Simulating Economic Values of a Genetic Improvement Program for Australian Farmed Saltwater Crocodiles

By

Emily Gray[1†] and Fredoun Ahmadi-Esfahani[1*]

[1] Agricultural and Resource Economics, Faculty of Agriculture, Food and Natural Resources, University of Sydney, NSW, 2006, Australia.

[†]Author is a first time presenter: egra1721@mail.usyd.edu.au

*Corresponding author: F.Ahmadi@agec.usyd.edu.au

Contributed paper presented to the
49th Annual Conference of the
Australian Agricultural and Resource Economics Society
Novotel Pacific Bay Resort, Coffs Harbour
9-11th February 2005

Simulating Economic Values of a Genetic Improvement Program for Australian Farmed Saltwater Crocodiles

Emily Gray[1†], Fredoun Ahmadi-Esfahani[1*]

[1] Agricultural and Resource Economics, Faculty of Agriculture, Food and Natural Resources, University of Sydney, NSW, 2006, Australia.
[†]Author is a first time presenter: egra1721@mail.usyd.edu.au
*Corresponding author: F.Ahmadi@agec.usyd.edu.au

Abstract

Farm profitability can be increased through the selection of genetically superior animals as future breeders. In genetic improvement programs, candidates for breeders are ranked by the profitability of their offspring, expressed as a weighted sum of the genetic gain from selection. Genetic improvement is expressed as a shift or change in the slopes of functions describing the biology of saltwater crocodiles. The weights, or economic values, are estimated as the change in profit when the bioeconomic profit function is reoptimised with respect to slaughter age following genetic improvement in each selection objective. Empirical results tend to show that farm profitability increases the most for a reduction in juvenile slaughter age, an increase in the percentage of first grade skins produced, and an increase in the number of viable hatchlings per clutch.

Keywords: genetic improvement programs, economic values, crocodiles

Simulating Economic Values of a Genetic Improvement Program for Australian Farmed Saltwater Crocodiles

Emily Gray[1†], Fredoun Ahmadi-Esfahani[1*]

[1] Agricultural and Resource Economics, Faculty of Agriculture, Food and Natural Resources, University of Sydney, NSW, 2006, Australia.
[†]Author is a first time presenter: egra1721@mail.usyd.edu.au
*Corresponding author: F.Ahmadi@agec.usyd.edu.au

1. Introduction

Until recently, research in the Australian crocodile industry has focused on husbandry practices, to the exclusion of genetics. The research by Isberg *et al.* (2004), Commissioned by RIRDC and undertaken in collaboration with the University of Sydney and Janamba Croc Farm, contained recommendations for the first practical genetic improvement program for use in the industry. Based on the responses to an industry questionnaire, the selection objectives (genetic traits under selection) were defined as follows: to increase the proportion of first grade skins by one per cent; to increase breeder output by one viable hatchling per clutch; to increase juvenile survival by one per cent; to reduce slaughter age by one week; and to decrease weekly feed consumed by one gram. This paper estimates the increase in farm profit arising from the production of genetically improved crocodiles, through the selection of breeders that are superior in the relevant traits. The change in profit is estimated within a framework of profit maximisation, expressing genetic improvement as a shift or change in the slopes of biological functions simulating crocodile growth.

Genetic improvement programs are common in the major livestock industries, especially the dairy industry. However, a more pertinent comparison can be made between saltwater crocodile farming and the intensive production of rabbits for the specialty meat market. Similar to the Australian crocodile industry, rabbit farming in Australia is a small industry. In 1998, Australia supplied 0.02 per cent of world (farmed) rabbit meat, while supplying one per cent of the global market for crocodilian skins (DOTRS, 2001). In the farmed rabbit meat industry, genetic improvement was seen as a sound research investment to help address the industry-identified concerns of high feed costs, disease and health problems and poor growth rates, which were blamed on the lack of a quality breeding stock (Eady and Prayaga, 2000). Likewise, the development of a genetic improvement program for saltwater crocodiles is an important step in the process of establishing breeding programs, and the development of a competitive industry.

In Section 2, the key features of the crocodilian industry will be outlined to demonstrate the competitive pressures faced by producers. Section 3 provides a background to genetic improvement programs and the methods used to estimate economic values. In Section 4 the bioeconomic model is explained. In Section 5 the economic values for the base case and alternate scenarios are discussed, followed by the policy implications for the Australian crocodilian industry in Section 6.

2. Background to the Crocodile Industry

The Australian crocodile industry is based on the production of saltwater crocodiles, *Crocodylus porosus,* for their skins, which are manufactured into luxury leather goods. Crocodiles are harvested when they have a belly width between 35 and 45cm, as this is the industry-preferred range for the handbag market, to minimise wastage during product manufacture. There is occasional demand for smaller skins, to be manufactured into small leather goods such as watchstraps, and for larger skins (greater than 50cm) in response to fashion trends towards larger sized handbags (MacNamara *et al*., 2003). Skins are sold on a US$/cm belly width basis in conjunction with a stringent, yet subjective, grading system that is dependent on the presence and number of blemishes on the belly area. A first grade skin will have no blemishes, four appendages and be well preserved. The presence of any bite marks, abrasions or knife holes results in an automatic downgrading of the skin (Manolis *et al*., 2000). Only first grade skins receive premium export prices on an ascending pricing regime with belly width, which demonstrates the demand for skins in excess of 45cm. In contrast, second and third grade skins are in competition with other crocodilian skins and receive a large discount in their value. Table 1 demonstrates a range of prices that are indicative of those received by Australian producers.

Table 1: A range of prices received by Australian producers for saltwater crocodile skins (salted)

	Prices received per centimetre (US$/cm)		
Belly Width (cm)	First Grade	Second Grade	Third Grade
25-34	6.00		
35-39	8.00	3.20-3.85	1.28-1.93
40-45	9.00		
46-50	10.00-11.00		

S. Barker (2003), personal communication, AU$1 = US$0.64 (20/08/03)

Trade in crocodile skins can be divided into 'classic' skins versus others, such as caiman and alligator. Saltwater crocodile skins are considered aesthetically superior due to a higher number of scale rows of a smaller, more evenly distributed pattern compared to other crocodilians (MacNamara *et al*., 2003). Another advantage is the absence of skin bones in the belly scales, which increase the risk of tearing during tanning and produce a pitted, discoloured appearance in the finished skins (Thorbjarnarson, 1999). Nevertheless, the strictness of the skin grading system has significant revenue repercussions for producers. Buyers prefer a constant supply of first grade, blemish-free skins of lower "quality" (such as American alligator) to a blemished saltwater crocodile skin. As seen in Table 2, a +36cm first grade alligator skin receives a significantly higher price than that received for similarly wide, second grade saltwater crocodile skin.

Table 2: Prices per centimetre for salted crocodile skins in $US (+36cm)

Species	Market Share (%)	First Grade Skins	Second Grade Skins
Alligator	20.6	4.50-5.00	N/A
Nile Crocodile	8.7	3.70	2.50-3.00
Saltwater Crocodile	1.9	9.00-9.50	3.50-4.00

MacNamara *et al*. (2003), AU$1 = US$0.64 (20/08/03)

The market for crocodilian skins is characterised by price fluctuations, with recent downturns in 1992 and 1996. These were caused in part by the relatively inelastic supply of crocodilian products, as the length of the production period limits the ