05)	.97 (.002)	.69 (.02)	E
	-.16 (.05)	-.21 (.05)	.38 (.04)	.34 (.04)	.27 (.05)	.99 (.001)	.74 (.02)	P
NINC	-.27 (.17)	-.35 (.16)	.59 (.12)	.54 (.13)	.39 (.12)	.99 (.004)	.88 (.04)	Hen$_I$
	0.18 (.31)	0.15 (.31)	.02 (.41)	.01 (.39)	na	1.02 (.02)	.46 (.31)	Ssire
	-.16 (.05)	-.21 (.05)	.26 (.04)	.20 (.05)	.12 (.05)	.97 (.003)	.69 (.02)	E
	-.14 (.05)	-.19 (.05)	.36 (.04)	.30 (.05)	.22 (.05)	.98 (.002)	.74 (.02)	P
NINF	0.94 (.05)	.92 (.05)	-.65 (.12)	-.69 (.10)	-.52 (.13)	.12 (.18)	-.39 (.15)	Hen$_I$
	0.96 (.05)	.91 (.05)	-.78 (.15)	-.81 (.13)	na	.25 (.23)	-.66 (.23)	Ssire
	.67 (.03)	.62 (.03)	-.44 (.04)	-.46 (.04)	-.07 (.05)	.30 (.04)	-.29 (.04)	E
	.81 (.02)	.78 (.02)	-.55 (.03)	-.58 (.03)	-.20 (.05)	.23 (.05)	-.37 (.04)	P
NHATCH	-.53 (.11)	-.60 (.10)	.84 (.05)	.81 (.06)	.73 (.07)	.84 (.05)	1.001 (.001)	Hen$_I$
	-.80 (.17)	-.77 (.17)	.83 (.13)	.82 (.14)	na	.53 (.25)	1.003 (.003)	Ssire
	-.52 (.03)	-.55 (.03)	.73 (.02)	.70 (.02)	.47 (.04)	.68 (.03)	.98 (.002)	E
	-.56 (.04)	-.58 (.03)	.78 (.02)	.75 (.02)	.56 (.03)	.72 (.02)	.99 (.001)	P
AEWT	-.26 (.12)	-.31 (.12)	.25 (.11)	.25 (.11)	.08 (.10)	.21 (.10)	.28 (.10)	Hen$_I$
	-.07 (.05)	-.15 (.05)	.25 (.04)	.18 (.05)	.17 (.05)	.48 (.04)	.35 (.04)	E
	-.14 (.05)	-.18 (.05)	.20 (.05)	.19 (.05)	.10 (.06)	.27 (.05)	.26 (.05)	P
ACWT	-.29 (.13)	-.34 (.12)	.36 (.11)	.33 (.11)	.24 (.10)	.01 (.12)	.23 (.10)	Hen$_I$
	.36 (.32)	.44 (.33)	-.67 (.47)	-.48 (.43)	na	.14 (.38)	-.18 (.44)	Ssire
	-.11 (.06)	-.11 (.06)	.18 (.05)	.13 (.05)	.16 (.05)	.26 (.05)	.28 (.05)	E
	-.13 (.06)	-.14 (.06)	.19 (.06)	.18 (.06)	.19 (.06)	.09 (.06)	.20 (.06)	P
AWTR	-.00 (.13)	-.00 (.13)	.14 (.11)	.14 (.12)	.43 (.15)	-.34 (.11)	-.10 (.11)	Hen$_I$
	-.04 (.05)	-.02 (.05)	.11 (.05)	.12 (.05)	.21 (.05)	-.10 (.05)	.03 (.05)	E
	-.02 (.06)	-.01 (.06)	.11 (.06)	.12 (.06)	.25 (.05)	-.20 (.05)	-.04 (.06)	P
TEWT	-.30 (.17)	-.38 (.17)	.59 (.13)	.55 (.14)	.39 (.12)	.96 (.01)	.86 (.05)	Hen$_I$
	.13 (.26)	.10 (.26)	.08 (.34)	.05 (.34)	na	.98 (.02)	.50 (.25)	Ssire
	-.18 (.05)	-.22 (.05)	.24 (.05)	.20 (.05)	.10 (.05)	.98 (.002)	.68 (.02)	E
	-.15 (.05)	-.20 (.05)	.34 (.04)	.30 (.05)	.20 (.05)	.97 (.003)	.73 (.02)	P
TCWT	-.54 (.11)	-.61 (.10)	.84 (.05)	.81 (.06)	.79 (.07)	.90 (.05)	.98 (.004)	Hen$_I$
	-.79 (.16)	-.77 (.16)	.85 (.14)	.85 (.15)	na	.41 (.31)	1.00 (.008)	Ssire
	-.58 (.04)	-.59 (.03)	.72 (.02)	.69 (.03)	.45 (.04)	.70 (.03)	.98 (.002)	E
	-.59 (.04)	-.61 (.04)	.78 (.02)	.75 (.02)	.57 (.04)	.75 (.02)	.98 (.002)	P

na = parameter not applicable; † parameter estimate outside the theoretical parameter space.

Table 11 (continued): Estimates of correlations between reproductive traits for hen (Hen$_I$) or service sire (Ssire) effects, along with environmental (E: above diagonal) and phenotypic correlations (below diagonal).

	PINF1	PINF2	HPERC1	HPERC2	HPERC3	EPP	CPROD	
PINF1		1.0 (.003) 1.0 (.003) .97 (.003)	-.74 (.08) -.98 (.10) -.67 (.03)	-.77 (.07) -.98 (.08) -.71 (.02)	-.53 (.12) na -.21 (.05)	-.22 (.17) .10 (.29) -.19 (.05)	-.56 (.11) -.80 (.18) -.54 (.03)	Hen$_I$ Ssire E
PINF2	.99 (.001)		-.79 (.07) -.98 (.08) -.71 (.02)	-.80 (.06) -.99 (.07) -.73 (.02)	-.56 (.11) na -.23 (.05)	-.29 (.16) .07 (.28) -.23 (.05)	-.62 (.10) -.76 (.17) -.56 (.03)	Hen$_I$ Ssire E
HPERC1	-.73 (.02)	-.77 (.02)		.99 (.003) 1.02 (0.01) .98 (.002)	.92 (.03) na .77 (.02)	.59 (.11) -.03 (.41) .32 (.04)	.84 (.05) .84 (.13) .76 (.02)	Hen$_I$ Ssire E
HPERC2	-.77 (.02)	-.79 (.02)	.99 (.001)		.93 (.03) na .78 (.02)	.56 (.12) -.08 (.40) .28 (.04)	.82 (.05) .84 (.14) .73 (.02)	Hen$_I$ Ssire E
HPERC3	-.30 (.05)	-.32 (.05)	.80 (.02)	.81 (.02)		.47 (.11) .23 (.05)	.74 (.07) .51 (.03)	Hen$_I$ E
EPP	-.14 (.05)	-.19 (.05)	.38 (.04)	.34 (.04)	.30 (.04)		.85 (.05) .46 (.29) .70 (.02)	Hen$_I$ Ssire E
CPROD	-.57 (.04)	-.59 (.03)	.80 (.02)	.77 (.02)	.58 (.03)	.73 (.02)		

na = parameter not applicable; † parameter estimate outside the theoretical parameter space.

3.4.3 Estimates of Genetic Correlations

Genetic correlations were estimated between pairs of traits that, from univariate analyses, had significant levels of genetic variation. These traits were DUL, AEWT, ACWT, AWTR and TCWT, and results are presented in Table 12. To prevent a somewhat spurious interpretation, bivariate analyses with hen effects separated into additive and permanent environmental components were not performed for trait combinations where one trait had poorly estimated additive effects, thereby excluding the remaining trait combinations from this section.

Table 12: Estimates of correlations between additive genetic (A), permanent environmental (PE) and service sire (Ssire) effects, along with environmental (E: above diagonal) and phenotypic correlations (below diagonal) for a subset of hen traits.

Trait	DUL	AEWT	ACWT	AWTR	TCWT	
DUL		0.38 (.19) 0.40 (.04)	.13 (.17) .17 (.05)	-.39 (.17) -.08 (.05)	1.05 (.20) 0.47 (.04)	A E
AEWT	0.26 (.05)		0.94 (.04) 0.91 (.11) 0.78 (.02)	0.43 (.30) -0.37 (.43) -0.09 (.05)	0.53 (.26) 0.33 (.28) 0.39 (.04)	A PE E
ACWT	.11 (.05)	0.87 (.02)		0.85 (.15) -0.01 (.44) - 0.67 (.03)	0.16 (.34) 0.64 (.41) -0.01 (.35) 0.31 (.05)	A PE Ssire E
AWTR	-.15 (.05)	0.05 (.07)	0.54 (.05)		0.01 (.40) -0.07 (.29) 0.06 (.05)	A PE E
TCWT	0.47 (.04)	0.38 (.05)	0.27 (.06)	0.01 (.06)		

Overall, estimates of variance components were not significantly different from those obtained by univariate analyses. Estimates of environmental and phenotypic covariances for specific trait combinations were also consistent with those estimated previously, and are not presented again here. The sum of additive and permanent environmental covariances was generally consistent with the estimated covariance between traits for hen effects, although any variations and their relative partitioning is discussed further below. For the majority of trait combinations, estimates of genetic correlations were associated with large standard errors and, for several trait combinations, were therefore relatively uninformative.

Genetic correlations between DUL and AEWT or ACWT were low to moderate and positive, and similar in magnitude to environmental correlations. Genetic correlations between DUL and AWTR were moderate and negative, compared to a significantly lower environmental correlation between these traits. The genetic correlation between DUL and TCWT exceeded the theoretical parameter space, but was not significantly different from unity. For all of these trait combinations estimates of genetic correlations were associated with high standard errors. However, there is a suggestion from the results that the relationship between DUL and AWTR or TCWT is greater for genetic compared to environmental effects.

The genetic correlation between AEWT and ACWT was close to unity, and of similar magnitude to the correlation between permanent environmental effects. Both these correlations were significantly larger than the corresponding environmental correlation. The genetic correlation between AEWT and AWTR was moderate and positive, but moderate and negative between permanent environmental effects of the hen for these traits. Thus, increased AEWT was strongly associated with increased ratios of chick to egg weight at the genetic level, whereas the reverse was indicated for permanent environmental effects. Standard errors, however, were very large making these parameters unreliable. The genetic and permanent environmental correlations between AEWT and TCWT was moderate and positive, indicating that average egg weights were moderately associated with the total mass of chicks hatched. However, the sum of genetic and permanent environmental correlations (~0.86) was not consistent with the correlation between hen effects estimated previously between AEWT and TCWT (~0.45).

The genetic correlation between ACWT and AWTR was very high, although no significant permanent environmental correlation was estimated between these traits. As above, the sum of genetic and environmental correlations between ACWT and AWTR (~0.84) was not consistent with the correlation between hen effects estimated previously (0.51). Further, given the high genetic correlation between AEWT and ACWT, the genetic correlation between ACWT and AWTR would be expected to be similar to that estimated between AEWT and AWTR, which was not the case. The genetic correlation between ACWT and TCWT was positive and low although not significantly different from zero, whereas the correlation between permanent environmental effects for these traits was high. Once again, the summation of genetic and permanent environmental correlations between ACWT and TCWT was not consistent with the correlation between hen effects estimated previously for this trait combination, and these estimates were associated with large standard errors. Estimates of genetic and permanent environmental correlations between AWTR and TCWT were close to zero, supporting the insignificant correlation estimated between hen effects for these traits previously.

In comparison to univariate analyses, both additive and phenotypic variances were increased for ACWT under the bivariate analysis of AEWT and ACWT. The heritability for ACWT correspondingly increased from 0.51 ± .17 to 0.62 ± .16. Additive variances were reduced for AEWT in bivariate analyses containing DUL, and the heritability of AEWT was reduced from 0.43 ± 0.16 (univariate analysis) to 0.33 ± 0.14 (bivariate analysis). Further, service sire effects were no longer significant for ACWT when this trait was included in bivariate analyses with AEWT or AWTR. Service sire effects for TCWT were also not significant when this trait was included in an analysis with AWTR. Thus, correlations are presented from bivariate analyses excluding service sire effects for these traits.

4 Reproduction Survey

4.1 Objectives

To obtain benchmark estimates for the levels of infertility, hatchability and chick mortality achieved in farmed ostriches around the world. To generate and benchmark associated reproductive traits. To identify factors associated with differences in reproductive performance.

4.2 Background

Relative to other livestock species, very little is known about the current levels of reproductive performance achieved by commercial ostriches in the farming environment. Deeming and Ar (1999) and Verwoerd *et al.* (1999) recently reviewed much of the available information on fertility and hatchability, chick mortality and egg production. However, the bulk of published results related to eggs incubated in South Africa or African countries, eggs imported from African countries to Great Britain for incubation, and/or results from very young flocks and countries which had newly established industries, and little experience, at the time of performance recording. Further, the number of flocks represented was relatively small outside South Africa, and may not be typical of commercial flocks operating today.

Considering that ostriches have been farmed in some countries outside South Africa for over 10 years, and industries in several countries have more recently undergone restructuring, it is important to establish benchmark figures for performance in the prevailing environments. This will provide producers with solid data against which they can use to assess their own performance, and as a guideline for developing achievable goals. Benchmarks will also illustrate what the best farmers have achieved in practice, and for different groups of producers may help to highlight possible factors that have contributed to differences in performance. Further, benchmark data should also provide indicators for the potential significance of research in specific areas, which was the motivation for this study.

Collection of data to this end using a variety of methods has largely been unsuccessful up to this point in time in several countries (Fiona Benson, Brian Cullis, David Michael, 2000, pers. comm.). Some success in collecting Industry information from producers was recently achieved by Alan Stables (Iberstruz, 2000), using the Internet as a method of informing potential respondents of survey details, and for retrieving information. Given the increasing access of many people to the Internet, compared to the relatively fragmented distribution of producers in each country, this approach seemed a logical step to obtain information on reproductive performance of farmed ostriches.

4.3 Methodology

An Internet based questionnaire was developed to survey producers regarding the reproductive performance they had achieved in recent seasons (refer Appendix C). The location of the survey, along with a range of supporting information, was emailed to producers around the world either directly (by the author) or through electronic newsletters (Ostriches On-Line, Blue Mountains Feed and Iberstruz). These newsletters had high Industry penetration in several countries through their provision of practical information, along with product and sales information. Inclusion of the survey location also occurred on various homepages (eg. British Ostrich Producers Association, National Ostrich Processors Association of South Africa), industry members in several countries voluntarily offered to promote the survey, and respondents were (where possible) asked to encourage other producers to answer the survey. Producers were also notified that they could respond via mail. However, with the exception of one respondent, all answers were submitted directly through the Internet.

Responses were collated during April-May inclusive in the year 2000. Duplicates were removed, the validity and consistency of data were evaluated, and the majority of respondents were asked to re-confirm their information for specific questions. The questions were structured to allow crosschecking of responses made. Information from respondents providing no performance data did not contribute to analyses.

Following collation, error handling and editing (see below), base procedures available in SAS software (SAS Institute) were used to characterise and analyse the data. PROC FREQ was used to quantify the frequency of response categories for information relating to management, breeding flock and incubation details. For benchmark figures, data were described according to mean values and ranked in quantiles to examine the impact of data distribution on expected performance (PROC UNIVARIATE). Benchmark statistics were generated from the complete data sample ignoring the small incidence of respondents with more than one season's performance, or containing data that was already averaged. Benchmark statistics were also generated from two other sub-samples of data. The first sub-sample was data from respondents with averaged performance (over a variable number of seasons), and the second was data from producers with more than 20 hens. Finally, PROC GLM was used in a step-wise progression to assess whether there were any consistent significant associations (at the 5% level) between response categories and the performance achieved.

4.4 Results

4.4.1 General Comments

More than 200 ostrich producers from 35 countries returned questionnaire forms via the Internet in the months of April and May. Countries of production included: America; Argentina; Australia; Belgium; Brazil; Canada; Chile; China; Croatia; Czech Republic; Denmark; Ecuador; Egypt; Ghana; Greece; India; Italy; Jordan; Kazakstan; Kuwait; Latvia; Malaysia; Mexico; New Zealand; Norway; Puerto Rico; Philippines; Portugal; Saudi Arabia; South Africa; Spain; Sweden; Turkey; the United Kingdom; and Venezuela. Approximately 20 returned questionnaires were discarded immediately for containing no pertinent information, and several duplicates were identified and removed. One hoax respondent was also identified and discarded.

Each questionnaire was examined for consistency and validity of answers, and the majority of respondents were requested to confirm their answers. However, only a relatively small percentage of respondents queried actually re-confirming their questionnaire entries. After editing, 116 responses (each generating 1 record) from 100 respondents were retained for analysis. Sixty-nine records related to a single complete season, whereas the remaining records were from almost complete seasons or averages across more than one season. Years from which information was provided ranged from 1992 to 2000, with the majority of retained records relating to the last complete previous season in any given country. Although two respondents practised natural incubation, the data retained related to artificial incubation only.

Respondents not included in the data analysed were generally excluded for 1) failing to provide any reproductive performance data, 2) providing data from the current and predominantly incomplete season, 3) providing very inconsistent answers, or 4) indicating that that their results were only estimates of their expected performance. Respondents fitting into the last two categories were removed from the data to minimise the risk of analysing erroneous records.

4.4.2 Data Errors and Editing

Inspection of the data showed that a percentage of respondents had misinterpreted the reproductive statistics requested. The common errors, and their likely influence on results, are as indicated below.

4.4.2.1 Fertility and Hatchability

Statistics requested were the **percentages of incubated eggs** that were infertile (PI) or hatched (PH). Errors firstly occurred with some respondents reporting the percentage of fertile eggs, but this error was easily detected, confirmed and corrected. Secondly, the sum of PI+PH had to be 100% or less for the answers to be considered valid. In cases where PI+PH was > 100%, the error confirmed was usually that the hatching percentage had been reported relative to fertile (rather than incubated) eggs only. Consequently, PH_{new} was recalculated as $(1-PI)*PH_{original}$ for obviously incorrect records, but left in original form for the remainder.

The incorrect reporting of PH relative to fertile instead of incubated eggs is not always detectable, and not reconfirmed by all respondents retained in the data. This error is easier to detect where the percentage of infertile eggs is high, and less easy to detect when PI is low. If a significant proportion of data retained is from respondents who have reported the percentage hatched of fertile eggs (PHF) instead of PH, results for hatching percentages will be biased upwards. For mean PI of 10%, 20% or 30% this bias is approximately +1%, 2.5% and 4.3% if ALL respondents reported the incorrect statistic. For the benchmark results for PH reported in this study, the upwards bias in percent hatched should be less than 2.5% given the presence of this type of error, particularly given the often high infertility levels reported.

4.4.2.2 Chick Mortality

Statistics requested were the **percentage mortality of chicks hatched** in the time periods covering hatch to the end week 1 (M1week), hatch to 1 month (M1month), and hatch to 3 months (M3months). In order for results to be valid, the percentage mortality must not decrease from M1week to M3months, because the mortality is the total mortality that has occurred at the end of that time period from hatching.

Some respondents reported the percentage of surviving rather than dying chicks in these time periods, which is easily detected, confirmed and corrected. Other respondents provided mortality from the periods 0 to 1 week, 1 week to 1 month, and 1 month to three months. This could be presented either relative to the original number of chicks that hatched, or relative to the number of surviving chicks from the previous time period. Where the mortality reported decreased with increasing time period, mortality was recalculated to indicate the total mortality at the end of the time period. This was done relative to the correct percentage of chicks for respondents who confirmed their approach. For those respondents reporting percentages relative to surviving chicks in the previous time period (rather than relative to hatching chicks) who did not confirm their approach, the recalculated mortality would overestimate the percentage chick mortality in M1month and M3months. This bias is expected to be less than +1%.

Overall, given that all respondents were asked to reconfirm their answers, particularly with respect to specific questions, it can probably be assumed that the majority of respondents who did not reply were satisfied that their answers were correct. Regardless of whether this is true or not, only small biases will result.

4.4.3 Countries Represented

From the records retained, the number of records from each country were:

Australia (12 records); Belgium (1); Brazil (2); Canada (5); Chile (1); China (1); Czech Republic (1); Denmark (3); Ecuador (2); Greece (1); Italy (2); Jordan (1); Mexico (7); New Zealand (9); Saudi Arabia (1); South Africa (3); Spain (4); Sweden (1); United Kingdom (2), and USA (57).

The number of respondents in each country was as above, with the exceptions of:

Australia (9 respondents); Denmark (2); New Zealand (6), and USA (48).

The following summary of responses is presented from all records retained.

4.4.4 Summary of Management Background

Respondents were asked to provide general information on their management background with respect to ostrich production. Almost all respondents provided this information. Results for the records retained are presented below.

The number of records within each experience class (1 missing) or recording class is shown below:

Class	Experience	Recording
<1 year	12	24
1-2 years	40	50
3-5 years	48	31
6-10 years	10	10
10+ years	5	1

The scale of operation ranged from: 1-10 hens (53 records); 11-30 hens (39); 31-50 hens (8); 51-100 hens (8); 101-250 hens (4); 251-500 hens (1); and 500+ hens (2).

The main occupations of respondents were: Ostrich Farmer (53 records); NON-Agricultural (44); Farmer-cropping (6); Farmer-extensive livestock (5); and Farmer-intensive livestock (8).

The main enterprises relating to ostrich production were: Breeder with on farm incubation (92 records); Breeder with no on farm incubation (20); and Incubation Service Provider (4). A variety of secondary enterprises were also listed.

4.4.5 Summary of the Breeding Operation

4.4.5.1 Information on the Breeding Flock

4.4.5.1.1 Usual Breeding Season

The usual breeding season reported by respondents varied both across and within countries, as expected, with a range of between 6-9 months. Relatively few respondents indicated that birds were separated in the non-breeding season. From single season records the mean season length over all countries was 8.76 months. However, many respondents used a 12 month season length to indicate no separation of breeders occurred between breeding seasons. The range was from 3 months (partial season) or 5 months (complete season) to 12 months. Some respondents indicated that egg laying occurred over the entire 12 months.

4.4.5.1.2 Ratio of females to males, and breeding structures

The average ratio of females to males ranged from 1:1 to 5:1. The most frequent ratios were 2:1 (50 records); 1:1 (19); 3:1 (15); and 1.5:1 (6). This reflected the most frequent structures of trios (39); mixed – usually pairs and trios (33); pairs (19); quads (12); and colonies (11). Colony size ranged from small (6 records), medium (3), large (1) to extra-large (1).

Producers carrying between 1 to 30 hens predominantly operated with pairs, trios or quads, with a low frequency of small (<10 hens) to medium size (<50) colonies reported. From 31-100 hens trios and mixed breeding groups were predominant. For operations with more than 100 hens, colonies were the predominant breeding structure. The total number of breeding groups managed ranged from one to 81.

4.4.5.1.3 Age of breeding flock

Respondents were requested to report the average age of their breeding females and males. Mean averages were 4.42 years for females and 5.11 years for males. This reflects that the majority of respondents had produced ostriches for 5 years or less, and/or predominantly used young birds for flock expansion. Mean ages varied across country, with countries new to ostrich production generally using the youngest birds for breeding. South African producers reported the oldest breeders.

4.4.5.2 Egg Collection and Incubation Procedures

4.4.5.2.1 Incubation capacities

Capacity of the main incubator was reported as < 300 (77 records); 300-600 (10); 600-900 (1) or 900+ (2). Total incubation capacity ranged from 16-5500 eggs/season.

4.4.5.2.2 Egg Collection, Transport, Storage and Setting

Egg collection was daily (91 records); every two days (4); twice-daily (20) or weekly (1). Transport distances were short (95 records), medium (8) or long (11). Egg storage (including transport time) was <=3.5 days (21 records); <=7 days (64); <=10 days (13); <=14 days (13) or over 14 days (2). Eggs were routinely set weekly (80 records), twice weekly (16) and less frequently than weekly (15). Sanitation methods included alcohol wipes (1 record); the use of Ultraviolet light (10); fogging (11); was not practised (12); or several different methods were practised (17); or through washing (65).

4.4.5.2.3 Egg Candling

Routine Candling occurred at 7 days (8 records); 10 days (2); 11 days (8); 14 days (66); 18 days (2); 21 days (5); 28 days (1); and 30 days (2). Some operations did a second candling at 14 days (2); 21 days (1); 35 days (1) or 38 days (1). Weekly candling occurred for six records, and 3 respondents indicated that they did no candling. Candling towards the end of the incubation period was unlikely to be for the purpose of identifying infertility. Eggs thought to be infertile were either blown (87 records) or broken out (27).

4.4.6 Benchmark Results I

The following results are obtained from the complete data sample. Tables of results from data subsets are presented in the next results section (Benchmark Results II). These subsets constitute data relating to average performance over the last variable number of years, or data from full single seasons only for farms with more than 20 hens. Comparison of the overall results from the full data set with those presented from subsets of data is also made in the Section titled Benchmark Results II.

4.4.6.1 Infertility, Hatchability and Mortality

A summary of results for the reproductive statistics queried directly in the questionnaire is presented in Table 13. Values presented in the Table are the mean value, and values for minimum and maximum statistics recorded. The 25%, 50% (Median value) and 75% quantile values represent the value achieved by 25%, 50% or 75% of records which are ordered by increasing value. Comparison of mean values to those achieved in different quantiles indicates the type of distribution of values observed in the data, which was generally skewed.

Table 13: Reproductive performance achieved in farmed ostriches (complete data)

Percent	*N*	*Mean Value*	*Min. Value*	*25% Quantile*	*Median Value*	*75% Quantile*	*Max. value*
Infertile	110	20.3	0	10	20	25	75
Hatching	103	63.8	17.5	50	65	80	99
Mortality (1 week)	103	7.26	0	1	5	10	50
Mortality (1 month)	103	16.9	0	5	10	20	90
Mortality (3 months)	104	26.2	1	9.3	18.7	40	100

Infertile: percentage infertility of eggs incubated
Hatching: percentage of incubated eggs which hatch
Mortality (1 week): Percentage of hatched chicks which died in week one
Mortality (1 month): Percentage of hatched chicks which died in month one
Mortality (3 months): Percentage of hatched chicks which died in first three months

Mean values indicate that 20.3% of eggs on average are infertile and a further 15.9% of fertile eggs fail to hatch. Of further significance is an average loss of 26.2% of all hatched chicks by three months of age. For the average farmer, chick mortality is highest in the first month (16.9%) relative to the following two months (9.3%). Losses are also relatively high, on average, in the first week (7.26%). Given these results, currently for each chick surviving to 3 months of age, 2.1 eggs on average were incubated. If 81.5% of all eggs laid are incubated (as occurred in this sample) then the number of eggs laid per chick surviving to three months is closer to 2.6.

Clearly, however, significantly better performance can be achieved than is indicated by these average values. The best results for each performance indicator are 0% infertile, 99% of all eggs incubated hatching, with total chick mortality at 3 months of approximately 1% (not necessarily on the same farm). These figures equate to 1.25 eggs laid/chick surviving at three months. Perhaps more realistically, at least 50% of producers have achieved 20% or less infertile eggs, with 65% of incubated eggs hatching and a total chick mortality by three months of 18.7%. Farmers achieving these statistics would obtain 1 chick surviving to three months from every 2.3 eggs laid. Obtaining the top 25% of performance indicators would give 1 chick per 1.7 eggs laid. The top 10% of producers should be able to obtain 85% of incubated eggs hatching and 4% or less chick mortality at three months. This gives 1 chick per 1.5 eggs laid (still assuming a mean of 81.5% of all eggs incubated). However, the percentage of eggs incubated can be substantially higher than the 81.5% recorded in this sample of producers.

4.4.6.2 Derived Efficiencies of Chick Production

The overall efficiency of chick production can be represented by the percentage of chicks surviving to three months relative to the number of eggs which were actually incubated. This was calculated directly for respondents given information on hatching percentages, total chick mortality at three months, and the percentage of eggs which were incubated.

In Table 14, the calculated efficiencies of chick production achieved by farmers providing full information from a single complete season are presented. Relative to those presented in the above paragraph, these figures allow for real differences between farmers in the percentage of eggs which were incubated, and does not assume independence of each statistic. The percentage of eggs incubated ranged from 0 to 100%, with 50% of producers incubating in excess of 91% of all eggs laid. Mean values indicate a low efficiency of 47%, with 5.12 eggs incubated (or 7.7 laid) for every chick surviving to 3 months. Median values, however, indicate that 50% of farmers achieve a similar efficiency (i.e., 45%) with at least 1 chick at 3 months for every 2.11 eggs incubated, or every 2.91 eggs laid.

Table 14: Relative efficiency of chick production in farmed ostriches (complete data)

	N	Mean Value	Min. Value	25% Quantile	Median Value	75% Quantile	Max. value
% Chicks surviving[=]	75	47.0	0	28.1	45.4	68.3	95.0
Eggs incubated/chick	74	5.12	1.05	1.46	2.11	3.36	40
Eggs laid/chick	62	7.70	1.12	1.79	2.91	4.54	143

[=] all indicators relate to the number of chicks surviving at the end of 3 months
% chicks surviving (**csurv**) = hatching percentage (of eggs incubated) × (1 – chick mortality)
% eggs incubated (**pinc**) = no. eggs incubated / no. eggs laid
Eggs incubated/chick (**eincchck**) = 1 / **csurv**
Eggs laid/chick = **eincchck** / **pinc**

The top 25% of farmers achieved chicks surviving to 3 months from 68% of eggs incubated. This equates to 1.46 eggs incubated (or 1.79 eggs laid) per chick surviving. The top 10% of farmers achieved chicks surviving to 3 months from 79% of all eggs incubated, or 1 chick per 1.27 eggs incubated (1.45 eggs laid). The best producer achieved 1 chick at 3 months from every 1.05 eggs incubated (1.12 eggs laid), equivalent to a 95% efficiency.

4.4.6.3 Derived Productivity Measures

The efficiency of chick production from incubated eggs along with total egg production determines overall productivity. Several additional statistics could be calculated from questionnaire responses. These included: 1) Number of eggs laid per hen; 2) Percentage hatchability of fertile eggs; 3) Percentage of all eggs incubated; 4) The number of chicks hatched per hen, and 5) The number of chicks surviving per hen after 1 week, 1 month and 3 months.

Results for these measures are presented in Table 15. Mean values indicate that on average farmers could expect approximately 35 eggs laid/hen. From 28.2 eggs incubated 18.5 chicks hatch, with 15.3 chicks/hen surviving until three months. In comparison, median values indicated that 50% of farmers achieved at least 30.6 eggs/hen, resulting in 13.4 chicks hatched, but with only 9.2 chicks surviving to three months. In contrast, the top 25% of farmers achieved at least 21.2 chicks/hen, and the top 10% achieved at least 37.4 chicks per hen at three months.

Table 15: Productivity measures of farmed ostriches (complete data)

	N	Mean Value	Min. Value	25% Quantile	Median Value	75% Quantile	Max. value
Eggs laid / hen	88	34.8	0	21.3	30.6	45.1	118.3
Percentage incubated	92	81.5	0	74.5	89.7	98.3	100
% hatched of fertile	111	78.8	0	70.0	83.3	90.3	100
Chicks hatched / hen	92	18.5	0	7.2	13.4	25.3	94.6
Chicks/hen (1 week)	89	17.4	0	6.8	12.1	23.8	93.7
Chicks/hen (1 month)	88	15.9	0	5.8	10.4	21.9	93.7
Chicks/hen (3 months)	86	15.3	0	5.0	9.2	21.2	90.8

Eggs laid/hen (**nlaid**) = number of eggs laid / number of hens
% hatched of fertile (**phoff**) = percent hatched / (1 – percent infertile) of eggs incubated
Chicks hatched / hen (**chatch**) = no. eggs incubated × hatching percentage / number of hens
Chicks/hen (1 week) = **chatch** × (1- mortality at 1 week)
Chicks/hen (1 month) = **chatch** × (1- mortality at 1 month)
Chicks/hen (3 months) = **chatch** × (1- mortality at 3 months)

4.4.7 Benchmark Results II

In order to maximise use of the data received, information from all respondents, whether contributed as averages or from a single season, were used to benchmark performance (Benchmark Results I).

Statistically this is undesirable given that averages have different properties to single records, particularly with respect to the magnitude of errors and variation expected. In addition, it is likely that the size of ostrich production units will increase under commercial operation in future to take advantage of economies of scale, yet the majority of respondents were relatively small in scale of operation. Consequently, subsets of data were analysed to compare with results from the full data sample.

Benchmark statistics are presented for data relating to average performances only. These statistics in general will relate to farmers who have performance recorded over several seasons, with a number of hens, and with changes in flock age structures and management strategies over time.

Benchmark statistics are also presented for farmers providing results from 20+ hens only. As scale increases, greater use of colony breeding and increased variability between individual hens may contribute towards greater difficulties in optimising breeding structures, incubation and management practices. Additionally, time constraints may reduce the ability of producers to provide high managerial control at the individual bird level.

4.4.7.1 Benchmarks using averaged statistics

The number of respondents in this data set from each country was 12 from the USA, 2 from South Africa, and 1 each from Spain and New Zealand.

4.4.7.1.1 Infertility, Hatchability and Mortality

Compared to results from Table 13, mean values from farmer averages (Table 16) indicated lower levels of infertility (14.6 vs 20.3) and a corresponding increase in hatching percentages (71.9 vs 63.8). Similar levels of chick mortality occurred in week 1 (7.35% vs 7.26%) and in total by three months (27.8 vs 26.2%). Slightly higher chick losses occurred by 1 month (19.9 vs 16.9).

The distribution of values for the above traits was reduced, particularly with respect to values at the top end of the measurement scales. This indicates that extremely high (or low) values for reproductive performance indicators did not occur repeatedly for these farmers. This is of significance for infertility and chick mortality figures, where high values are undesirable. For hatching percentage the opposite trend was evident. That is, the minimum value was substantially higher than was apparent from Table 13 (56 vs 17.5%). Therefore, very poor hatchability results did not occur with high frequency.

Table 16: Reproductive performance achieved in farmed ostriches (averages across seasons)

Percent	*N*	*Mean Value*	*Min. Value*	*25% Quantile*	*Median Value*	*75% Quantile*	*Max. value*
Infertile	16	14.6	2	10	15	20	25
Hatching	16	71.9	56	63.3	73.5	75.8	93.1
Mortality (1 week)	16	7.35	0	2	5	12.5	25
Mortality (1 month)	16	19.9	3	6	15.3	27.5	50
Mortality (3 months)	16	27.8	3	10	23.5	50	60

See Table 13 for trait definitions

4.4.7.1.2 Derived Efficiencies of Chick Production

Compared to results from Table 14, mean values from farmer averages (Table 17) indicated that the relative efficiency of chick production was higher for farmers who provided average figures. The percentage of chicks surviving to three months (relative to the number of eggs incubated) was 52.3% compared to 47%, with less than half the number of eggs incubated per surviving chick (2.19 vs 5.12) or laid (4.03 vs 7.70).

The distribution of values for these traits was also reduced. In particular, minimum values for the percentage of chicks surviving was increased from 0 to 27.9%. Substantial reductions in maximum values for the number of eggs incubated or laid per chick surviving were also evident.

Table 17: Relative efficiency of chick production in farmed ostriches (producer averages)

	N	*Mean Value*	*Min. Value*	*25% Quantile*	*Median Value*	*75% Quantile*	*Max. value*
% Chicks surviving	16	52.3	27.9	33.7	49.3	68.2	90.3
Eggs incubated/chick	16	2.19	1.11	1.47	2.03	2.96	3.58
Eggs laid/chick	9	4.03	1.45	1.86	3.42	3.46	13.8

See Table 14 for trait definitions

4.4.7.1.3 Derived Productivity Measures

Compared to results from Table 15, mean values from farmer averages indicated that there was a reduction in the percentage of eggs incubated (74.2 vs 81.5) and substantial reductions in the number of chicks hatched and surviving per hen (Table 18). Of note, chick production per hen could be calculated for four records only (ie 25% only of the sample).

As occurred previously, the distribution of productivity measures was decreased. Minimum values were increased particularly with respect to the average number of eggs laid/hen (27.8 vs 0), the percentage of eggs incubated (10 vs 0) and the % hatchability of fertile eggs (68.3 vs 0). Maximum values were decreased substantially for the average number of eggs laid per hen (50 vs 118.3), and the number of chicks produced per hen (eg. 15 vs 90.8 at three months). Median values were similar for these traits.

Table 18: Productivity measures for farmed ostriches (producer averages)

	N	*Mean Value*	*Min. Value*	*25% Quantile*	*Median Value*	*75% Quantile*	*Max. value*
Eggs laid / hen	5	36.2	27.8	28.6	35	40	50
Percentage incubated	9	74.2	10	60	83	90	100
% hatched of fertile	16	83.4	68.3	78.2	83.3	89.1	95
Chicks hatched / hen	4	13.7	2.4	6.63	15.01	20.8	22.5
Chicks/hen (1 week)	4	12.5	2.4	6.1	13.0	18.8	21.3
Chicks/hen (1 month)	4	9.8	2.2	5.8	10.9	13.7	15.1
Chicks/hen (3 months)	4	8.82	2.1	5.1	9.1	12.6	15.0

See Table 15 for trait definitions

4.4.7.2 Benchmarks for farmers with > 20 hens and results from a single season

The number of respondents from each country in this data set was USA (5), Australia (4), Spain and Brazil (2 each), and 1 respondent each from Belgium, China, Denmark, Italy, Mexico, Saudi Arabia and South Africa.

4.4.7.2.1 Infertility, Hatchability and Mortality

Compared to results from Table 13, mean values from Table 19 indicate higher levels of infertility (26.1 vs 20.3), a consistent reduction in hatchability (57.1 vs 63.8) and slightly reduced levels of chick mortality over all time periods.

Minimum values for infertility (4 vs 0) and hatchability (21 vs 17.5) were slightly higher, but identical minimums occurred for chick mortality figures. Maximum values were reduced for all traits, particularly with respect to chick mortality. Median values indicate that although 50% of farmers with > 20 hens achieved similar performances to the complete sample with respect to infertility and chick survival, hatching percentages were reduced.

Table 19: Reproductive performance achieved in farmed ostriches (producers with > 20 hens)

Percent	*N*	*Mean Value*	*Min. Value*	*25% Quantile*	*Median Value*	*75% Quantile*	*Max. value*
Infertile	26	26.1	4	20	21.9	30	70
Hatching	28	57.1	21	41	58.3	75	93
Mortality (1 week)	26	5.03	0	1	2.5	7.5	30
Mortality (1 month)	26	13.8	0	5	12.5	20	40
Mortality (3 months)	25	24.6	1	12	19	40	67

See Table 13 for trait definitions

4.4.7.2.2 Derived Efficiencies of Chick production

Relative to results from Table 14, mean values from Table 20 show a reduction (43.9 vs 47.0) in the efficiency of chick production. The number of eggs incubated (3.08 vs 5.12) or laid (3.67 vs 7.70) per chick produced at three months is also lower, probably as a result of substantial reductions in the maximum recorded for these traits.

Although the minimum percentage of chicks surviving increased (12.5 vs 0), other quantile values showed substantial reductions in the efficiencies of chick production for most farmers with > 20 hens. 50% of farmers achieved an efficiency of 34.9% compared to 45.4% from the complete sample. However, the number of eggs incubated per chick produced were similar within the 25 to 75% quantile regions.

Table 20: Relative efficiency of chick production in farmed ostriches (producers with >20 hens)

	N	*Mean Value*	*Min. Value*	*25% Quantile*	*Median Value*	*75% Quantile*	*Max. value*
% Chicks surviving	25	43.9	12.5	28.1	34.9	60.1	91.1
Eggs incubated/chick	25	3.08	1.1	1.66	2.86	3.56	8.02
Eggs laid/chick	22	3.67	1.35	2.29	3.22	4.89	9.08

See Table 14 for trait definitions

4.4.7.2.3 Derived Productivity Measures

Compared to results from Table 15, mean values from Table 21 indicate reductions in the average number of eggs/hen (33.3 vs 34.6), the percentage hatchability of fertile eggs (76.4 vs 78.8), and the number of chicks produced per hen (eg. 12 vs 15.2 at three months) for producers with > 20 hens. These reductions were predominantly the result of substantial decreases in maximum values for these traits, given that values for intermediate quantiles were similar to those in Table 15. A significant increase in the percent of eggs incubated also occurred, with substantial increases in values at the minimum and other quantile regions.

Median values indicate that 50% of farmers with > 20 hens had similar egg production and incubated the same percentage of eggs as 50% of farmers from the complete sample. However, substantial reductions in the hatchability of fertile eggs occurred (74.7 vs 83.3) compared to the complete sample of farmers.

The maximum value for the total number of chicks produced per hen was substantially reduced for farmers with > 20 hens (eg. 46.1 vs 90.8 chicks/hen at three months) compared to the complete sample.

Table 21: Productivity measures for farmed ostriches (producers with > 20 hens)

	N	*Mean Value*	*Min. Value*	*25% Quantile*	*Median Value*	*75% Quantile*	*Max. value*
Eggs laid / hen	24	33.3	2.98	23.6	29.3	44.7	65.1
Percent incubated	24	87.2	33.3	85.0	90.5	97.0	100
% hatched of fertile	27	76.4	35.6	68.5	74.7	93.7	98.7
Chicks hatched / hen	26	15.5	0.25	7.7	11.3	21	49.3
Chicks/hen (1 week)	25	15.0	0.18	7.6	10.3	18.5	47.8
Chicks/hen (1 month)	24	13.4	0.15	5.8	9.4	16.9	46.6
Chicks/hen (3 months)	24	12.0	0.13	4.6	7.2	16.1	46.1

See Table 15 for trait definitions

4.4.8 Variables Associated with Performance

The variation in results for Benchmark figures from different samples of data suggests that there are factors contributing to variation in the performance indicators examined. Known factors which could contribute to this observed variation in performance included:

- Country and year of production
- Managerial and recording experience
- The scale of operation
- Occupation of the manager
- Enterprise operating
- Length of season
- Breeding structure
- Average flock age
- Egg collection and Incubation procedures

This information was requested from all respondents. SAS GLM procedures were used to identify whether these factors were associated with some of the observed variation in performance indicators. Results of significant factors for each performance indicator (on a qualitative basis only) are presented below.

4.4.8.1 Percentage of Infertile Eggs

Scale of operation affected the percent of infertile eggs recorded. Operations with 1-10 hens, 11-30 hens and 31-50 hens had similar percentages of infertile eggs. An increase in the percentage of infertile eggs occurred for the 51-100 hen class. For operations with more than 100 hens results were variable.

4.4.8.2 Hatching Percentage of Incubated Eggs

Scale of operation was associated with variation in hatching percentages. Operations with 1-10 hens and 11-30 hens had similar hatching percentages. Lower hatching percentages were indicated for the 31-50 hens and 51-100 hen classes. For operations with more than 100 hens results were largely uninformative due to large standard errors.

4.4.8.3 Percentage Chick Mortality at 1 Week

Country of production was associated with mortality at 1 week. Many factors within country will contribute to this association, and there is little to be gained from making comparisons between countries specifically.

4.4.8.4 Percentage Mortality at 1 Month

The main occupation of the respondent was associated with the percentage chick mortality at 1 month. Relative to all other farming occupations (ie, ostrich farmer, cropping farmer, or farmers with extensive or intensive livestock enterprises), producers listing NON-Agricultural occupations as their main occupation had substantially higher levels of chick mortality at 1 month.

There was a suggestion that increasing frequency of setting was also associated with increased chick mortality at 1 month. Compared to the most common practice of weekly setting, setting less frequently was associated with lower chick mortality, whereas setting twice weekly was associated with higher chick mortality.

4.4.8.5 Percentage Mortality at 3 Months

The level of chick mortality at 3 months was associated with year of production and the main occupation of the producer.

Year by itself is relatively uninformative, as many influences within a year will contribute to results. As with results for chick mortality at 1 month, producers with NON-Agricultural occupations had substantially higher levels of chick mortality.

4.4.8.6 Relative Efficiency of Chick Production

No consistently significant factors were identified which influenced the total number of chicks surviving until three months of age.

4.4.8.7 Number of Eggs Incubated or Laid per Chick Surviving (at 3 months)

No consistently significant factors were identified which influenced the number of eggs incubated per chick, or which were associated with variation in the number of eggs laid per chick surviving until three months.

4.4.8.8 Average number of eggs laid per hen

Country of production was associated with variation in the average number of eggs laid per hen. As above, no direct comparison will be made.

4.4.8.9 The Percentage of Eggs Incubated

There was a suggestion that length of storage was associated with differences in the percentage of eggs incubated. Relative to storage of <=7 days, storage of 8 or more days was associated with reductions in the percentage of eggs which were incubated.

4.4.8.10 Percentage Hatchability of Fertile Eggs

Level of experience was associated with differences in the hatchability of fertile eggs. Relative to farmers with <1 year of experience, or 3 or more years of experience, there was a tendency for those with 1-2 years experience to have a reduced hatchability of fertile eggs.

4.4.8.11 Chicks Hatched per Hen, and Surviving to 1 Week, 1 Month or Three Months

Country was the only factor consistently associated with the actual number of chicks hatched and surviving at 1 week, 1 month and three months. Countries are not directly compared for these traits given that actual ranking tends to be influenced by the sample of producers used in the analysis.

4.5 Discussion

4.5.1 Profile of Respondents

The questionnaire was open to all producers in all countries, but was only answered by those producers with access to the Internet, and generally subscribing to electronic ostrich media. The exceptions were in South Africa and Australia where producers were notified of the questionnaire through other sources also. However, of the data retained for analysis, approximately 50% of respondents were from America, ~50% operated on a small scale (eg. respondents with < 10 hens), ~38% obtained their main income from NON-Agricultural employment, and ~75% had between 1-5 years experience in ostrich production. The majority (~80%) of respondents operated a complete enterprise consisting of their own breeders, on farm incubation and chick raising. In most cases only recent entrants to the Industry (ie those with <1 years experience) had performance recorded continuously, whereas many other more experienced producers had actually recorded for significantly fewer years than they had been in operation. This type of profile would appear consistent with the development of a new Industry, regardless of country of production. Benchmark results are thus probably most representative for a producer operating in a developing Industry.

As noted previously, a large proportion of the original respondents did not provide performance information. This suggests that routine performance recording is currently not widespread in ostrich production. A number of respondents also indicated that they had not incubated over the previous year or two due to poor market prospects, and several US respondents indicated that they were going out of the ostrich business. In contrast, respondents from other countries where ostriches have not traditionally been farmed extensively indicated that they were investigating setting up new ostrich breeding ventures. Thus, worldwide ostrich production appears in a state of flux. Comments made by a number of respondents indicate that basic production and marketing problems still need to be overcome in several countries.

With respect to larger scale operations, three respondents from Australia, China and the USA had more than 200 hens. Given the relative youth of the Ostrich Industries in these countries, these large flocks also contained a high proportion of young breeders. It is well known that the majority of larger-scale operations exist in South Africa, generally with relatively mature flocks of breeders.

4.5.2 Benchmark Results

It is clear from the Benchmark results presented that at an Industry level substantial improvement in aspects of reproductive performance, and therefore productivity, are possible over what is achieved currently. A wide variation in actual performances achieved is apparent, even within the same country and experience levels. Current reproductive performance is very poor for a large proportion of producers relative to what is achieved by the best producers.

Results for different performance indicators are discussed separately below. It is important to note that results are probably more accurate for requested information than for some of the derived performance indicators. This is because derived indicators are generally based on multiplicative operations, which may magnify any errors in the original data. Further, some caution is necessary in the comparison of Benchmark I to Benchmark II results. The majority of respondents with data from a single full season contribute to results for all performance indicators in Benchmark I. However, in Benchmark II results substantial reductions occur in the number of producers providing data, particularly for some traits. Finally, results for producers with more than 20 hens (in Benchmark 2) are a subset of producers in the complete data set. Therefore, these data samples are not independent.

4.5.2.1 Infertility, Hatchability and Chick Mortality

Mean infertility from the complete data set is 20.3%. This is substantially lower than that indicated by producers with > 20 hens (26.1%), but significantly higher than that indicated for producers who have operated over several seasons (14.6%). In comparison, average infertility calculated from statistics presented by Deeming and Ar (1999) was 32.3%, and from the LKADC data was between 22-24.5%. Relative to the full sample of respondents, producers providing averages over several years generally had more experience and older breeding flocks. Producers with > 20 hens also had more experience (and their main occupation was ostrich farming) but operated with a similar flock age, and with relatively higher use of colony breeding structures. Break out frequency was >50% in this sample, which could also suggest that the level of infertility was overestimated in the complete sample where eggs were predominantly blown. Deeming and Ar (1999) suggested that infertility based on candling at 14 days needed to be confirmed by opening eggs to check for early embryonic development (and therefore fertility).

Mean hatching percentages from the complete data is 63.8%. This is lower than that indicated for producers who have operated over several seasons (71.9%) and higher than that achieved by producers with > 20 hens (57.1%). Results averaged from Deeming and Ar (1999) are much lower at 42.9%, and are approximately 42% for the LKADC data over eight years of production. Much of the difference between results from the complete data sample and producers with >20 hens is consistent with the above-mentioned changes in infertility levels (ie, a 5.8% increase in infertility with a 6.7% reduction in hatching percentages). However, results from producer averages would suggest that improved hatching percentages are not solely associated with improved fertility levels (ie, a 5.7% increase in fertility with and 8.1% increase in hatchability). Improved hatchability probably also relates to increasing experience with incubation and improving facilities etc. over time.

Results from a range of studies summarised in Deeming and Ar (1999) predominantly reflect infertility and hatchability of eggs incubated in South Africa or African countries, eggs imported from African countries to Great Britain for incubation, eggs produced from experimental flocks, and/or results from very young flocks in countries which had very new and small industries at the time of performance recording. It is speculated that data collected under these conditions are not likely to represent reproductive performance achieved by respondents with the above profile. Moreover, relatively few flocks contributed to the summary of Deeming and Ar (1999), so it is also unclear how representative results are of overall performance achieved by producers in several countries prior to 1999.

Data from the current study would suggest that some improvement has occurred in overall fertility and hatchability world-wide, although the profile of respondents is very different between studies which reduces the validity of making this comparison. Further, data from this study indicates that high fertility (up to 100%) does occur infrequently in small breeding groups, but averages across breeding groups and seasons will generally be significantly lower. Hatchability of fertile eggs may also be significantly higher than the top value of 70% presented in the summary by Deeming and Ar (1999). Given the substantial difference between hatchability results from this study, and the summary produced by Deeming and Ar (1999), it can also be speculated that hatchability results from this study may be biased upwards by some producers reporting hatchability relative to fertile eggs. However, the amount of bias estimated was <3% under prevailing levels of infertility, giving a conservative estimate of hatchability at around 60%.

Means for chick mortality at 1 week, 1 month and 3 months were 7.26, 16.9 and 26.2% from the entire sample. In comparison, means were slightly lower for farmers with > 20 hens (5.03, 13.8 and 24.6%) and slightly higher for farmers presenting average figures (7.35, 19.9 and 27.8%). Verwoed et al. (1999) indicated that mortality at 10 days should be less than 10% for good quality chicks. These authors defined quality in terms of weight and assistance required at hatching, with chicks of low weight or requiring assistance at hatching being considered as poor quality chicks. Little is known of incubation or management strategies on farms in this study with respect to hatching and chick rearing, so it is difficult to speculate exactly what caused differences in chick mortality between producers. However, some producers with very low chick mortality indicated that they did not assist chicks to hatch and/or had improved breeder nutrition. Some with very high mortality indicated retrospective identification of disease organisms, and adverse weather conditions during rearing periods. Systematic studies of chick mortality may better identify causes of variation exhibited between farms.

The majority of producers providing data showed a declining rate of mortality with increasing chick age. Given the above figures, in week 1, 7.26% of hatched chicks died. Yet in the time period between week 1 and the end of 1 month, mortality occurred at less than 3% per week on average. After 1 month, mortality was around 1% per week on average. Thus, losses in the first week after hatch would appear the most significant currently. However, follow on effects between time periods are unknown, and it is the cumulative mortality that is economically important to producers.

Overall, mean values are not necessarily representative of what will be achieved by a large proportion of producers, because mean values may be significantly altered by extremes in performance indicators (in one direction) of relatively few farmers. Therefore, means for infertility are likely to substantially increased by a few farms with very poor fertility, and similarly hatchability will be biased downwards by results from a few farmers with very poor hatchability. Similarly, very high chick mortality is seen more frequently than extremely low mortality. In some cases, respondents with very extreme values indicated that their results reflected an unusual event or circumstance. For example, severe obesity and mate incompatibility may contribute to excessively low fertility, contamination and pathogens may reduce hatching successes, and unexpected storms may contribute to increased chick mortality, and so on. At an individual farm level these can be considered temporary influences, but at an Industry level the frequency of such comments reflect common problems for several producers. Thus, although these extreme results are not necessarily typical for a particular farm (and generally will not occur repeatedly under good management), the same types of causal factors were indicated by a number of respondents in several countries. Thus, such data was retained for analyses, but it remains important to examine what a large proportion of farmers achieve under the USUAL circumstances.

Examination of the median values for the total sample indicates that 50% of producers reported 20% or less infertility, 65% or higher hatchability, and 5, 10 and 18.7% chick mortality by 1 week, 1month or 3 months. The corresponding values from producers presenting average values was <=15% infertility, =>73.5% hatching percentages, and 5, 15.3 and 23.5% chick mortality. Thus, although improvements in fertility and hatchability are apparent for a large proportion of this group, chick mortality after 1 week appears to have increased. Corresponding figures for 50% of producers with >20 hens were 21.9% infertility, 58.3% hatchability, and 2.5, 12.5 and 19% chick mortality. These figures would suggest that although hatchability is reduced for producers with larger hen numbers, increased infertility is less problematical than was suggested by mean values. It is possible that with a larger numbers of hens, optimising egg handling and incubation management may be more difficult, resulting in reduced incubation success and hatching percentages.

The top 10% of records from the complete sample had 5% or less infertility, 85% or more hatchability, and 0, 2 and 4% chick mortality at 1 week, 1 month or three months. From average figures, the best 10% of records indicated infertility levels of 8.5% or less, hatching percentages of 85%, and 0, 5 and 6% chick mortality over the above time periods. The top 10% of single season results for producers with > 20 hens also had higher infertility (13%), but with similar (84%) hatching percentages, and corresponding chick mortalities of 0, 1 and 4%. Similar hatching percentages for each group despite apparently different infertility levels shows that a combination of factors is contributing towards differences in overall hatching percentages. These factors firstly include accuracy of determining infertility compared to early embryonic mortality (eg. break out vs blown). Other factors include flock and incubation management and infrastructure, along with factors such as flock age structure.

The results indicate that although less than 1 chick produced per two eggs incubated is often considered normal, the top 10% of farmers should be able to achieve better than 1 chick surviving to three months for every 1.25 eggs incubated. This is examined more closely in the following section.

4.5.2.2 Derived Efficiencies of Chick Production

As noted previously, the efficiency of chick production is considered in terms of the percentage of chicks surviving until three months from each egg incubated, or the number of eggs incubated or laid per chick surviving at three months. From the complete data sample, the mean efficiency of chick production was a very poor 47%, with on average 5.12 eggs incubated and 7.7 eggs laid per chick surviving until three months. Experienced farmers providing average figures had an improved efficiency of chick production, with corresponding mean values of 52.3%, and 2.19 or 4.03 eggs incubated or laid per chick. Mean results for farmers with > 20 hens indicated a lower efficiency (43.9%) for incubated eggs, but also fewer eggs incubated (3.08) or laid (3.67) per chick. These results are consistent with the differences in fertility, mortality and hatchability noted above, but also with the percentage of eggs which are incubated. Producers with > 20 hens were ostrich farmers, and incubated a high percentage of eggs produced. Producers providing averages were a similar profile to the complete data sample, but tended to have lower incubation percentages.

As above, median values may be more representative of what is most frequently achieved. Median values from the complete data indicate that 50% of farmers achieved an efficiency of 45.4%, but with 2.11 eggs or less incubated and 2.91 eggs laid per chick at three months. Thus, the means for eggs/chick were substantially inflated by infrequent high values, although efficiency of chick production was only slightly overestimated. Corresponding values for farmers providing averages were 49.3%, and 2.03 eggs incubated or 3.42 eggs laid/chick, suggesting improved efficiencies post setting. Median values for producers with > 20 hens showed substantial reductions in efficiency for this group overall. That is, even though means for the two groups were similar, the percentage of chicks surviving to 3 months (relative to eggs incubated) was only 34% or less for 50% of farmers. Very high efficiencies for some farmers contributed to the mean of 43.9% for this group.

In stark contrast, the top 10% of records from the complete sample indicated that relative efficiencies could be 79% or more, or at least 1 chick produced per 1.27 eggs incubated (or 1.45 eggs laid). This is very close to what was suggested above as a probable outcome for the top 10 % of farmers from all data samples, given no negative interactions between different performance indicators. In comparison, from average figures the efficiency of chick production was 76.1%, or 1.31 eggs incubated (1.45 eggs laid) per chick surviving at three months for the top 10% of producers. Corresponding values for farmers with > 20 hens were 78.5%, and 1.27 eggs incubated (1.53 eggs laid) per chick.

Thus, it would appear that high performance in fertility, hatchability and chick mortality can occur concurrently. With the exception of the number of eggs laid per chick, similar improvements in these indicators occurred in data samples across different percentages of eggs incubated.

4.5.2.3 Derived Productivity Measures

The above measures have a high bearing on the costs of producing each chick, particularly with respect to the fixed overheads of maintaining a breeding flock, along with incubation and chick rearing facilities. However, in addition to improving relative efficiencies in chick production, it is also necessary to consider aspects of productivity. There is little value in achieving high efficiencies without also achieving a high egg output per hen, as the actual number of chicks produced (and surviving) will ultimately determine profits from slaughter birds.

Mean values from the complete sample indicated on average that producers could expect a mean of 35 eggs laid/hen and 78.8% hatchability of fertile eggs. These figures translate into 18.4 chicks hatched per hen, with 15.2 chicks per hen surviving until three months. However, means from producer averages or for producers with > 20 hens suggest that although the average number of eggs laid was similar between these groups, the number of chicks per hen at three months was lower than 15.2. Farmers with more than 20 hens produced on average only 12 chicks per hen. However, only four producers providing average figures contributed to results for chicks produced and surviving per hen, so results may not be representative of this group.

Egg production reported in other studies is highly variable, and comparisons are generally complicated by variation in the length of the breeding season. Alternative measures to account for variation in season length have also been proposed, such as egg production performance (EPP, defined by van Schalkwyk *et al.*, 1996) or eggs produced per month of breeding exposure (More, 1997), but sufficient information was not available from this study to calculate these measures. Relative to means for egg production of 50 (Smith *et al.*, 1995) and 55.5 (van Schalkwyk *et al.*, 1996) reported in South Africa (8-9 months breeding), an average of 35 eggs/hen is very low.

However, several respondents had young unproductive hens and low mean flock ages. Egg production is known to improve significantly with hen age (see section 3.2.2).

Median values from the complete sample indicate that 50% of producers obtained only 30.6 eggs and 9.2 chicks per hen. Thus, poorer performance than is indicated by the above mean values was more commonly achieved. In comparison, producers with > 20 hens had similar median values for the number of eggs laid/hen (29.3), but almost 2 chicks/hen less at three months. This result was probably associated with the poorer hatchability of fertile eggs. Larger operations are generally associated with larger incubation facilities, but have less opportunity to optimise incubation procedures to allow for substantial variability between hens in their egg characteristics. Further, other issues such as egg contamination may be important, although such factors cannot be illustrated in this study.

In contrast, the top 10% of results from the complete data indicated that hens averaged 62 or more eggs, but were still producing only 39.7 chicks/hen at three months. Thus, high productivity was heavily offset by poor efficiency thereafter for the majority of producers with highly productive (often mature) flocks. This outcome is disappointing, but to be expected given the very poor efficiencies of chick production shown by many producers overall. On the other hand, the top 5% of producers achieved an average of 54.5 chicks per hen. Thus, high chick numbers per hen are achievable, but only where both productivity and incubation efficiency are high, and combined with good chick survival. High egg production per hen is related to factors including age, management, genetics and nutrition, the relative influence of which cannot be illustrated from information provided in the questionnaire.

4.5.3 Variables Associated with Performance

For a number of known factors, very little variation between respondents occurred in the answers given, reducing the power to examine whether there were any significant associations between particular response categories and the reproductive performance achieved. Therefore, any failure to demonstrate that specific factors had a significant impact on performance should not be constituted as hard evidence that such an association does not exist. This is particularly the case given the relatively small number of producers who contributed data.

For any given trait, the only factors reported to be significantly associated with trait outcomes were those that showed a consistent effect over a range of models and data sub-samples. However, additional care remains to be exercised in attributing a causative, rather than associative, nature to these factors. For example, other unknown factors (the ‘true’ causative factors) may be confounded with the known factor that by itself has no direct bearing on performance achieved.

Keeping the above in mind, significant differences in the performance between countries only occurred consistently for chick mortality at 1 week, and the average number of eggs laid per hen. Therefore, although the number of chicks hatched and surviving per hen also varied between countries, this was apparently not due to differences in overall fertility or the efficiency of incubation. There is little value in ranking countries on productivity, given that relatively few producers represented each country.

Year of production also significantly affected chick mortality at three months. Some respondents cited seasonal factors, such as adverse weather conditions, to have influenced mortality after 1 month. The significance of this factor is thus consistent with previous results. However, in the absence of further information, the significance of year alone provides little information towards explaining differences in chick survival.

Scale of operation was associated with variation in the percent of infertile eggs and hatching percentages. Similar percentages of infertile eggs were reported for operations with 50 hens or less, whereas between 50-100 hens had higher levels of infertility, and results for larger operations were variable. Reductions in hatching percentages with increasing scale did not solely correspond with declining fertility. Hatching percentages were similar for operations with 1-10 or 11-30 hens, but decreased for 31-50 and 51-100 hens, and again were variable for larger operations.

Increasing scale of operation was generally associated with greater use of colony breeding structures (as opposed to use of pairs, trios and quads) and increasing total incubation capacity or incubator size. In addition, for some producers increasing scale was also associated with the use of a high proportion of young birds in the breeding flock. Colony breeding might be associated with reduced fertility, perhaps due to fighting between males, immaturity in some cases, and an inability to identify and cull males with fertility problems. Although no conclusive evidence for fertility differences between breeding structures has been published, anecdotal evidence for improved fertility in smaller groups sizes has been put forward (Deeming, 1996), which results from this study support generally. Although the effects of breeding flock age have not yet been published, results from South African data indicate that the average difference between 2 year old and mature hens is over 20 eggs (see Figure 3). Therefore, a comparison of different flock structures may also be influenced by age differences if different aged hens are placed in different types of breeding groups.

As mentioned previously, variability between characteristics of eggs of different hens under incubation also may be high, and increasing flock size may therefore increase the difficulty of optimising incubation management for all eggs, thereby reducing hatchability. Blood et al (1998) reported a high repeatability of evaporative water loss within pairs, which is consistent with highly repeatable water loss under incubation for individual hens. Further, an optimum water loss is required to maximise hatchability. The significance of variation between hens in egg characteristics on hatchability will be increased where a single large multi-phase incubator is used, as was indicated to occur generally in practice with an increasing scale of operation. The comparison of benchmark results for the entire data set with results from operators with > 20 hens supports a loss of incubation efficiency (over that resulting from changes in infertility) with increasing scale of operation.

Although not a significant factor for chick mortality at one week, the main occupation of the respondent was significantly associated with the percentage of chick mortality at 1 month and three months. Respondents with NON-Agricultural main occupations reported substantially higher levels of chick mortality after 1 week. It can only be speculated how this association has occurred, but it is possibly related to differences between Agricultural and NON-Agricultural respondents in facilities they have available, their experience with raising livestock, overall stockmanship and time available to dedicate towards chick rearing.

Mortality at 1 month also appeared to be influenced by frequency of setting, although this association varied in significance across data samples. There was a tendency for chick mortality by 1 month to be higher where eggs were set very frequently (eg. twice per week), compared to setting weekly or even less frequently than weekly. This association may be related to differences in chick quality at hatching (due to egg composition differences and subsequent chick development during incubation), and changes in batch rearing strategies for different setting frequencies. It is commonly accepted that eggs should not be stored for too long before setting to maximise hatchability. However, no work has been conducted to establish whether delayed setting may influence chick mortality after hatch. Nevertheless, the profile of frequent setters included small breeding flock size, low incubation capacities and relatively little experience, the latter of which particularly may be consistent with elevated chick mortality.

The percentage of eggs that were incubated was negatively associated with the length of the average storage period. Producers with longer storage periods tended to incubate proportionally less eggs. Therefore, in practice the impact of length of storage on traits such as hatchability may be influenced by choices made and therefore characteristics of eggs which were incubated.

Finally, differences in hatchability of fertile eggs were associated with the level of experience reported by respondents. Reduced hatchability of fertile eggs was apparent for producers with 1-2 year's experience, relative to those in other experience classes. Improved incubation management may be expected with increasing experience, as was evident in this study. However, producers with < 1 years experience (but having recorded one complete season of performance) also had improved hatchability, which is probably not to be expected. The profile of these new producers generally included new low capacity incubators, few breeders in paired or trio structures, and possibly better control of incubation and breeder management (as suggested by the choice to performance record immediately upon the commencement of production). Thus, it can be speculated that relative to those in business over 2-3 years, very new producers have information and facilities available to them which have improved their prospects for incubation efficiency. Other issues may include reduced build up of disease organisms and better breeder flock health in young flocks which have no produced previously.

4.6 Conclusions

The most obvious conclusions that can be drawn from the survey results are that reproductive performance in farmed ostriches remains highly variable world-wide, and that a large proportion of producers achieve very poor results both in terms of the efficiency of chick production and overall productivity. In particular, it would appear that for the majority of producers achieving high egg production per hen, this advantage is largely negated by a poor efficiency of chick production from eggs incubated. Consequently, there remains a need to look for ways to improve incubation efficiency and hatchability, and reduce early chick mortality, particularly under increasing scales of operation.

With respect to the profile of respondents to this study, they are atypical of producers in other commercial livestock industries in that many had very small breeding flocks, were involved in NON-Agricultural main occupations, and a number of respondents had relatively little experience. However, this profile is probably typical of producers in new or novel Industries, and is considered representative currently of the average producer outside South Africa. Most notable was the questionnaires' failure to attract data from many experienced producers in South Africa, where the history of ostrich farming is much longer. However, in part this may be due to lack of reliable access to the Internet in South Africa, and may also be due to the effects of recent changes in ostrich farming in this country. Ostrich production re-emerged as a new Industry in many other countries in the late 1980's or early 1990', yet few producers responded who had operated over this period of time. This would suggest that there are very few experienced producers who remain in the Industry, yet there are new producers (and new countries) who have commenced ostrich production in recent years. Further, as is evidenced by low average flock ages in this study, new producers have tended to build up their flocks from young, unproven breeders, rather than potentially pay higher prices for mature birds.

Lack of experienced producers (and relatively young flocks) is consistent with the relatively poor productivity achieved by a large proportion of respondents in this study. High variability is also consistent with a range in the knowledge base (steep learning curves), facilities, macro and micro-environments (including country, season and flock), and individual bird effects. In a recent survey by Stables (Iberstruz, 2000) producers were asked to rank the importance of factors influencing their success (or otherwise) in their Ostrich Industry. Respondents in several countries indicated that lack of markets and infrastructure for slaughter and tanning were major limiting factors inhibiting Industry development. In contrast, other respondents cited production problems as of major importance. The relative importance of these issues probably is a matter of perspective, where those with what they perceive as adequate production relative to their peers see marketing as an important issue. Several experienced respondents to this survey also indicated that they were going out of business, or not producing slaughter birds currently (but maintaining breeders), due to lack of markets/infrastructure. Improved Industry stability and viability may contribute to better productivity if it results in improving overall experience levels within the Industry, and production with more mature flocks. However, a low efficiency of chick production from incubated eggs remains a problem even for many experienced producers.

Benchmark figures indicate that although producers in many countries accept the standard of one chick hatched per two eggs incubated as ‘normal’, substantially better performance than this may be achieved. Across all data samples examined, the top 10% of producers achieved hatchability for eggs incubated of 85%. This can only occur in the presence of high fertility, good flock health, and optimal incubation strategies. Given results from this study, a hatchability of 85% will probably not be achieved by inexperienced producers with young flocks, or those operating with large colonies, or undergoing significant flock expansion or disruption, under current management practices. Similarly, the success of facilities involved in incubating other producers eggs will be limited by the fertility levels of the eggs they receive, so the appropriate performance indicator is hatchability of fertile eggs. In excess of 85% hatchability of fertile eggs should be achieved at least over the main part of the breeding season under optimal conditions. Some specialist incubation facilities achieve these results or better (Hallamore, personal communication). Producers with currently poor fertility should also aim to achieve hatchability for fertile eggs in excess of 85%. However, some caution should be exerted in recommending maximum hatchability, if this compromises chick quality and subsequent survival.

As noted above, a high hatchability for incubated eggs is dependent on initially high fertility levels. Respondents achieving high levels of fertility (eg. >90%) were experienced producers and operated generally with small mature flocks (particularly males) in relatively small breeding groups (ratios of 4:1 or less, and no colony with more than 10 hens). Moreover, one significantly larger scale (ie more than 250 hens, mean age of males 6.5 years) respondent also achieved infertility of <5% for small to medium colonies with ratios up to 4:1. Thus, it would appear possible to achieve excellent fertility levels even with larger scale operations, and at sex ratios higher than is commonly used. More research should be directed towards the influence of different breeding structures, sex ratios and group sizes on egg fertility, particularly with increasing scale of operation. Further, should large colony breeding increase in popularity with increasing scale of production, as has occurred in South Africa, better indicators of male fertility may be required to assess and cull less fertile males.

Benchmark figures also indicate that chick mortality can be substantially reduced from what is commonly achieved. Although 50% of respondents reported mortality at three months of <19%, 10% of producers achieved mortality of <5% in the corresponding time period. Producers with low chick mortality were relatively experienced, frequently listed their main occupation as ostrich farmer, operated flocks with <50 hens, practised egg sanitation, and often had multiple low capacity incubators rather than single large capacity incubators. Experience, better overall hygiene and time spent on chick rearing probably contributed to improved chick survival. It may also be speculated that use of multiple incubators may also have contributed to higher chick quality at hatch, with subsequent improved survival thereafter. However, many other unknown factors may also have contributed to improved chick survival for these producers.

From information provided by respondents, the efficiency of chick production (the percentage of chicks surviving to three months relative to the number of eggs incubated) was calculated. Low efficiencies will result under high infertility, poor hatchability of fertile eggs, and/or high chick mortality prior to three months. This performance indicator is useful because it describes chick production relative to eggs incubated. From this value, it is also possible to calculate the average number of eggs incubated or laid per chick surviving, which relates to the overhead costs of producing each chick. 50% of farmers achieved efficiency of 45.4%, yet the top 10% of farmers achieved in excess of 79%. Thus, high performances in fertility, hatchability and chick survival do occur concurrently, and also occurred over a range of incubation percentages. At approximately this level of efficiency, producers achieve 1 chick at 3 months for every 1.45 eggs laid.

The final performance indicators derived were the average number of chicks produced per hen, which relates to returns from sale of slaughter birds. Benchmark figures indicate that relative to reported egg production in mature South African flocks of between 50-60 eggs/hen (eg. Smith *et al.*, 1995; van Schalkwyk *et al.*, 1996), egg production in this sample was quite low at around 35 eggs/hen. Low levels of egg production have also been reported previously (Horbanczuk and Sales, 1999; More, 1996), typically in countries with a short history of ostrich farming. This sets a low ceiling on the average number of chicks that can be produced per hen. However, many flocks operated with young breeders, and relatively few high producing flocks were present in the data. Nevertheless, age of females is known to have a substantial impact on egg production, so increasing flock age Industry wide should result in improved chick production. Of significance was that high egg production was often offset by poor efficiencies at incubation and post-hatching. Thus, achieving high egg numbers does not necessarily result in substantially improved chick production. The best 10% of producers with > 20 hens achieved an average of 27 chicks per hen at three months (from 46-49 eggs laid/hen), the next producer achieved ~34 chicks per hen (from 51 eggs/hen), and the top producer achieved 46 chicks/hen (from 62 eggs/hen). These results clearly show that improvements in efficiency of incubation and chick rearing provide greater benefits than improvements in egg production.

Associative factors were also identified qualitatively in this study. However, although results were consistent with expectation and with observed differences between Benchmark results for different groups of producers, the data was not well structured or of sufficient detail to specifically identify causative factors influencing reproductive performance. Finally, some caution must be exerted in interpretation of results for derived data, although potential biases should be low and conservative in nature.

5 General Discussion

Several components of this project require discussion. Firstly, the implications of poor data availability in the Australian Industry to the success of the project are discussed in the following section. Then, discussion of results relating to parameter estimation follows, but will largely be confined the general significance of results towards our understanding of performance in farmed ostriches and how these results allow the project objectives to be met. Finally, the significance of results from the benchmark study will be used to achieve some perspective into the importance of reproductive traits in farmed ostriches.

5.1 Performance Recording

It is clear (see section 2.1) that lack of performance recording in the Australian Industry initially hindered the collection of data suitable for estimation of genetic parameters for traits recorded in farmed ostriches. This limitation was eventually overcome through the acquisition of data for analyses from South Africa, a discussion of which occurs in the following section. However, what was not so clear were the longer-term implications of performance recording issues for the outcomes of this project, and the Australian Ostrich Industry overall.

Lack of performance recording remains a significant barrier limiting our ability to implement a genetic evaluation system in this Industry. Deficiencies in data recording are apparent at both the farm and Industry level, with many producers failing to adequately performance record on-farm, and with no significant centralised database for performance recording routinely used by Industry members. Further, recording of pedigree information is hindered by increasing use of colony breeding with increased scale of operation, and historical pedigree information maintained at ABRI is of little practical value for genetic evaluation purposes. Consequently, Industry wide genetic evaluation is currently not possible, and relatively few farms are in a position to consider routine use of advanced genetic evaluation techniques (eg. Best Linear Unbiased Prediction). As is evident from the survey results, a similar situation would appear likely in other ostrich producing countries.

This outcome clearly shows that the objective to implement a genetic evaluation system in the Industry was not fully met within the time frame of this project. However, a substantial contribution to knowledge of genetic and non-genetic factors affecting performance in farmed ostriches has been achieved. Thus, implementation of results is possible in the future given appropriate education and motivation of Industry members. Further, less advanced genetic evaluation techniques (eg. mass selection) and culling based on previous performance can be advocated immediately as methods to improve reproductive performance and weight gains for slaughter birds.

5.2 Parameter Estimation

5.2.1 Systematic Effects Influencing Performance

Effects that systematically influence the performance of economically important traits must be accounted for to allow accurate comparisons between animals in their performance. This is important from the perspective of genetic evaluation, but also in comparisons which will be made for culling purposes. Several important systematic effects were identified during the modelling process required for the estimation of genetic parameters, and these are briefly discussed below.

5.2.1.1 Individual Egg, Chick and Live Weight Traits

Macro-environmental factors represented by production year and/or month (of hatch) significantly affected all egg, chick and live weight traits to varying degrees. However, considered in isolation, year and month effects (and their interaction) explained only around 4% of variation in egg and chick weights. This result is consistent with the fairly constant farming environment provided both within and between years at LKADC. With respect to later weights, the relative importance of year and month effects in isolation was not possible to estimate, given that age at weighing also differed across both years and months, and age significantly influenced weight. Nevertheless, macro-environmental effects commonly influence the performance recorded in both extensively and intensively farmed livestock, so were to be expected also in this study.

Hen age and the position of the egg in the complete laying sequence also had significant effects on egg and chick weights. After accounting for seasonal effects, hen age explained approximately 8% and 6% of variation in egg and chick weights respectively. Significantly larger eggs and chicks will be obtained on average from hens older than two years, although decreasing again for hens older than 11-12 years. Egg position in the laying sequence accounted for a further 4% and 1% of variation in egg and chick weights, with a high proportion of chick weight increases associated with egg weight increases occurring within the first five eggs laid. However, hen age and egg position in the laying sequence had no significant impact on live weights recorded at later ages, suggesting little effect of egg characteristics on later live weights.

The remaining identifiable systematic causes of variation of egg and chick weights in the data were dietary treatments. Relative to the above factors, these effects although significant did not account for a large proportion of variation in these traits. Thus, the specific treatments may have been of little practical significance to individual egg and chick weights, unless there were subsequent effects on chick mortality. Unfortunately the effects of egg or chick weights on chick mortality could not be investigated using the available data. There also appeared to be no significant carry over effects of these parental dietary treatments on later live weights of their progeny, although data were relatively limited in this respect.

When considering results at the level of individual eggs or chicks, systematic effects do have implications for management, particularly with regards to incubation. Although it may be extremely difficult to modify global environmental effects in the vicinity of production (eg rainfall, light intensity etc) it would appear that these had relatively little impact on egg and chick weights from year to year in an otherwise controlled farming environment. However, hen age and egg sequence effects, which also cause variation in egg weights, do have implications for incubation settings and/or the successful hatching of eggs throughout the laying cycle or from hens of different ages.

The presence of these effects would suggest that less than optimum results will be achieved from use of constant settings in large multi-phase incubators, particularly for a breeding flock of mixed age structure. Optimum settings are often calculated based on an average egg weight, which will differ between hens of different ages and at different stages throughout the laying cycle. Thus, different setting regimes for younger and/or older hens, and throughout the breeding season, may be required to maximise hatchability of incubated ostrich eggs. In a review on hatchability in species of domestic importance, Hodgetts (1991) indicated that refinements in incubation techniques were most easily achieved through the use of single stage incubators, although this implies greater capital expenditure and gains achieved must be balanced against this. Further, Wilson (1991) suggested sorting eggs by weight prior to incubation as a possible method for improving the efficiency of incubation. These incubation strategies have generally been suggested for other domesticated poultry species, which primarily have to contend with egg sequence effects rather than variation in hen age within flock, and already retain high hatchability. In ostriches with significantly lower average hatchabilities, it is probable that refinements in incubation strategies will yield significant results.

Egg sequence effects are further complicated by a change in ratio of chick to egg weights (see Figure 2). Continuing increases in egg weights were not always mirrored by proportional increases in chick weights under a constant incubation strategy. This result implies that egg composition also changed with egg sequence position, and/or that chicks hatched less successfully from larger eggs. It is generally accepted that eggs with extreme weights have reduced hatchability in domestic poultry species (Wilson, 1991), and this is often attributed to hen age effects on egg shell quality and/or egg composition. Results from this study would suggest that changes in composition during the laying period (independent of hen age effects) were at least in partly responsible for alterations in chick weights, and further work may be required in this area. Hen age and laying cycle effects are often generally confounded in small domestic poultry species, so the separation of these factors is more difficult (particularly if individual egg fertility is unknown). Moreover, when fertile ostrich eggs from this study were grouped by weight into 10 approximately equal sized groups (ascending order), the hatching percentages were lowest for groups 1 to 3 and group 10. That is, a higher proportion of high weight eggs did fail to hatch, yet above average weight eggs overall hatched better than below average weight eggs.

An alternative to optimising incubation conditions to allow for variation in individual eggs is to attempt to reduce variability in egg weight. This option may be difficult to achieve given that variation between hens is the major factor contributing to variation in egg weights (see next section). Nevertheless, management aimed at attempting to synchronise the commencement of lay, or reducing variation in flock age, along with culling hens which produce extreme egg weights, may reduce egg weight variability. Given the high relationship between egg and chick weights, a reduction in egg weight variability could also be expected to reduce variability in chick weight. It is important to note, however, that variation in both egg and chick weights relative to their meana are already quite small. Further, as noted above, the implications of chick weight on chick mortality after hatch also needs to be considered.

5.2.1.2 Hen Traits

Year of production also contributed to significant variation in all hen traits, with the exception of hatching percentages expressed relative to the number of eggs laid and incubated (Table 4). Generally speaking, traits of the hen were more affected by production year than either individual egg or chick weights. Production year accounted for ~12.4% of the variation in the time taken for hens to commence laying, and over 8% of variation in the duration of lay and number of eggs laid. This variation in part will reflect year to year variation in seasonal cues which induce breeding. Some of the variation between production years, however, can also be attributed to management decisions – such as choice of the month in which to pair breeding adults.

Moreover, length of the breeding season was significantly associated with traits such as the duration of lay, the number of eggs laid, and percentages of infertile eggs. Consequently, season length also influenced hatching percentages and alternative measures of total chick production. For all traits where duration of lay was significant, increased duration was associated with improved measures of reproductive performance. However, this is unlikely to be the case when the season length is extended beyond an optimum interval, which probably varies with the prevailing season. Thus year and length of season effects are of significance for comparing the performance of individual hens, and must be appropriately accounted for. The accuracy of comparisons between hens based on average performances will also be affected if hens performed in different years and over different length seasons.

With the exception of traits relating to egg infertility, hen age class also significantly affected all hen traits to varying degrees. Two-year-old hens generally took longer to commence laying, had a reduced duration of lay, laid fewer and lighter eggs on average, and therefore produced fewer and lighter chicks than older hens. Peak egg production occurred at 8-9 years of age. However, peak average egg and chick weights occurred for younger hens (between 3-6 years of age). Gradual decreases in total chick production occurred after 11 years, coinciding with significant reductions in average chick weight. In this flock, it would appear that there was generally little advantage in terms of chick production in retaining hens for breeding after the age of 11 years. However, it is important to note that average egg and chick weight records represent both changes in individual egg and chick weights, and differences in the number of eggs contributing to the average.

When adjusted for seasonal differences, mature hens at their peak production laid on average 23 eggs more than two-year-old hens per year. This has major implications for comparing performances in egg production across flocks with different hen age structures. Moreover, the number of eggs laid compared to chicks hatched diverged with increasing hen age (Figure 3). Thus, the relationship between egg and chick production is not consistent across all hen age groups. It would appear that even though ostrich hens are capable of maintaining high rates of egg production until old ages (> 20 in this data), there is no advantage to retaining old hens in the breeding flock in terms of chick production, given gradual declines in hatching percentages (Figure 4) and reduced average egg and chick weights (Figure 5). However, it is important to note that alternative management strategies may alter the relative performance of different hen age groups.

The age of males used in the breeding flock also had significant implications for chick production, predominantly through effects on egg fertility. The number of infertile eggs recorded was relatively higher for two and three year-old service sires, and service sires over 10 years of age (Table 6, Figure 6). Sires between these ages were associated with fewer fertile eggs. The same trends were evident for the percent of infertile eggs, but were of greater magnitude. This type of trend could be expected, allowing for the expected effects of reproductive immaturity at young ages and a possible decline in performance at older ages. The use of older males in a second production year has been shown to have a detrimental effect on fertility in broilers (Rosa *et al.*, 1998, cited in Ledur and Rosa, 1999). However, standard errors in this study were quite large for service sire age effects, so the actual magnitude of service sire age effects on fertility in ostriches is more difficult to quantify with certainty. Nevertheless, it would appear from this data that poorer fertility might become a problem for service sires older than 10 years of age. These results are also consistent with observed differences in fertility with respect to flock age structure noted from the reproductive survey.

Dietary treatments and supplements trialed during the course of data collection had relatively small and inconsistent effects on both egg production (the number of eggs laid) and chick weights, and tended towards significance only at the 10% level. This is consistent with results for individual egg and chick weights, which indicated little practical significance of either set of treatments. Significant dietary effects were evident for the percentage of infertile eggs produced, but were of lesser significance with respect to chick production. However, as noted previously, the ultimate importance of dietary treatments on production needs to be assessed relative to the number of chicks produced and subsequently surviving. Identification of the treatment codes will allow the significance of these effects to be further considered in the future.

5.2.2 Effects with No Significant Influence on Performance

For individual egg, chick and live weight traits, and hen reproductive traits, the influence of several other factors on performance were also examined, but had no significant effects on the traits recorded. Identifying factors that do not affect performance is also of value, and the factors examined without significant impact are discussed here.

There was no consistent evidence for any heterotic effects (whether direct or maternal) on hen traits or individual egg, chick or live weight traits. Thus, after accounting for other significant factors, the crossing of commercial, feather and blue-neck strains did not appear to result in significant differences in reproductive output, or individual egg, chick or later live weight traits. This result was not necessarily expected. However, it should be noted that the sample of parents and eggs from the blue neck strain was very small, reducing the ability to assess any differences in traits for this particular strain of birds. Further, allocation of parental birds (and subsequently their eggs and progeny) to a particular strain or strain cross did not necessarily represent genetic diversification. The majority of birds whether “feather” or “commercial” were obtained from the Oudtshoorn area, and their origin was the only basis on which allocation to a strain was made. Thus, strain definition could be considered somewhat arbitrary and non-additive effects of little significance in this particular case. This is not to say that non-additive effects will not be of importance in the crossing of more diverse populations of birds. In addition, larger samples of unrelated crossbred parents in the current data may have been required to identify significant heterotic effects in this flock.

Sex of the growing bird had no significant influence on live weights recorded prior to maturity. Comparison of live weights or carcases in other studies (eg. Cilliers *et al.*, 1995; Sales and Oliver-

Lyons, 1996) has suggested that gender effects on growth or carcase characteristics are non-existent in juveniles to small in mature birds, which is consistent with results from this study. Significant sex effects reported by Deeming *et al*. (1993) on early chick growth were not supported in this study, and may have resulted due to their relatively small data sample. Thus, separate sex rearing aimed to accommodate sex differences would not seem to be required in this species.

Several additional factors were addressed for hen reproductive traits. These included evaluating the significance of age differences between mates, and re-pairing of mates on reproductive performance. The former provided inconsistent results across data subsets, which may be attributable to the relatively high confounding between ages of mates combined with specific effects relating to individuals breeding with mates of different ages. In the full data set, there was no indication that either of these effects had a significant impact overall on reproductive performance. Further, providing a new breeding partner did not result in adverse effects on egg production under the prevailing management system. This would suggest that ostriches do not necessarily pair for life, and will breed successfully in captivity with different partners. This is consistent with the polygamous behaviour observed in birds breeding in the wild (Graves and Kimwele, 1999). A possible proviso to this statement is indicated by the observation that the majority of hens that were allocated to new mates were relatively mature and had prior breeding experience. Studies involving caged bird species which form pair bonds have shown forced repairing to be detrimental to reproductive success of inexperienced breeders, but not of experienced pairs (Stone *et al*., 1999). Further, anecdotal evidence suggests that unnecessary changes to breeding pairs made during the breeding season may detrimentally affect performance.

Service sire age had no significant direct effect on egg production, and variation due to age in remaining reproductive traits was best described by hen rather than service sire age. Thus, it would appear unlikely that individual service sires stimulate better egg production from their mates, and this is supported by a failure to identify substantial variation between service sires for the number of eggs laid (see next section). However, it should be noted that the level of confounding between the age of service sires and their mates was moderate. Thus, the data was not entirely suitable to fully separate age of hen from age of service sire effects. It is possible that through behavioural stimuli, some service sires may encourage better reproductive performance in their mates (as suggested anecdotally). However, the data in this study did not support this.

5.2.3 Random Effects

5.2.3.1 Individual Egg, Chick and Live Weight Traits

With the exception of live weights recorded at approximately three months of age, significant levels of additive genetic variation were estimated for all egg, chick and live weight traits. This indicates that parental selection can effectively be used to improve future performance in these traits, although it is not necessarily clear what improved performance constitutes for egg weight *per se*.

The absence of additive variation for live weight measured at three months suggests that genetic potential for live weight gain has largely been unexpressed at this age. This may simply reflect the significant environmental factors that affect growth at early ages (often health related, and including chick survival) rather than an absence of genetic potential for early growth. Additional information on chick rearing may have improved our ability to detect genetic variation at this age, and analysis of further data sets with more detailed chick data may be required.

In comparison to results from previous analyses (Bunter *et al*., 1999) although heritability estimates and additive variances for individual egg and chick weights were similar in magnitude, a large amount of variation previously attributed to breeding paddock effects was repartitioned towards effects of the hen. Consequently, an even larger maternal effect of the hen (consisting of heritable maternal and permanent environmental effects) on egg and chick weights was evident in the current study, and the importance of breeding paddock was diminished. Reallocation of hens to different breeding paddocks in the more recent data facilitated better discrimination between hen, service, sire and breeding paddock effects through improved data structure. Thus it would appear that breeding paddock effects on egg and subsequently chick weight are of lesser importance than previously indicated.

Use of the complete data also resulted in the identification of significant carry over effects of the hen on their progeny live weights recorded at three, six, ten or approximately 14 months of age. These effects were not significant in the previous study (Bunter *et al.*, 1999). However, progeny in the subset of live weight data represented fewer parents and fewer progeny per parent. Thus, although this effect may have been present, the data structure did not facilitate its identification. Fitting additive and permanent environmental effects of the hen concurrently resulted in reduced heritability estimates for live weight traits, and concurrently larger standard errors for this parameter estimate. Consequently, although live weight traits remained moderately heritable in the current study, results indicate that selection for live weight will be less effective if effects due to the hen on live weights are not accounted for.

Genetic correlations between early (egg and chick) and later weight traits (6, 10 and 14 month weights) were generally not significantly different from zero. This result was due in part to large standard errors. However, genetic correlations further diminished in magnitude under multi-trait analyses which allowed for prior selection. Thus, hatched chick weight would not appear to be a strong indicator of genetic potential for later growth, although results suggest that this correlation overall may be positive. Low to moderate phenotypic correlations between hatchling and later weights potentially reflects both additive and carry over maternal effects. Positive genetic correlations between egg weight and later weights are consistent with larger birds laying larger eggs, but this was unaccompanied by significant phenotypic correlations. In addition, the direction of genetic correlations between egg and later weights were inconsistent in magnitude and direction. Thus, any association between egg weight and mature weights would appear tenuous. This provides some conflict given the strong association between egg and chick weights. However, as noted previously, chick mortality may differ according to both egg and chick weight characteristics.

Results from analyses containing all traits allow for selection based on earlier weights. Higher heritability estimates and additive variances were subsequently obtained for later weights in multi-trait analyses, suggesting that selection had occurred when the choice was made as to which birds to carry through to later weights. High genetic correlations between weights recorded at 6, 10 and 14 months of age indicate that many of the same genes are expected to control these weights. Thus selection on weight at earlier ages (6 months) should also be effective for improving later slaughter weights.

5.2.3.2 Hen Traits

For all hen traits examined, moderate to high repeatabilities were estimated. This indicates that the performance of hens for a range of reproductive traits could be predicted reasonably accurately (depending on the specific trait) from previous performances. Thus, the culling of non-productive hens would clearly generate improvements in current flock performance, providing appropriate allowances were made for seasonal differences and hen age effects on performance records when comparisons are made. What is not so clear is whether partial season results can provide accurate information for selection and culling decisions.

Cloete et al. (1998) reported that repeatability within a season was high for egg weights. This result suggests that hens could be culled based on measures of reproductive performance recorded earlier in their breeding season. A similar argument can be drawn for other reproductive traits that also exhibit high repeatabilities across seasons, although this appears to have been examined to a lesser extent for other traits. However, the opportunity to use partial season results is not well supported for traits examined in this study, including egg weight or measures of egg and chick production.

Results from this study indicate that although a delay in commencement of laying (TTL) would clearly be detrimental to early season egg production, TTL was only moderately correlated phenotypically with the total number of eggs laid (~-0.5). Total annual output is obviously determined by both TTL and the rate and duration of lay throughout the remainder of the breeding season once the hen has commenced laying, and hens vary in both these components. Similarly, egg position in the laying sequence affects egg weight. For comparisons made over a fixed time interval early in the season, it is also possible that hens will not be compared over the same egg sequence effects if the commencement of laying is poorly synchronised across hens. Consequently, it appears preferential to base selection and culling decisions on reproductive performance recorded over at least one complete season, rather than on partial season results where the effects of a delayed start may not sufficiently be compensated for in a short time period. Once again, non-genetic influences on performance must be accounted for.

What is also not so clear is the effect of selection and culling on future flock performance for the reproductive traits that can be considered as traits of the hen. Concurrently fitting additive and permanent environmental effects of the hen generally contributed to relatively large standard errors for heritability estimates, which overall reduces the ability to assess the real significance of these estimates. The only traits with significant heritability estimates were average egg and chick weights, along with their ratio. The moderate heritability estimates for these traits are consistent with the relatively large maternal influences that were found when egg and chicks were treated as individual records in the previous analyses. Thus, the significance of the hen in determining egg and subsequently chick weights is confirmed in the alternative approach, ie., that egg and chick weights should be considered as traits of the hen.

With the exception of clutching, fertility and hatchability traits, for which no significant additive variation was apparent, the remaining traits of the hen were lowly to moderately heritable. Heritabilities of low magnitude are common for reproductive traits in all species, and generally indicate that genetic improvement will be slow to achieve through selection, particularly in small breeding units. However, given that these traits were highly variable even after accounting for systematic effects, a low to moderate heritability also corresponded to substantial estimates of genetic variation in hen traits. For example, despite heritabilities as low as ~0.10, estimates of additive variation for the number of eggs laid or hatched were approximately 70 and 39 eggs^2 after accounting for seasonal differences and systematic effects. These results would suggest that genetic improvement for egg and chick production will occur with appropriate selection and culling procedures, particularly if flock size is large and advanced genetic evaluation techniques are available to improve the accuracy of selection. However, selection and culling for improved performance must also be balanced with the strong influence hen age has on the egg production achieved.

With respect to egg fertility, this is generally considered to be attributable to both male and female related factors. Under natural mating, possible factors affecting fertility include aspect of sperm quality, the timing of insemination relative to oviposition (behaviour), and also differences in female physiology. Results for fertility traits in this study would suggest that the service sire largely determined egg fertility in ostriches. Thus, it would generally appear inappropriate to consider fertility solely as a trait of the hen, even though moderate estimates were also apparent for hen effects. Variation between females in fertility levels achieved after artificial insemination has been shown in poultry, and is attributed to both genetic and non-genetic causes (Beaumont, 1992 and Beaumont *et al.*, 1992). Under artificial insemination with pooled semen, such variation has a physiological rather than behavioural basis, which may also partially explain the significant hen effects for fertility traits in this data. Mate incompatibility has also been cited as a cause of poor fertility levels in ostriches through reducing mating frequency or success. However, in the past there has been only poor evidence for behavioural effects on reproductive success. More likely in this data was that repeated pairing of the same males and females created a data structure conducive to repartitioning variance between males and females. Thus some of the service sire effect may have inflated variation in fertility due to the hen. There was no evidence in this data for a heritable service sire component on fertility traits.

Moderate estimates of service sire effects on fertility traits, after allowing for service sire age effects, would suggest that service sires whose hens exhibit poor egg fertility should be culled. However, some caution needs to be exerted with regards to culling based on a single season of poor fertility as only a small proportion of service sires generally have more than mate. Ideally both male and female fertility should be assessed from data where both have been paired with more than one mate, or through the development of appropriate techniques of assessing fertility outside the breeding season. The former provides a good case for routinely reallocating mates from year to year, particularly in light of results indicating that egg production is unaffected by this strategy. However, mate compatibility issues, although still anecdotal, may complicate this approach. Successful procedures for assessing fertility outside the breeding season are also warranted, given that hatchability and therefore chick production is ultimately the result of fertile eggs. However, to date assessments of male fertility through sperm quality are complicated by collection difficulties, and are not routinely conducted. In addition, ultrasound images of the female reproductive tract early in the season have proved poor indicators of total egg production in healthy females (Helet Lambrechts, 1999, pers. comm.), and are generally not recommended for this particular application.

In contrast to results for fertility, service sire effects were substantially lower than hen related effects for hatching percentages, particularly as relates to hatchability of fertile eggs for which no significant service sire effects were observed. The prior discussion on both individual and hen average egg and chick weight traits has already covered the substantial impact individual hens have on egg and chick weights, and the impact egg weights have on the percentage of chicks which hatch. Thus, variation in egg weight can be considered as one factor which may have influenced hatching percentages between hens. In addition, variation in egg shell quality and egg composition between hens may also have influenced hatching percentages, thereby contributing to the large hen effect for these traits. Unfortunately, no specific data were available to examine this aspect. However, data from this flock on water loss during incubation has been analysed (Blood *et al.*, 1998). A significant repeatability between pairs, which in the prevailing data corresponds with the repeatability of individual hens, for water loss was evident in this study, and it is well known that the hatchability of individual eggs is strongly influenced by evaporative water loss. Thus variation between hens in the average evaporative water loss of their eggs (representing aspects of shell quality) would have also influenced hatchability percentages.

Overall, interpretation of results for hen traits, particularly with respect to the identification of additional random effects, must be treated with caution. The relatively small data set with respect to the number of hens combined with selection, both deliberate and natural, in the data complicated identification of significant random effects for hen traits. Further, it is possible that the level of confounding in the data may have resulted in repartitioning of variances between alternative additional random effects, between which sampling correlations exist. Although a substantial amount of care was taken to minimise this risk, it is not always possible to identify whether effects are spurious or not with relatively poor data structures.

5.2.3.3 Relationships between Hen Traits

A substantial volume of results was presented detailing the relationships between various reproductive traits of the hen. However, these will only be discussed generally for the sake of brevity.

The first observation to make is that several traits had unity correlations. This greatly simplifies the discussion of correlations between hen traits by reducing the number of independent traits that need to be considered. Traits that may in all practicality be considered as identical are as follows:

- Egg production percentage (EPP) is equivalent to the total number of eggs laid under a different scale.
- Chick production percentage (CPROD) is equivalent to the total number of chicks produced under a different scale.

- The number of eggs incubated (NINC) reflects the number of eggs laid, but is influenced by deliberate selection decisions as discussed previously.
- The total egg weight recorded reflected the total number of eggs produced rather than the weight of individual eggs and, given the above, had unity correlations with EPP.
- The total chick weight recorded reflected the total number of eggs which hatched more than the weight of individual chicks and, given the above, was also unity correlated with CPROD.
- The percent of infertile eggs expressed relative to either the number of eggs laid or incubated were essentially the same, but marginally influenced by selection of which eggs to incubate.
- Given the above, hatching percentages expressed relative to the number of eggs laid or incubated are essentially the same trait. However, the hatching percentage of fertile eggs can be considered as a different trait.

EPP and CPROD have been suggested as more appropriate measures of reproductive performance for hens whose records are compared over seasons with different lengths (Schalkwyk *et al*., 1996). Results from this study, where the majority of variation in season length is between rather than within years, have indicated identical results are achieved with a practical unit of measurement (ie., the egg) without the need for rescaling. The usefulness of EPP must be considered debateable given that EPP as defined is simply the number of eggs laid rescaled in relation to the number of days over which eggs are laid, and according to the expectation of one egg being laid every two days. Clearly this expectation is unrealistic for all age groups of hens, and may also be increasingly unrealistic for very extended or very short breeding seasons. In addition, EPP allows little differentiation to be made between records indicating a low number of eggs laid over a wide range of season lengths. Further analysis of data containing variation both within and between years in season length may help elucidate the most appropriate measurement for reproduction traits recorded over variable season lengths.

Evaluation of total egg and chick weight records would also appear unnecessary if the number of eggs laid or hatched is known, and average egg and chick weights are calculated. No effective additional information is provided through the analysis of these totals. Further, total chick weight at hatch is only of interest if it is ultimately related to the total weight of slaughter progeny produced. Results from analyses of individual egg and chick records would suggest that chick weight at hatch has relatively little bearing on the slaughter weights achieved for individual birds.

With respect to fertility traits, unity correlations indicate that there is little benefit to be had in expressing infertility relative to both the numbers of eggs laid or hatched for this flock. However, this result may not hold if there is strong selection on egg characteristics between laying and incubation, particularly if the basis of selection for incubation has an association with other traits of interest. A similar argument can be drawn for the first two hatching percentage traits.

Apart from identifying which performance measures provide essentially the same information, as above, of relevance for genetic evaluation purposes is the identification of antagonistic relationships between traits. From analyses of this data there would appear to be very few reproductive traits with antagonistic associations that are of sufficient magnitude to complicate selection procedures. Generally, there were no significant antagonistic correlations between egg production and fertility, average egg and chick weights, or hatchability traits. Indeed, several reproductive traits were favourably correlated, suggesting that selection for some traits would have beneficial effects on others. However, it is also likely that the presence of egg sequence effects on traits such as egg weight, fertility and hatchability (which will also influence mean records for hens) may have generated some degree of auto-correlation between these and egg production traits. More sophisticated analyses may be required to allow for auto-correlative effects, and could alter correlations from their current favourable direction. However, such analyses are computationally demanding, and are probably only warranted when data quantity and structure are sufficient to allow accurate separation of genetic from permanent environmental effects of the hen.

Of particular interest also were trait combinations where correlations between random effects differed in magnitude or direction according to the level examined. A number of correlations between traits at the level of the hen were significantly different to correlations estimated at the environmental or phenotypic levels, and are briefly summarised as follows:

- At the hen level, a delayed commencement of laying was associated with improved fertility and hatchability. However, delayed TTL was unfavourably associated with fertility and hatchability trait both environmentally and phenotypically.
- At the hen level, the number of clutches recorded was negatively associated with egg production, and unfavourably correlated with egg fertility, hatchability and subsequently chick production. However, phenotypic correlations between clutching and other traits were low and insignificant due to opposing environmental correlations.
- At the hen level, the number of eggs produced was negatively correlated with the ratio of chick to egg weight. This was also apparent to a lesser extent in environmental and phenotypic correlations between these traits.

Environmental and phenotypic correlations between TTL and fertility traits indicate that a delayed commencement of laying was generally associated with poor fertility. However, at the level of the individual hen, a delayed commencement in laying was associated with improved fertility. Both of these results are consistent with poor male fertility at the commencement of egg laying, which individual females may compensate for only with a delayed commencement of egg laying. This result potentially has implications for managing flock fertility, particularly with respect to male fertility.

Management of this flock involved separation of males and females in the non-breeding season, and it is possible that under this type of management inadequate stimuli were present prior to the breeding season for males to become fully fertile before females commence laying. Studies by Soley *et al.* (1991) revealed that a positive relationship existed between sperm quality and egg fertility when birds were not physically separated in the off-season. However, the influence of alternative management strategies on fertility has not been well quantified in this species. On the other hand, it is possible that delayed fertility in males is desirable and simply reflects a natural adaptation, given the much smaller eggs (which will yield only small chicks) that are laid by hens at the beginning of the season. The second alternative may be of no significance in a controlled farming environment, and evaluation of methods to stimulate earlier achievement of male fertility may be warranted. However, achieving early male fertility may not be desirable if factors other than fertility reduce hatchability of early season eggs (as reported in poultry), if subsequent chick survival is compromised, or male fertility is then detrimentally affected later in the breeding season.

Phenotypic correlations between the number of clutches laid and other reproductive traits were generally close to zero, suggesting that clutching pattern was generally unrelated to other measures of reproductive performance. Consequently, varying degrees of clutching behaviour may be observed in hens across a wide range of egg production values. However, increased clutching at the hen level was detrimentally associated with egg production, and in particular the number of chicks produced. These results are consistent with an increased percentage of infertile eggs, and more significantly strong negative affects of increased clutching on hatching percentages. The detrimental effects of early sequence eggs on hatchability, which is generated by clutching behaviour, are thought to be related to aging in the oocyte and changes in egg composition in domestic poultry. This study provides strong evidence to support the presence of a detrimental clutching effect on chick production. However, the number of clutches laid had a low repeatability, indicating that clutching behaviour of individual hens may have altered from year to year. This reduces the ability to cull hens accurately based on aspects of their laying pattern. The relative importance of clutching patterns is ultimately determined by its impact on chick rather than egg production.

Clutching behaviour may alternatively be an indication of disruption during breeding. This trait was one of the few traits examined for which a consistent breeding paddock effect occurred. Cluster analysis of paddock solutions for clutching frequency (while also allowing for the number of eggs produced per clutch) indicated that increased clutching occurred in breeding paddocks close to a busy road and human thoroughfare, as well as paddocks known to suffer jackal intrusions. These results would suggest that external disruptions may ultimately affect chick production, even if there is little evidence for a major disruption in egg laying. In addition, clutching was indicated to occur with greater frequency in older hens which, as indicated previously, also have reduced hatchability. Whether disruption affects chick production through adversely altering the status of the female reproductive tract (eg. through atresia; see Kelly and Nili, 1998), oocyte aging, through changes to egg composition, or due to disruption at mating is currently unknown.

The third point illustrates that hens with high egg production generally produce lighter chicks relative to egg weight on average. This trend was also observed to a lesser degree in environmental and phenotypic correlations, and is also consistent with results for egg sequence position effects on individual egg and chick weights. However, the greater magnitude of correlations at the hen level would suggest that hens that lay large numbers of eggs possibly do so with an altered egg composition. This is also probable given that high egg production did not adversely affect hatchability percentages, so it would appear that the sample of chicks which hatched was unlikely to be significantly affected.

If compositional changes do occur predominantly for egg content (yolk and albumin) rather than shell characteristics, greater reductions in chick weight relative to egg weight would be expected. However, it is possible that the observed relationship may not occur under different dietary regimes. For example, the diet may have been inadequate for high producing hens who were then unable to maintain a consistent egg composition, and that egg composition would be better maintained with improved nutrition. Nevertheless, this result may also be related to the oft cited syndrome of poor performing late in season chicks.

Finally, with respect to the influence of service sires, a comparison of results from both single and multi-trait analyses would suggest that they have little impact, if any, on egg production or egg characteristics of their mate. This outcome refutes the sometimes-held belief that service sires directly influence egg production of their mates. Consequently, the influence of service sire on hen performance is most probably largely confined to their impact on egg fertility. This effect obviously has some carry over effect by providing a limitation to the sample of eggs which can hatch.

5.3 Survey Results

A paucity of reference material is available to benchmark the performance achieved by farmed ostriches around the world, whether reproductive traits or those relating to the slaughter bird. Even the most recent and comprehensive text about ostriches ("The Ostrich Biology, Production and Health", edited by D.C. Deeming, 1999) summarises reproductive results from less than 15 independent sources of data. This sample size can hardly be considered adequate for benchmarking reproductive performance of farmed ostriches around the world, and provided the motivation for obtaining a larger sample of results for reproductive performance in farmed ostriches under current management conditions. The survey results as reported represented a sample of less than 50% of the total respondents to the questionnaire, but still in excess of 100 independent producers. These producers can best be described as being typical of ostrich producers operating outside South Africa, with a relatively small contribution from large scale operations. Thus results are predicted to predominantly represent those achieved by often small-scale producers in a developing Industry climate.

Results from the survey showed highly variable reproductive performance both within and between countries. Given the highly variable performance observed within a single flock (see section 3.1.2), and in light of previously reported results (see Deeming and Ar, 1999), this outcome was not surprising. However, survey results clearly indicated that a substantial number of producers had very poor results, and a significant improvement in reproductive performance can thus be achieved.

Generally, realistic targets for ostrich producers appear to be in the regions of <=10% infertility and =>85% hatchability of fertile eggs, which in combination would give overall hatchability for eggs incubated in excess of 75%. With respect to chick mortality, <10% in total by three months of age has been achieved by a number of producers. However, given the relatively poor response rate from large commercial operations it is difficult to establish whether these targets are realistic for large-scale production facilities.

Realistic targets for egg and chick production achieved on a per hen basis are much more difficult to establish from the survey results, given that in the data received the upper limit to chick production was less than 35 (based on egg production). It is well known that substantially higher levels of average egg production can be achieved than is indicated by this figure (eg. see Deeming and Ar, 1999), and seasonal and management factors, along with hen age, are known to have a significant impact on the egg production levels achieved (see section 5.2.1.2). Consequently, it is probably more realistic to suggest that culling of poor producing individuals based on previous records should occur (regardless of current production levels), while balancing flock age structure, and selection of replacement breeders should also consider aspects of reproduction. Results from the reproductive questionnaire suggested that improving incubation efficiency yielded greater gains than increasing egg production per hen, reducing the relative impact of gains in egg production on chick production. Conversely, very low egg production from a reproductively mature flock will increase the importance of selection for improved egg production.

Overall, the response rate to the questionnaire was excellent. However, respondents were typically small-scale producers with relatively low levels of experience. Consequently, there is still a need to establish exactly what levels of reproductive performance are achieved and should be targeted in the (larger scale) "commercial" industry of today (or the future). Extrapolation of results from the current survey to this scenario may not be warranted, given that results from flocks with very few hens may be significantly influenced by individual hen performances and the relatively high managerial input per hen. This aspect was highlighted in the previous discussion of results from the survey, along with implications of scale of operation on the optimisation of incubation strategies. Further, reproductive performance in large-scale operations may be adversely affected by poor overall management, which encompasses aspects such as reduced individual breeder selection and monitoring, and ‘false economy’ decisions (eg. lower feed costs and quality) (Doug Black, pers. comm.).

Finally, an additional degree of caution in interpreting results is required when Industry data are used for benchmarking procedures. Even with careful data scrutiny and editing, it is possible that data errors went undetected. However, it is predicted that even with a systematic error the bias in averaged or median results should be quite small for fertility, hatchability and chick mortality figures. Unfortunately, errors may potentially be magnified in derived traits.

5.4 Further Work

Some additional work will be conducted for the purpose of including in a PhD thesis. This will include examining aspects of hatchability (treated as a 0/1 trait) at the individual egg level. Further work envisaged for November (2000), when Schalk Cloete from South Africa visits AGBU, will be to examine chick mortality data.

6 Implications

Results from the parameter estimation study indicate that selection and culling can be used to improve current and future performance in several reproductive and production traits, for breeding birds and/or their progeny destined for slaughter. Moreover, results from the reproduction questionnaire indicate that for many producers substantial improvements in reproductive performance are necessary to bring them in line with their better performing peers. Significant advances in knowledge of both genetic and non-genetic factors influencing performance are outcomes of this project. Given this knowledge base, producers can implement simple selection and culling strategies immediately to improve traits of economic interest. Improved efficiencies of production through appropriate selection and culling will ultimately increase the viability of ostrich production in Australia.

However, the Australian Ostrich Industry is not currently in a strong position to implement and adopt advanced genetic evaluation procedures, which could be used to further increase response to selection over simpler strategies. Significant limitations still exist in the Industry with respect to performance recording (which will also limit simple individual performance based decisions). Lack of performance recording can be attributed to various factors, including: lack of education as to the benefits of performance recording; lack of motivation within the Industry; the breeding structures commonly used (which limit the recording of pedigree and performance of individual birds); inadequate training in ostrich handling and lack of development of satisfactory handling facilities; along with the low availability of suitable software for on-farm performance recording. Recording of data in a centralised database has also not occurred. However, this phenomenon is probably symptomatic of the dearth of on-farm performance recording.

Consequently, although the outcomes of this project constitute a significant advance in the knowledge base for farmed ostrich production, dissemination of this information will be crucial in ultimately determining outcomes within this Industry. In all other major livestock Industries, substantial improvements in production have resulted from the implementation of effective breeding programs. The same result can be expected in the future for the Australian Ostrich Industry given sufficient education and motivation of ostrich breeders.

7 Recommendations

Several recommendations can be made based on outcomes from this project, and these are presented in point form below. However, it is important to recognise that to some extent these recommendations will differ for ostrich producers according to whether they are predominantly breeders (ie., who produce seedstock for sale at premiums above the value of slaughter birds) or commercial operators (producing slaughter birds). Hereafter, producers from these two different sectors will be differentiated as ostrich breeders and commercial producers. Recommendations which may differ for breeders vs producers are addressed where necessary below.

1. **Ostrich farmers must establish whether they are a breeding or commercial operation.** This determines the emphasis they need to place on performance recording and genetic selection (for future gains). For breeders, maximising genetic gain may come at the cost of reduced current generation gains, and must be offset by premiums achieved through the sale of superior breeding stock. Conversely, for commercial producers, use of strategies that maximise current generation gains is desirable.
2. **Ostrich breeders need to be pro-actively educated as to the benefits of performance recording to themselves and their Industry**. **Producers also need to recognise that adequate levels of performance recording are required to monitor and improve performance of their operations.** Moreover, external limitations to effective performance recording in the Industry, such as inadequate training in ostrich handling, lack of development of adequate handling facilities, and the low availability of cost effective and suitable performance recording software need to be addressed.
3. **Ostrich breeders must use small, controlled breeding structures (eg. pairs or trios) to achieve adequate performance and pedigree recording for genetic evaluation.** Other breeding structures commonly used (eg. quads or colonies) increasingly limit the effective recording and use of pedigree and/or performance data. For paired mating structures, producers should consider reallocating birds to new partners each season (to maximise information retrieved). Results from this study suggest that egg production in mature (experienced) hens will not be affected by this strategy. **Commercial producers also need to consider the implications of using larger breeding groups on their ability to monitor individual performances and control production levels. Methods to identify poor performing individuals in colony breeding structures need to be developed, with particular reference to poor male fertility and low egg production in females.** Cost effective methods of parentage determination and/or the development of artificial breeding procedures (eg. Artificial Insemination) may have a role in future ostrich production.
4. **Egg and chick weights will respond to selection, and this may have implications for optimising hatchability and reducing chick mortality, which need to be investigated further. However, insignificant genetic correlations suggest that selection for egg or chick weights will have little impact on later weights. Consequently, later weights (in juveniles) must be recorded for selection purposes.** Heritability estimates for individual egg and hatchling chick weights are moderate. However, egg weight should be considered as a reproductive trait of the hen, and incubation conditions and the weight of the egg from which it hatched predominantly regulate hatched chick weight. Consequently, additive variation estimated for these traits is not directly utilised during the selection procedure, as hens will be selected for egg weight traits rather than individual eggs or chicks. In addition, there were no significant genetic correlations between egg or chick weights and later weights, indicating that these weights are not good indicators of genetic potential for later growth.
5. **Live weights recorded at three months of age should not be used for selection decisions to increase later live weights.** No additive variation was detected for chicks with weights recorded at approximately two to three months of age. This probably reflects the large amount of environmental noise affecting live weights at this age rather than a total absence of genetic variation *per se*.

6. **Selection of parents based on juvenile live weights should be considered to improve future flock live weight gains.** Moderate heritability estimates for live weights recorded after three months of age indicate that selection for improved weight gains is possible in this species. Further, weights recorded at six and ten months are relatively good predictors of slaughter weights achieved at later ages. Appropriate adjustments for non-genetic influences on performance will be required. These systematic effects generally include year and month of production, along with age and date at recording.
7. **Current flock performance for reproductive traits can be improved through culling based on previous performances.** The majority of traits considered to be reproductive traits of the hens had moderate repeatabilities, indicating that a hen's future performance can be predicted from her previous records. However, corrections for non-genetic influences are required, and the most appropriate culling regime will differ for breeders vs producers. For the former, selection intensities and generation intervals are more important, whereas for the latter, culling decisions will be balanced with simultaneous changes in flock age structure. Hen age, year of production and duration of the breeding season significantly influenced performance in a number of reproductive indicators.
8. **Reproductive traits may need to be expressed in alternative ways if hens are to be compared across different laying periods.** The most appropriate definition of reproductive traits could not be established from the data available. However, clearly where the majority of hens on farm produce over the same length of breeding season, the most appropriate measures of reproductive success are actual egg and chick production.
9. **Genetic improvements in several hen reproductive traits can also be achieved, indicating that breeders should select for improved reproductive capacity.** Hen reproductive traits were generally only lowly heritable. Nevertheless, low heritability estimates generally corresponded to significant levels of additive variation, indicating that improvements can be achieved given adequate selection pressure. Genetic improvement in reproductive traits will depend on adequate flock size and an improved accuracy of selection, the latter of which is usually achieved using advanced genetic evaluation procedures. Maximising current production levels with genetic improvement in reproductive traits introduces some conflict in goals, particularly given the late age at which peak egg production is achieved by hens (around 8-9 years of age).
10. **Service sires older than 11 years of age and/or with poor fertility should be culled.** Fertility traits largely appear to be a function of individual service sire performance. In addition, age of the service sire will significantly influence the percentage of infertile eggs laid by their mate. Males achieved peak fertility in this data between four and seven years of age inclusive. Accurate culling of infertile males will be complicated under repeat pair mating (unless the female effect on fertility is known with accuracy), colony breeding strategies or where mate incompatibility is an issue. Clearly, a relatively rapid turnover of service sires is required for ostrich breeders to maximise rates of genetic gain, whereas commercial producers will wish to retain fertile males for a longer time period.
11. **Research is required to establish factors which affect male fertility (including management alternatives), and for methods of assessing male fertility.** Delayed male fertility, or lack of synchronicity between male fertility and female egg laying, is indicated as a possible cause for poor fertility in this species. It is unclear whether delayed male fertility should be considered as a natural adaptation or a management issue. Little is known about the development of male fertility under alternative management systems, and development of techniques to evaluate male fertility is required, particularly for colony breeding operations.
12. **Hatchability is influenced by both fertility constraints and additional hen related factors. Hatchability of fertile eggs is the trait of interest for comparisons between hens, whereas fertility traits are appropriate for comparisons between males. Current flock performance for hatchability can be improved with appropriate culling.** It is speculated that hen related factors relate to egg weight and egg quality characteristics, although no specific data were available to examine the latter. Although no significant additive variation was detected for hatchability traits, moderate repeatability estimates would indicate that current flock performance could be achieved through culling hens with poor hatchability. However, culling of hens for poor

hatchability should be based only on hatchability of fertile eggs. Further caution is necessary given that refinements in incubation strategies may improve hatchability differentially for individual hens. Finally, given the overall poor hatchability of ostrich eggs, identifying causal factors influencing hatchability should remain a research priority in this species. One such factor may be clutching patterns.

13. **Significant factors influencing chick mortality are unknown, and research is required in this area.** Farmers contributing to the reproductive questionnaire generally reported relatively high levels of chick mortality (median values of ~18-20% at three months). Further studies are required to address almost complete lack of knowledge in the area of predicting ostrich chick mortality.
14. **Better dissemination of accurate information is obviously required to minimise the frequency of extremely poor performance levels achieved by less experienced producers within the Industry.** Survey results indicate the mean performances for farmed ostriches are approximately 20% infertile eggs, 64% hatched of eggs incubated, and total chick mortalities of 7, 17 and 26% at 1 week, 1 month and three months. Median results indicated similar fertility and hatchability figures but lower chick mortalities. Very poor results are only infrequently indicated within a producer, but their frequency across producers in the Industry would suggest lack of a strong knowledge and communication base within the Industry.
15. **Achievable production goals are: less than or equal to 10% infertile eggs; 10% chick mortality at three months; and greater than or equal to 75% hatchability or 85% hatchability of fertile eggs.** Survey results also indicate that significantly higher levels of reproductive performance can be achieved than is indicated by the mean performance, or alternatively the performance achieved by 50% of producers (median performance). Hatchability in excess of 85% of fertile eggs can be achieved, and should be aimed at by both producers and contract incubation facilities. Fertility levels and chick mortality at three months of 10% or less would also appear achievable with reasonably mature male birds. Producers should aim for high reproductive performance, while allowing for factors which may hinder their flock's ability to meet these goals. These factors include flock age, the influence of different breeding structures and mating ratios, and management and nutrition etc, the effects of which could not be accurately quantified from survey information. It is undesirable to directly compare reproductive performance of farmed ostriches with performance of other domestic poultry species given the very different management conditions under which these species perform, and the fact that many poultry studies consider measurement made during only one laying cycle.
16. **Survey results indicate that further work is required to identify factors contributing to the reduced efficiency of chick production with increasing scale of operation**. It is speculated that the loss of reproductive efficiency with increasing hen numbers can be at least partially attributed to reductions in incubation efficiency, and may necessitate refinement of incubation procedures to that which will allow for natural variation in egg characteristics between individual hens and due to mixed flock age structures. However, other management-related factors may also be important.
17. **A larger quantity of well-structured data is required to accurately separate genetic from permanent environmental effects for hen traits**. **Larger scale breeders should be encouraged to pursue accurate performance recording to achieve these aims.** This would allow genetic correlations between traits to be estimated more satisfactorily. Further, ideally parameters should be estimated from more than one population of individuals. Averaging of parameters across populations and environments can provide estimates that are more robust under environmental variation (including management) and which are less population specific.

8 Appendices

8.1 Appendix A: Guidelines for ON FARM Performance Recording in the Australian Ostrich Industry

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Introduction

Accurate pedigree and performance records are essential for assisting in both management decisions and for genetic evaluation. In all major livestock species, individual performance recording is widely carried out at least by the breeding sector of the Industry, and to a lesser extent in commercial sectors where records on individuals may aid in culling and management decisions. In the breeding sector, costs of recording and genetic evaluation are recouped through higher purebred productivity and sales of superior breeding stock to other industry sectors at a premium. The Industry overall is advantaged by performance recording through both current generation gains and with dissemination of genetic improvement. Both non-genetic and genetic improvements can not be obtained, however, without some form of objective measurement of performance, coupled with accurate genetic evaluation systems.

The Australian Ostrich Industry is a comparatively young Industry, and financial gains to date have primarily arisen from the multiplication of breeding stock. However, it is apparent from the low availability of performance data in the Australian Industry that very little consideration has been given to improving productivity in the longer term. It is essential that Ostrich owners identify their role in the Industry, either as a breeder or commercial producer, and performance record appropriately. This will ensure that significant genetic and non-genetic improvements will be possible in the Industry.

This document provides guidelines, developed after working with Australian field data, for effective pedigree and performance recording for reproduction and weight traits in the Australian Ostrich Industry. In the longer term it is envisaged that slaughter traits and hide quality traits will also be recorded. However, these types of traits will be recorded off-farm and are not included in these guidelines.

Rules for Accurate Recording of Pedigree

Good pedigree information provides unambiguous and unique parental information on individual birds over all generations in the data. In ostriches, accurate recording of this information is complicated by the following factors:

- several mating types may be used (e.g. pairs, split pairs, trios, colonies)
- individuals may be replaced within a breeding group throughout the long breeding season
- breeding season lengths are variable, and the location of some birds may change
- there is potential for loss of permanent identification between conception and adulthood through egg, chick and juvenile transfers, particularly if high chick mortality discourages the use of microchips at an early age.

Observing the following recommendations will help to alleviate problems that may be encountered in the data due to the above factors.

- **Use Permanent identification**
  Permanent identification should be assigned as early in the life of an individual as possible. If permanent IDs are assigned at hatching, this alleviates the problem of tracing a series of temporary IDs throughout an individuals lifetime, decreasing the potential for pedigree errors.

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- **Permanent ID’s should be unique, easily read without error, are not re-usable, and have a low probability of becoming detached from the bird.**
  Micro-chips ensure that the bird is identified throughout its lifetime with the same unique ID. Re-using micro-chips or permanent IDs for different birds, or altering these IDs upon some specific event (e.g. death) in your recording system, makes it very difficult to trace a bird from season to season, or pedigrees from parent to offspring. The AOA can store up to three chips for permanent identification, allowing for electronic failure or “loss” of original chips. Consequently, breeding birds and potential breeding replacements should all be microchipped. It would also be advantageous for breeders to identify slaughter birds with microchips to ensure feedback of carcass data when this becomes available.

- **Where early permanent identification is not feasible, temporary identification methods can be used if they ensure unique identification of individuals.**
  Temporary identification numbers are usually assigned to animals at the same time as some other identifying code (e.g. year/season of birth). Used *together* these codes create a unique signature identifying individual birds. The same signature must not be present in the data for different animals at any stage.

- **Information on breeding groups should be recorded.**
  The type of mating structure used (e.g. Pair, Trio, Split Pair, Colony), the start and end dates for the specific group of mating individuals involved, and the pen in which they are located should all be recorded. Identifying separate mating types allows parentage to be confirmed or otherwise in the data. For example, the sole male in a trio will be a known sire of resulting eggs/offspring, whereas the dam will be considered as unknown. This is not the case generally for colonies, where all parents in the pedigree would be listed as unknown.

- **Only record *permanent IDs of definitely known parents* for the pedigree of any particular egg/chick/individual.**
  Known parents of offspring should always be identified by their permanent ID. This is particularly important if outside agencies will be analysing the data. It is not possible for data to be altered manually for analyses in many cases.

- **Where facilities allow, choose to maximise pedigree and other information recorded by using management structures which improve the usefulness of data collected.**
  For example, rather than running trios, the split-pair management option can be a valuable tool for maximizing known pedigree of chicks, and allows direct evaluation of female reproductive performance. Where trios or colonies are the only mating types which may be accommodated on the property, it is still possible to make some use of the pedigree data from these systems if sibs are present together in a mating group. For example, the reproductive performance of full (more so) or half (less so) sisters mated to a single male in a trio will contribute information to the breeding value (estimated genetic merit) of their own sire and dam for reproductive traits. Consequently, although it may not be possible to distinguish between the sisters themselves in this case, it is possible to distinguish between the offspring of several sires and dams for reproductive performance.

Recording Reproductive Data

Recording reproductive data on males and females is intrinsically tied with recording pedigree information of their progeny. However, apart from identification issues relating to the breeding group, it is essential to know event dates and the fate of each egg in order to accurately evaluate reproductive performance and productivity of breeding birds. Further, it is impossible to obtain meaningful information on the reproductive performance of different individuals if there is selective recording of particular individuals or eggs (e.g. broken or unset eggs are not recorded in the data), or where individuals are recorded over different, but unknown from the data, time periods. The following guidelines should be adhered to.

- **Record EVERY egg laid and its fate.**
  If details are recorded only on eggs which were incubated, it is not possible to accurately calculate variables describing the true reproductive performance of individual hens, or identify potential causes of poor reproductive performance.

- **Essential information for each egg laid includes:**
  - a unique egg identification number.
  - known parent(s) and/or mating group ID.
  - date of lay.
  - whether the egg was incubated or not (i.e. fate of egg - stage 1).
  - date and weight at setting. If eggs are routinely set in batches, and/or may be set in more than one incubator, these details should also be recorded.
  - date of hatching or discarding (fate of egg - stage 2). NB. Only eggs that have been incubated should be coded as failing to hatch due to infertility or embryonic mortality.
  - For eggs that hatch, the resulting unique chick identification number should also be noted

- **Optional details include:**
  - egg weight at lay. It is highly desirable that egg weight at set is recorded, given that set egg weight appears to be a significant factor influencing hatchability More (1996). Whether egg weight at lay also needs to be recorded is yet to be determined, given that it is likely highly correlated with weight at set. Consistent recording of weight at either lay OR set is desirable.
  - condition of egg and any variation in management procedures. For example, washed versus unwashed, or fumigated etc.
  - Intermediate weights between setting and hatching.
  - reasons for discarding. This includes reasons for both stages 1 and 2. For example, an egg may be discarded before incubation due to a cracked shell or poor shell quality, or discarded during the incubation process due to embryonic death etc.
  - chick weight at hatching.

  These details, which are often recorded by breeders, are considered ‘optional’ as they are less essential for genetic evaluation of breeding pairs or individuals for general reproductive traits. An exception is where it is wished to identify whether there are genetic causes of variation in infertility, embryonic mortality etc. Moreover, this type of information may be important for improving routine management.

- **Minimise written comments and/or provide unique codes to describe specific events or outcomes.**
  Excessive detail in the way of written comments makes little sense from the perspective of data analyses. However, using several unique codes to describe particular outcomes makes it possible to store a lot of detail on the fate of individual eggs, chicks and birds in a useable fashion. For example, disposal codes will make rapid entry of information relating to the fate of each egg or bird possible. However, for any variable (e.g. reason for disposal) described by codes, it is important to make sure each code is used for a single purpose, and not changed throughout different time periods in the data set. If there are any changes to the codes used, the date when codes were changed must be recorded also.

- **Use a unique code to describe breeding groups in a given pen environment.**
  If the breeding group is shifted in entirety to another pen, or the members of a breeding group retained in the same pen are altered, this should result in the breeding group being assigned a *new* breeding group code. Further, for each breeding group code, the start and end dates of that particular group in that location should be recorded. This information will eventually allow pen

environment effects to be separated from bird differences affecting reproductive performance (providing the same birds are not always in the same pens). The breeding group code should also be accompanied by a mating type code as was noted above to facilitate checking of pedigree information.

Recording Weight Data

Weight records are required if improvements through selection in final weights, or rate of growth until slaughter, are to be made. Consequently, at least final or slaughter weights for individual birds should be recorded. However, the recording of intermediate weights between hatching and slaughter will also provide the opportunity to examine growth patterns. This has relevance where slaughter ages may range from say 10-12 months (for efficient meat production), to later ages and higher weights (e.g. 14-16 months) where high quality skin end products are also targeted. Several ages in the growth curve of ostriches may be targeted as potentially useful to record weights. These include:

- **at hatching:** related to later weight gains as well as early survival.
- **at three to four months of age:** following the time period of high mortality, and often coinciding with changes in chick management.
- **at ten to twelve months of age:** where weighing individuals prior to slaughter is of dual benefit (facilitating management of target weights and evaluation of potential breeding birds).
- **at sixteen months (or similar):** as above but where later slaughter ages are targeted.

Given that several weights may be of interest, the following guidelines may help you determine a suitable strategy for recording weights.

- **Along with hatching and slaughter weights, it is desirable to record at least one intermediate weight at a specific age on all birds.**
  It is important to select the specific age at which weights will be recorded to ensure that useful volumes of data are generated. Continually changing the average age at weighing over time restricts the usefulness of weight records.

- **Record the management groups of birds at weighing.**
  A management group refers to any group of birds managed together in the same way. Birds reared together in the same pen/paddock over the same time period, given access to the same diets and routine care, constitute a management group.

  For birds which have been managed differently, it is important to record this in the database as a separate management group. For example, if birds are reared in different paddocks, fed significantly different diets or additives, or have been sick and treated or removed from their contemporaries, this information should be available in the data (preferably coded). In order to make fair comparisons between individuals for genetic merit, it is necessary to know when they have been managed differently or were ill for a period, as these factors could cause differences in performance which may otherwise be mistaken for genetic differences.

- **Assuming that birds of similar age are going to be reared together, it is important to weigh *all* birds within a management group at the same time, even if only some of them will reach, for example, target slaughter weights.**
  It is more informative to compare animals within larger rather than smaller groups. Effects such as differences in age at weighing can be easily accounted for in analyses.

- **Essential information for each weight recorded includes:**
  - chick or bird identification (preferably permanent)
  - date of weighing
  - management group of the bird at the time of weighing
  - unadjusted bird weight to the appropriate accuracy of the scales used

Selection of Software for Performance Recording

Large volumes of data can not be efficiently maintained and analysed when stored manually, so it is important to find computer software which will store the data in a useful form. The following features are present in good performance recording software, and should be considered when evaluating software alternatives.

1. Pedigree and performance data can be stored for specific individuals.
2. Fail-safe devices are present to prevent re-use of temporary and permanent IDs for new entries.
3. Simple data checking systems are inbuilt to ensure that data entries lie in a valid range. Outlier records should be audibly alarmed on entry, but it is possible to override the alarm if the entry is valid.
4. The software is user friendly, easy to navigate and understand, with a GOOD reference manual and on-line HELP.
5. It is possible to achieve rapid entry of new data for all of the performance traits of interest. The software should differentiate between mandatory and non-mandatory data, and issue appropriate warnings when important information (for example, egg identification) is missing.
6. It is possible to generate useful summary statistics with a very clear description of how such statistics are calculated. Graphical display options should be available. This helps spotting outliers and discrepancies in the data.
7. Stored data can be downloaded into external files in a variety of formats.
8. The software is provided with prompt and efficient support from the supplier.
9. There is a fail-safe backup and restore facility, and ideally the recording system is recoverable to the last completed entry prior to a power failure.
10. Flexibility exists to record with an eye on current and likely future productivity issues.
11. The software is based on a widely used database system (e.g. Microsoft Access, Borland, Paradox or FoxBase) to enable migration of data to another recording system should the current one prove inadequate or poorly supported. Recorded data is a valuable resource, so the ability to migrate it to alternative systems must be possible should the need arise.
12. The software is not limited as to the amount of data that can be recorded.

It is important to note that good PERFORMANCE recording software is not necessarily a recording system combined with accounting and other farm or ostrich specific management facilities. However, species specific software packages for Ostriches are available in the Australian Industry. Other alternatives which exist are generic across species, but have many of the features desirable for accurate and efficient performance recording in the Ostrich Industry.

Finally - Failure to Performance Record will Hinder Progress in this Industry!
Without routine and accurate performance recording, it will be difficult for the Australian Ostrich Industry to focus on improving productivity either through non-genetic and/or genetic approaches. For those who wish to remain in the Industry with a profitable enterprise, I encourage you to consider at least where you are at, where you are going, and how best to get there. It is unlikely that the Industry overall will significantly improve on farm productivity without good performance recording first, followed by genetic evaluation and selection in the seedstock sector. To do this, you must have a workable strategy! Decide what is feasible for you to routinely and consistently record, and what is important to record for your enterprise. In this way, you are more likely to find performance recording manageable and useful. In this report, some guidelines are provided which will facilitate the effective recording of information within the Industry.

Acknowledgments

I would like to thank those Ostrich breeders who provided us with their on-farm data for the benefit of the Australian Ostrich Industry.

References

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Summary of Information Required for Performance Recording

The following table contains a summary of the information required for pedigree and performance recording of reproduction and weight traits of individual birds, subdivided into categories of interest. It should be noted that there can be some duplication of information recorded in different categories. However, this is an issue of database organisation and does not mean that information should be re-entered separately into different database files. The exceptions to duplication are identification details which are used to link data from different information categories.

Table 1: Summary of Data Required for Performance Recording

Information Category	Information recorded	Comments	Frequency of Recording
Breeding group	Group ID - list all members (Perm_ID) Starting date End date Pen/Paddock number		Group identification and details should be recorded when: 1) the season starts 2) group members change 3) group location changes
	Mating type (eg) - Pair, Trio, Quad, Colony	Best described with a simple coding system	
Egg details	Egg ID		For EVERY egg
	Group ID	Link to pedigree info.	
	Lay date Weight at laying (optional?)		
	Shell quality* - normal, chalky, etc.	Best described with a simple coding system	
	Egg treatment* - untreated, washed, etc.	Best described with a simple coding system	
	Set date Weight at setting (optional?) Incubator No. Batch No.		For every egg set
	Egg fate - not set, infertile, embryo death, dead in shell, hatched, etc.	Best described with a simple coding system	For every egg
	Discard Date		For every which failed to hatch
	Hatch date		For every egg hatched
Incubator details (optional)	Incubator No. Date/time of recording Temperature - internal, external Humidity - internal, external	For routine incubator management and for trouble shooting. Little value for performance recording	Often daily or twice daily
Egg weight details (optional)	Egg ID Incubator No. Date of weighing Egg weight	Often not routine for all eggs and therefore of limited value for Performance recording	Usually weekly

*Optional or additional information

Table 1 (continued)

Chick details	Chick ID Egg ID Weight at hatching Chick condition at hatch* - weak, strong, oedematous Defects at hatch* - congenital defects Chick fate at one week - alive, sick or dead (+cause) Date of death	Link to egg details Best described with a simple coding system Best described with a simple coding system Best described with a simple coding system	At hatching and in first week for *all* chicks which hatch
Bird Identification and Pedigree Details	Egg ID Chick ID Temporary ID Permanent Bird ID Permanent ID of Sire Permanent ID of Dam (Acquired) Defects* - tibiotarsal rotation Date defect noted* Bird fate at three months - alive, sick or dead (+cause) Bird fate after three months* - slaughter, breeding, died etc.	From breeding group details or DNA samples Best described with a simple coding system Best described with a simple coding system Best described with a simple coding system	Updated as required
Bird weights	Bird ID - temporary or permanent Date of weighing Weight Management Group	Method of identification should be consistent for all birds	At selected significant ages

*Optional or additional information

From complete information, such as outlined above, it is possible to evaluate male and female reproductive and production traits. For example, this database would allow the evaluation of:

- No. of eggs laid and set
- No. of eggs hatched (as a percentage of those set and/or fertile)
- No. of chicks surviving to 1 week or three months (as a percentage of those eggs hatched), to assess productivity
- Weight gains - early and juvenile, or mature weights if recorded
- Any of the above considered over specific time intervals

Further, to analyse these traits in such a way as to make valid comparisons between birds, the known and possible environmental factors which may have affected performance of individual birds must also be accounted for. These are also present in the database directly, or can be calculated. For example, the number of eggs laid may have been influenced by the ages of the breeding birds, seasonal effects, mating type or management systems used (including diet), and breeding pen environment. The necessary details for each bird would be present in the above database.

8.2 Appendix B: Significant genetic parameters for egg, chick and juvenile weight traits in Ostriches

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SUMMARY

Estimates of genetic parameters for egg weight (EWT), day old chick weight (CHWT), and liveweights recorded at ten (LW10) and 14 months of age (SLWT) in ostriches were obtained under an animal model using 24 745 egg records from a large commercial South African operation. Heritability estimates for these traits were generally moderate to high (0.21, 0.13, 0.42, 0.45). Age of the breeding hen influenced egg and subsequently chick weights. Furthermore, additional random effects of hen (independent of age) and breeding paddock were significant for egg (0.26 and 0.38) and chick weights (0.31 and 0.29), but insignificant for weights recorded at later ages. Parameter estimates obtained indicate that selection for improved performance is possible in ostriches.

Keywords: Ratite, heritability, variances, animal model.

INTRODUCTION

In established livestock industries genetic evaluation systems have enabled selection of superior breeding stock for many traits, and resulted in visible genetic improvement. However, for relatively new industries, such as the ostrich industry, little is known about the genetic basis of observed variation in recorded traits, and breeding programs are yet to be developed. Use of selection to improve productivity implies that the selected traits are under some degree of genetic control. Genetic parameters for traits recorded in ostriches have not been estimated previously. The potential contribution of genetic improvement to increased monetary revenue in commercial ostrich operations is usually derived from parameters estimated for similar traits in poultry. This is less than ideal given the very different management conditions under which ostriches are maintained.

Obtaining genetic parameters for performance traits of ostriches has been hindered by several factors. Firstly, colony mated ostriches share communal nests and the parentage of eggs will often be unknown. Such data obviously cannot be used for parameter estimation until parentage can be established using appropriate techniques (eg. DNA fingerprinting). Secondly, there is evidence to suggest that ostriches are induced breeders, territorial, and may create bonds with their mate when bred as pairs. Traditional mating strategies that allow for these characteristics (repeat mating of the same pair in the same breeding paddock, year after year) will compromise data structure with regards to parameter estimation. In addition, the potentially long productive life of ostriches limits the turnover of breeding stock. Management issues and large numbers of offspring also restrict breeding flocks to a small size. These factors currently contribute to a very limited pedigree depth for reproductive traits in particular, but also for other production traits.

In this study, genetic parameters were estimated for egg, chick and juvenile weight traits of ostriches using data from a large commercial pair breeding flock located in South Africa. Knowledge of genetic parameters will facilitate the development of effective genetic evaluation systems in the ostrich industry. The identification of non-genetic factors also affecting these traits is implicit in this process.

MATERIALS AND METHODS

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[*] The AGBU is a joint institute of NSW Agriculture and the University of New England

24 745 egg records were used from an ostrich breeding flock maintained on the Klein Karoo Agricultural Development Centre, near Oudtshoorn, South Africa. Parents of eggs were known, representing 159 different breeding pairs mated over six seasons. Two parental strains of birds (feather quality and commercial strains) were present in the data. A high percentage of pairs were repeat mated over years, often in the same breeding paddock, with only 16.5% of breeders having more than one mate over time. Management of breeding pairs and eggs are described in Van Schalkwyk *et al.* (1996) and Cloete *et al.* (1998). All breeding pairs received the same diet throughout the annually defined ± 9-month breeding season. Day old chick weights were recorded for eggs which hatched, and liveweights were recorded at approximately ten and fourteen months for a limited number of birds reared to slaughter age. No incubation details for eggs, or management details for birds reared to slaughter, were included in the data set. Specific weighing dates were also not available, but it is known that chronological age varied within age groups. All chicks received the same complete diet during the growing out phase.

Appropriate fixed and random effect models were developed, and parameter estimates obtained, using ASREML software (Gilmour *et al.* 1998). This program estimates variance components under mixed models by restricted maximum likelihood, and employs an average information algorithm which concurrently provides estimates of standard errors for parameter estimates (Gilmour *et al.* 1995). An animal model, treating each egg record as an individual, was used to estimate variance components.

RESULTS AND DISCUSSION

Characteristics of the data are presented in Table 1. Substantial variation was evident for all recorded traits, as expected, with coefficients of variation ranging from 9.8 for egg weight to 14.8 for liveweight at 10 months. Distributions of records were approximately normal for all traits.

Significant fixed effects identified for each trait are presented in Table 2. Year and/or month effects were significant for all traits recorded. Age of hen at breeding further influenced egg and chick weights. Relatively low R^2 values for the fixed effects models for juvenile weights suggested that significant factors influencing recorded traits were unknown. By contrast, high estimates of random effects for egg and chick weights suggest that much of the variation in these traits would not be accounted for with additional fixed effects. However, use of incubation details for eggs and chicks or rearing and weighing details of juveniles may improve fixed effect modelling for these traits.

Chick weight is highly correlated with egg weight in many avian species (Wilson 1991), being almost fully described by initial egg weight, incubation loss and weight of the remaining shell and residues. In this study egg and chick weights were considered as separate traits. Consequently, chick weight was unadjusted for egg weight. Similarly, juvenile weights were unadjusted for day old chick weight despite the presence of a significant positive relationship between these weights.

Table 1. Number of records (N), mean, raw data standard deviation (SD), coefficient of variation (CV) and data range for egg weight (EWT), day old chick weight (CHWT), and live weight at 10 months (LW10) or slaughter (SLWT)

Trait	N	Mean	SD	CV	Range
EWT (g)	24745	1419	139	9.8	859-1945
CHWT (g)	11452	850	98	11.5	505-1234
LW10 (kg)	843	82.7	12.2	14.8	44-120
SLWT (kg)	687	109	12.5	11.5	62-150

Table 2. The number of dams, sires and breeding paddocks represented, along with levels of fixed effects (ns=not significant, excluded from model) and proportion of variation explained by the fixed effects included in the model (R^2), for individual ostrich traits

Trait	Number of			Year	Month	Y×M	Hen age	R^2
	Dams	Sires	Paddocks	(Y)	(M)		class	(%)
EWT (g)	134	133	102	6	10	36	7	5.7
CHWT (g)	126	124	99	6	9	36	7	6.1
LW10 (kg)	72 (ns)	72 (ns)	64 (ns)	3	5 (ns)	11(ns)	6 (ns)	5.6
SLWT (kg)	77 (ns)	78 (ns)	69 (ns)	4	6	14(ns)	6 (ns)	14.2

Year: year of lay; **Month:** month of lay; **Y×M:** interaction term; **Hen age class:** class 1: 2-3 years old; class 2: 4-6; class 3: 7-9; class 4: 10-12; class 5: 13-15; class 6: 16-18; class 7: 19-20.

Strain effects. No significant differences between genetic group solutions of feather and commercial strains were apparent for egg weight, chick weight, and weights recorded at 10 months of age or slaughter. There was some indication ($P<0.10$) of direct (positive) and maternal (negative) heterosis for both egg and chick weights, although not significant at the 5% level. Subsequently, genetic parameters presented in this paper were estimated from a model excluding terms for strain or heterosis.

Other fixed effects. As expected, seasonal effects such as year and month of recording significantly affected performance in the traits recorded. Age of the hen was a significant factor influencing egg and chick weights, but not liveweights recorded at later ages. Other factors examined that had no significant impact on any of the above traits included sex of chick (often unknown in juveniles) and age of the male bird at breeding.

Random effects. In addition to age of hen effects on egg and chick weights, significant additional random effects of the hen and breeding paddock were identified. These effects may occur due to reproductive characteristics of individual hens (eg. egg production differences) and variable suitability of breeding paddocks. Potential service sire effects were confounded directly with sire in these analyses, but are not expected to have any impact on egg or chick weight over direct genetic effects.

Estimates of genetic parameters for each trait, along with their standard errors, are presented in Table 3. With the exception of chick weight, heritability estimates for the remaining traits were moderate to high, indicating that improved performance may be achieved in these traits through selection. Estimates of heritability for juvenile weight traits are higher than those found in poultry (Koerhuis and McKay 1996), but suggested by a high repeatability for mature weight in ostriches (Van Schalkwyk *et al.* 1996). Large estimates for the additional random effects of hen and breeding paddock signify the importance of maternal and breeding paddock effects on egg and chick weights. The data did not allow the separation of maternal genetic from maternal environment effects.

Table 3. Heritabilities (h^2) and the additional random effects of the hen (c^2_{hen}) and breeding paddock ($c^2_{paddock}$), where significant, for egg weight (EWT), day old chick weight (CHWT), and liveweight at 10 months (LW10) or slaughter (SLWT), along with phenotypic variances (σ^2_p)

Trait	h^2	c^2_{hen}	$c^2_{paddock}$	σ^2_p
EWT (g)	0.21±0.06	0.26±0.06	0.38±0.07	22493
CHWT (g)	0.13±0.06	0.31±0.06	0.29±0.07	11900
LW10 (kg)	0.42±0.09	-	-	142
SLWT (kg)	0.45±0.10	-	-	136

Typical ostrich breeding practices complicate estimation of random effects because of confounding between mating pairs and their breeding paddock and the tendency to repeat mate established pairs over several seasons. Consequently, it can be difficult to distinguish between potential paternal, maternal and breeding paddock effects in the data. Additional analyses treating egg and chick data as repeated traits of the hen may help to elucidate the most appropriate random effect models for these traits. More suitable data for analysis will only be achieved with the introduction of innovative mating systems. Ostrich industries need to be challenged with this goal.

ACKNOWLEDGMENTS

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8.3 Appendix C: Ostrich Reproduction Questionnaire

This questionnaire may best be viewed from:

http://www-personal.une.edu.au/~kbunter/questionnaire.html

8.4 Appendix D: Performance recording for a genetic evaluation of ostriches.

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Introduction
The Australian Ostrich Association together with the Rural Industries Research and Development Corporation (RIRDC) are funding the Animal Genetics and Breeding Unit (AGBU) to research and develop a genetic evaluation system for the Australian ostrich industry. This will allow ostrich breeders to then select genetically improved stock that enhance the profitability of the industry.

AGBU is a research unit jointly run by NSW Agriculture and the University of New England located on the campus of the University in Armidale, NSW. AGBU has for more than 15 years been developing genetic evaluation systems for the beef, dairy and pig industries. Its best known works are PIGBLUP and BREEDPLAN Australia's pig and beef cattle genetic evaluation systems. Both are available through the Agricultural Business Research Institute (ABRI) the Australian Ostrich Association's central pedigree processing center.

To develop a similar system for the ostrich industry AGBU is looking for the cooperation of many ostrich breeders. This article will outline the requirements for performance recording as it relates to genetic evaluation.

Why recording for genetic evaluation
Modern genetic evaluation systems are based on objectively measured records and pedigree information. The aim is to compare the performance of birds under the same management and combine this with the information on relatives in the same and other flocks to provide a ranking for young and old birds for all economically important traits. The results of the calculations are Estimated Breeding Values (EBVs) for each trait recorded. These EBVs can be weighted economically and combined in one index value.

Genetic selection only makes sense if at least part of the differences between animals are caused by the genetic makeup and are therefore passed from parents to progeny. There are many reports about the differences of production characteristics (eg. Eggs laid, eggs fertile or eggs hatched) between pairs. We also know that some of the performance differences are well repeated from year to year. It therefore makes sense to cull low producing birds, but we know very little about how much of the difference in the performance of birds is passed to progeny, or in technical terms is heritable. Therefore the first goal of our project is to estimate the heritability and the genetic relationships between different traits starting with the fertility traits: number eggs laid, number of fertile eggs, number of eggs hatched.

The data
To be useful in the first step of our work the hens laying the eggs and the cocks mated to the hens must have their pedigree recorded together with their birthdates. This information is readily available in the database at ABRI for many birds. Birds selected in the wild will be of unknown parentage and most likely unknown age. Their data can not be used in the study of the heritability of the fertility traits. However, for these birds EBVs can be estimated once the heritabilities for fertility traits have been estimated from the pedigree data. The following information is required in a database:

- **Pedigree of cocks and hens and their birth dates, together with breed**

- **Pedigree of egg (pairs or trios)**
- **Day egg laid**
- **Day egg set**
- **Day egg hatched**
- **Egg fertile or unfertile**
- **Chick survival in first week**

Of additional benefit might be egg weight and weight loss during incubation, but this is not mandatory.

If you have more than one incubator these incubators should be numbered and the number should be recorded for each egg, particularly if you set eggs on the same day in more than one incubator.

Mating pairs or trios run in separate pens. The size, direction, wind exposure can effect the performance of the birds and therefore pens should be numbered and recorded. In any one year the performance of a pair may be biased by being in a good or bad pen. However, if pairs change pens each year, we might be able to adjust for good and bad pens at a later stage. A way to fairly compare pairs each year might be to frequently rotate pairs during a season from pen to pen, if this is at all feasible.

Some of the information we asked to be recorded might seem to be excessive, but our aim is to separate genetic from environmental effects. Currently we don't know which environmental effects are important and we can only find out if we record the information and assess the effect on the performance of animals.

Records for survival and growth

After hatching survival and weight gain of individual chicks are the next important traits we want to evaluate. Therefore we recommend weighing birds at 3 or 4 month of age and again at around 10-12 month. It is very important that all birds in a group/pen are weighed on the same day. We will lose a lot of information if you sell and weigh the strong birds at 3 month of age and the lighter ones four weeks later. So it is best to weigh all birds at three months and record the weight for each bird. You then don't have to weigh them again at 4 months. Please no selective weighing !

It is also important that progeny from different pairs are running together in a group, because only then can we compare the parents. If you have a number of pens for the chicks as is usually the case, number the pens and record the pen number with the weight for each animal (like the incubator). Pens might be an important contributor to the differences in chick growth and survival. Therefore record the following:

- **Weight at 3 to 4 month**
- **Date of weighing**
- **Pen number**

Chick survival is obviously a very important trait and large differences between the progeny of different pairs are reported. However in other species genetic differences are commonly very difficult to detect as the environment plays a very big role. Therefore it is important that any identifiable events which have nothing to do with the animals but cause the death of a chick is recorded. Such events are eg. a dog attack or loss of birds in a panic movement of the whole flock. Your veterinarian also would like to see that you record identifiable deceases as part of his total health program for your flock. If one can agree on a commonly used key for different health problems we might be later able to investigate if genetic differences for the prevalence to specific health problems exist. The same is of course also true for any deformities.

Records for carcase and leather quality traits

Carcase traits like meat yield, fatness or meat quality will have to be recorded in the abattoir and leather or feather quality will be scored by trained experienced staff. This requires planning and discussions with the industry. We will try to develop such a scoring and recording system with the Ostrich Company, however this is about a year away. Of course it is very important, that we are able to identify carcases and hides in a way that allows us to merge this data with your farm information particularly pedigrees. All this will eventually be done electronically.

Points to keep in mind

An important aspect of performance recording for genetic evaluation is the uniqueness of animal identification. An animal should only have one unique number regardless how often it is sold. Never should two animals have the same number. For our work the ownership of the birds is not important. What is important is a clear definition of management groups from start to the end. This includes incubators, chick pens, grower pens and finisher pens as well as slaughter group. The larger the groups the more information we will have and the more accurate the evaluation will become, however there is little gain made going from 20 birds in a group to 50 provided the birds are from different parents. The more parents presented in a group the better. The best is an equal number of progeny from each pair. It is also important to know that management group effects might carry over for quite some time. Eg. if a consignment of 20 slaughter birds consists of 10 birds each out of two paddocks, the real group size for meat quality traits might only be 10 birds, if the paddock (management group) has an influence on meat quality. Many management practices, which make common sense to maximise output, can become detrimental for genetic evaluation if not properly recorded, eg. if at around 3 month of age young birds are classed according to their size (weight) and placed in different grower paddocks without this being recorded, any genetic evaluation that follows will be seriously biased.

How to record

The Agricultural Business Research Institute has developed a recording system which allows all the data for fertility traits to be centrally stored and analysed. Growth modules will follow shortly. AGBU will have access to this data. However we are also interested to hear from anyone who uses a recording system on a PC if it has included the information mentioned above. We will try to advice you how to download the data on a disk so that we can utilise it in our analysis.

We have developed this research project for a postgraduate student who we hope will start in early 1997 and will work for at least two and a half years. So results will not be available for the 97/98 mating season. However the more data we can access early in the project, the better we can design future recording needs and tell you what are the very essentials and what might be add ons for use in genetic selection.

One important message at the end. Not every ostrich farmer can be a seedstock producer who is going to sell highly selected and genetically proven birds. Most farmers will be ostrich producers which sell all their birds for slaughter. They might run parent birds in larger groups so are unable to record individual pedigrees and their scope for genetic improvement is therefore limited. These producers then have to rely on the seedstock breeders to provide them with genetically superior stock recorded and evaluated for all economically important traits.

If you can contribute to our project and for any questions you might have please contact: Dr. Hans Graser Technical Director. Animal Genetics and Breeding Unit, University of New England, Armidale 2351 , NSW Tel: 067 733332 Fax 067 73 3622 or email: hgraser@mendel.une.edu.au

8.5 Appendix E: Performance Recording and Estimated Breeding Values

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ABSTRACT

This paper outlines the requirements for performance recording as it relates to genetic evaluation. Unique identification of animals and complete recording of performance in large groups with progeny of different parents are the keys to quality data, which allows the estimation of breeding values with increased accuracy. Estimation of breeding values is best done with sophisticated computer programs on a regular basis. As an example EBVs from pigs are discussed.

INTRODUCTION

Modern genetic evaluation systems are based on objectively measured performance and pedigree information. The aim is to compare the performance differences of animals under the same management and combine this with the information on relatives in the same and other flocks to provide a ranking for young and old animals across all groups for all economically important traits. The results of these calculations are Estimated Breeding Values (EBVs) for each trait recorded. For ease of use and for maximum economic selection response these EBVs can be weighted economically and combined in one index value. Such evaluation systems are used today in Australia by the beef (BREEDPLAN), pig (PIGBLUP), dairy (ABV), lamb (LAMBPLAN) and wool industries. This paper outlines the requirements for good performance recording and provides examples for EBVs.

PERFORMANCE RECORDING

Why record performance?

Performance recording allows us to

- Cull unproductive animals to improve current generation performance
- Estimate genetic parameters
- Calculate breeding values for genetic selection

There are many reports in the literature about large differences between ostrich pairs for production characteristics, for example eggs laid, eggs fertile or eggs hatched (Table 1). We also know that some of the performance differences are well repeated from year to year, with repeatability values of 0.35 to 0.5. It therefore makes sense to cull low producing birds after two or even one season and by doing so improve the productivity of the current generation.

Table 1: Mean performance and range for fertility traits of ostrich pairs for a South African flock (Schalkwyk *et al* 1996)

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[1] AGBU is a joint unit of NSW Agriculture and The University of New England

Trait	Mean	Range
No. of eggs per 200 days paired	45.8	0 - 93.2
Infertility (%)	17.1	0 - 100
Embryonic deaths (%)	21.1	0 - 77.1
Hatchability (%)	61.8	0 - 100.0
No of live chicks per 200 days paired	28.9	0 - 83.7

However we know very little about how much of the difference in performance between ostriches is passed from parents to progeny, or using a technical term, what the heritabilities are for the traits of interest. Genetic selection only makes sense if at least part of the differences between animals is caused by genetic differences between animals which will be passed from parents to progeny. Therefore one aim is to use performance data to estimate heritabilities for traits and the genetic relationships between traits starting with the fertility traits (number eggs laid, number of fertile eggs, number of eggs hatched) then growth traits and finally carcass, meat quality and leather quality traits.

What can we expect? The literature provides no information about heritabilities for any trait in ostriches. However poultry have been well studied and we can use these results to see what we might find in ostriches. Table 2 presents heritabilities for a number of traits for different poultry.

Table 2: Heritabilities for some economically important traits in poultry

Species	Trait	h^2
Fowls	Egg production	0.20-0.40
	Shell quality	0.20-0.45
	Feed per kg egg	0.20
Ducks	Body weight	0.15-0.30
Turkey	Body Weight	0.26
	Egg production	0.34

Genetic parameters like heritabilities and correlations are population specific. They are estimated from samples of populations and can vary from one sample to another. Most traits in poultry have low to moderate heritability and can therefore be improved by selection. We must however remember, that poultry is managed under very uniform conditions, e.g. sheds with temperature and light control regimes, where the environmental differences affecting the performance of birds can be minimised.

Extrapolating from these results we might find that between 10% and 40% of the differences between ostriches will have a genetic base and can therefore be passed on to progeny. The remaining differences are caused by the environment and will not be transmitted to the next generation. I expect slightly lower heritabilities for most reproductive traits in Ostriches than those presented in Table 2 due to the fact that the paddock environment is not as standard as the environment in carefully monitored poultry sheds.

To improve the accuracy of genetic selection for traits of low to moderate heritability a sophisticated approach to estimation of breeding values is required. Selecting animals only on their own performance is not the best solution. Because related birds have genes in common, the performance of one bird provides information about the breeding value of related birds as well. To combine the information from related birds and from related traits requires computer programs, which implement modern genetic evaluation systems.

How should one performance record?

Quality data is a prerequisite for accurate genetic evaluations. It is very important to realise that if poor data goes into the evaluation poor results will come out or, the principle of GIGO works very well.

Good data is complete data; this starts with unique numbers for all birds and in the case of ostriches, for all eggs. All birds (eggs) have to be treated equally. Where this can't be done because of management restrictions, so-called management groups have to be recorded. For example different incubators or even different runs with the same incubator might produce different results in the percent of eggs hatched, in which case it would be necessary to record which incubator and run the egg was. Different management of mature birds can affect all reproduction traits, in particular different locations of paddocks (e.g. uphill - downhill) or different sizes. If such differences can be identified they should be recorded, particularly different farms.

Which traits are of interest?

As we know very little about the genetic background of different traits in ostriches we may investigate more traits than we will finally find to be of economic importance. First let us look at reproduction. In my opinion the following information should be recorded:

- Every egg laid with laying date, fate of egg and pedigree

With fate of egg I mean how it is treated, date placed in incubator, fertility status (yes or no), date hatched and incubator number. From this we can calculate the number of eggs per hen per season (or 200 days), the percentage of fertile eggs and the % of hatched eggs. Obviously the most fertile pairs of birds are those which produce the maximum number of chicks with the fewest number of eggs. Infertile eggs and embryonic death are an economic burden; it might be better to get 45 chicks from 50 eggs than 50 chicks from 100. Reproduction characteristics are traits of the hen and cock and in most flocks the number of pairs will be much smaller than 50, which means we will have relatively little data and careful designs are required to get the most from this information. It is important to be able to separate the genetic potentials of males and females. This can only be done if pairs are mixed every season.

- Growth rate of birds

Once a chick has hatched it requires unique identification and the link to its pedigree and egg number. Growth performance after hatching is a record of the bird and we have normally plenty of records for these traits. It is important to identify optimal ages for weighing, and to stick to them in the management routine. Animals should be weighted before they are regrouped e.g. at 4 weeks, 3 months or 10 months of age. It is always important to weigh all animals in the group. Apparent problems which may have affected the performance of individual birds should also be noted, e.g. injuries.

It is best to have records on as many progeny as possible and records on other relatives as well. Having more than one weight is also desirable. This will allow weight records from younger half and full sibs, e.g. 3 month weight, to be utilised when evaluating and selecting 12 month old birds as parents for your own flock or as seedstock animals for sale.

- Carcass and hide characteristics

Recording of carcass, meat and hide quality requires a reliable link between live bird identification and carcass and hide number as well as a good electronic feedback system. As carcass and meat quality most likely vary from slaughter day to slaughter day (slaughter day is defined by abattoir and day of slaughter) it is important to have reasonably large groups of birds for slaughter. These groups have to include birds with different pedigrees to be able to compare parents. Breeding values for live birds for carcass quality traits can only be estimated as the average of their parent EBVs unless we can identify and measure live animal characteristics that are closely correlated to carcass traits. Parent EBVs can only be estimated if animals from different parents are in the same group. From a genetic analysis point of view it is advisable to use sex as a classification criteria if birds have to be regrouped in smaller units. We expect that sex will affect growth, carcass and hide measurements and that the effect will change with different aspects of the environment. This can be accounted for in the analytical model. The high reproductive rate of ostriches will allow high selection intensities and thus fast genetic gain for growth. Genetic gain for carcass and hide traits and for fertility will be slower as the number of animals tested will be considerably smaller.

Selection of replacement birds for the flock is a regular event that happens a number of times during a year whenever birds are ready for slaughter. A timely analysis is therefore required. This can be done either on a within flock basis with a PC or, if sufficient genetic links between flocks exist, on an across-flock basis on a central computer. An across-flock evaluation requires unique and equal identification of all birds, which generate the genetic links across flocks. This is best done through registration numbers, however performance recording and registration are two different things. A serious seedstock breeder should performance record all his eggs and birds. He might choose to only register a small fraction of them.

Performance recording packages for ostriches have to cater for the large amount of data that is generated every year. It is therefore important that they are designed in a way, which allows the performance information to be stored for many years with a minimum of disk space. The performance database has to be restricted to the essential information for genetic analysis; ownership of birds and financial information is not essential data for genetic evaluation. Deleting performance records on a yearly basis makes the database nearly useless for genetic evaluation.

ESTIMATED BREEDING VALUES

As we cannot (yet) identify an animal's genes as they relate to quantitative performance, we have to use performance data and statistical programs to calculate what we call Estimated Breeding Value or short EBV, to indicate an animal’s genetic value for a defined trait. On average one half of an animal’s breeding value is passed on to progeny, with a considerable spread around this one half. As progeny receive half their genes from each parent, the expected breeding value for any progeny is the average of the breeding value of the parents.

As explained previously EBVs are calculated from performance data. The simplest example of an EBV is one calculated from an animal's phenotypic performance deviated from its group mean and then multiplied by the heritability (h^2) of the trait.

$$\text{EBV} = h^2 (P_{\text{individual}} - P_{\text{group}})$$

Multiplying the observed performance difference with the heritability accounts for the already-mentioned observation that only part of the phenotypic differences in performance arise from differences in the genetic makeup. A more accurate EBV can be calculated if one uses the relationship structure among all the birds in the data. Related animals have genes in common and therefore the performance of one animal can tell us something about the expected genotype of related animals. Obviously, the closer the relationship the more valuable the performance data will be. The most valuable relatives will always be progeny and for lowly heritable traits only a large number of progeny will allow us to estimate the breeding value of an animal with high accuracy, or in other words with a small error.

As genes can affect more than one trait, a record on one trait can provide information about another trait. For example, genes that affect growth rate in early life will most likely also have some effect on growth rate in later life. This relationship, if known, can be utilised when calculating EBVs. In the extreme we might even record a trait that is easy to measure but which has no direct economic value if it has a moderate to high genetic correlation with an economically important trait that is difficult and expensive to record. This requires however good knowledge of the genetic correlations between traits. The calculation of EBVs from all relatives and correlated trait data is best done using an 'Animal Model' based on Best Linear Unbiased Prediction (BLUP) technology (Henderson 1975).

With close to a dozen potential traits for genetic evaluation in ostriches, the question arises as to how much emphasis should be placed on each trait. Provided market forces are rational the best way to combine a number of EBVs is an economic index, where each EBV is multiplied by the economic value of the trait under commercial production and market conditions (marginal benefit - marginal costs) and then summed over traits. Calculation of economic values for different traits is a science in itself and requires market experience and industry knowledge. Who knows today what the relative value of ostrich meat versus ostrich leather will be in 3-4 years, the time when today's selection decision will have an effect on the quality of the product you produce. We can help you with this, but essentially you have to make a start and the Index we would derive for you would very much rely on your good judgement.

EXAMPLE OF ESTIMATED BREEDING VALUES

To demonstrate what EBVs can do for the ostrich industry I would like to use pigs as an example. With their large litters and short generation intervals they come closest to the ostrich of any livestock we have worked with so far. Number of piglets born alive (NBA), average daily gain (ADG) and back fat (BF) are the most commonly recorded traits in pigs. Table 3 presents a list of young boars, performance tested for growth and back fat with their EBVs and a $ Index from an Australian breeding company.

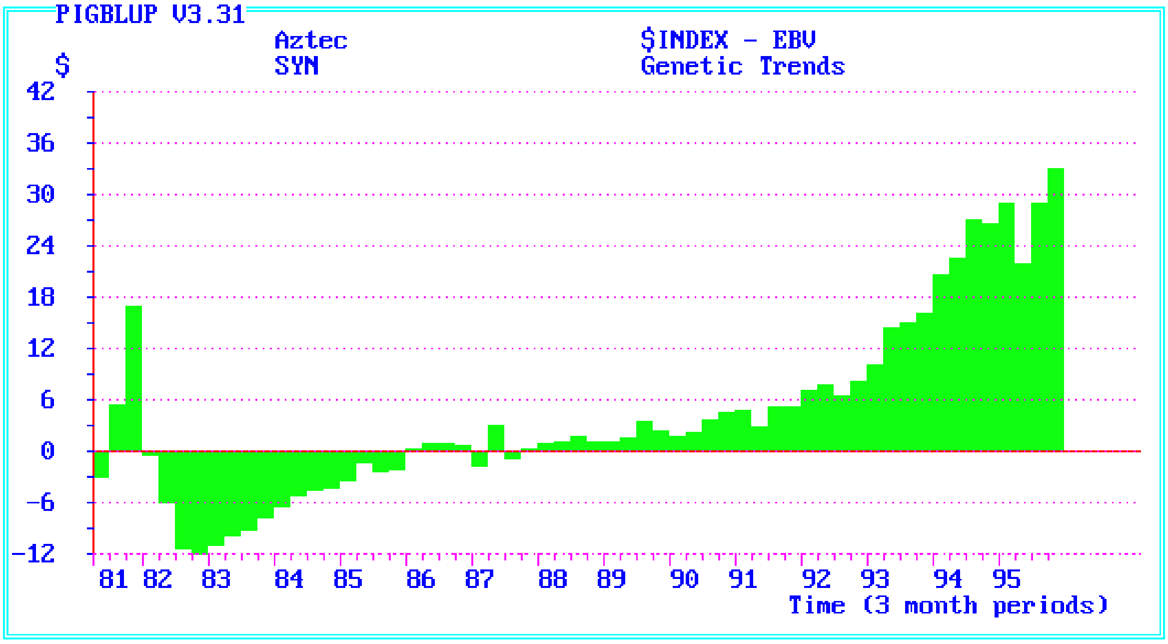
Table 3: EBVs of young boars from an Australian piggery for economically important traits.

Boar number	Birth date	ADG	BF	NBA	$Index
9550401SE1	26/09/95	-9.61	-1.07	0.60	+12
9601111SE1	5/10/95	35.63	-0.49	0.12	+26
9601113SE1	28/ 9/95	-30.46	-0.59	0.48	-7
9605018SE1	28/ 9/95	81.18	-0.94	0.43	+60

As one can see there is already a large variation for every trait in these EBVs within the first four boars of 1400 sorted on animals ID. What do these EBVs mean? For ADG we expect that mated to similar sows the progeny of boar four will grow about 55g [(81g - -30g)/2] per day faster than the progeny of the first boar in the table. Remember progeny get 1/2 of their genes from each parent. Daughters from boar 1 will have about 0.25 piglet more born alive per litter than daughters from boar 2, and the profit made per year from daughters of boar 4 will be $33 more than daughters of boar 3.

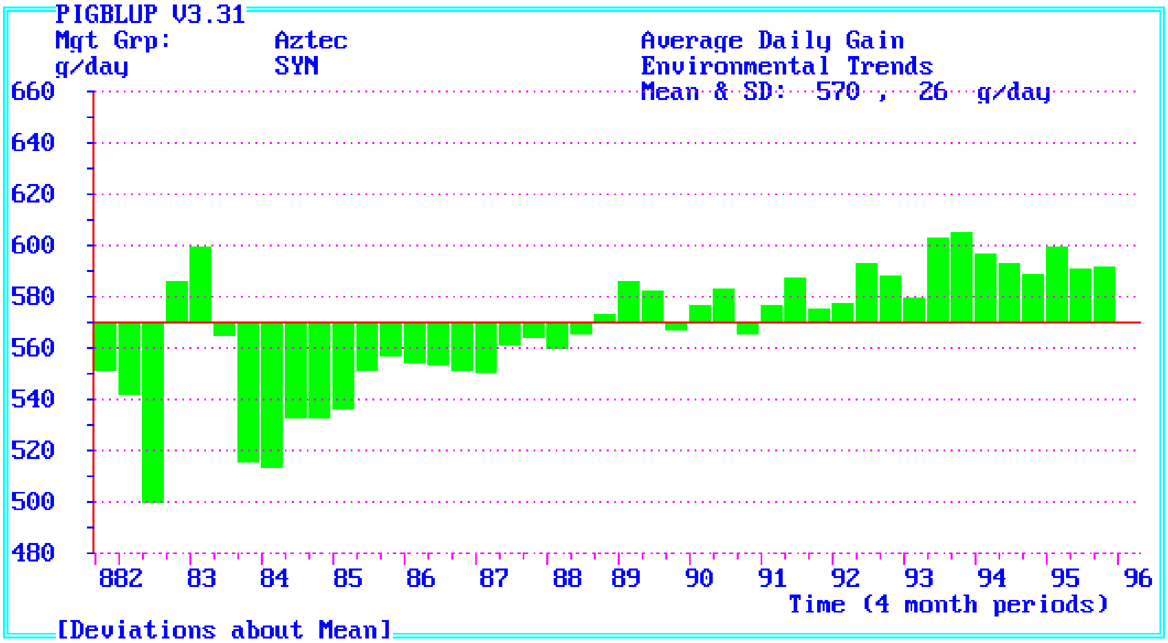
From such performance data it is possible to estimate genetic change by averaging EBVs over years. Figure 1 shows the $ Index-EBV progress made in this 630 sow piggery. This herd was established between 1982 and 1984 and has since then been closed to introductions from outside.

Figure 1: Estimated genetic trend for $ Index-EBV of an Australian pig breeding company



In 1993 the farm manager started to use a system of genetic evaluation based on multi-trait animal model BLUP technology (PIGBLUP). We estimate the herd makes $15,000 more profit per year now than it did 4 years ago simply through genetic selection. This is on top of any improvement in management that may have occurred. Figure 2 shows how improvement in the environment (non-genetic) over the same period has affected average daily gain. Due to management changes, most likely improvement in nutrition, ADG improved by about 80g per day. In addition, the genetic contribution to improved ADG is 60 g per day with the majority of this being generated during the last 4 years.

Figure 2: Changes in environmental performance for ADG



If we get enough support from individual ostrich breeders, by providing us with data as described in this article, we will make a genetic evaluation system available to the ostrich industry within the next two years.

CONCLUSION

Quality performance recording and genetic evaluation can be a powerful tool in the ongoing improvement of ostrich productivity. Careful planning and cooperation between different sectors of the industry is required to achieve this goal.

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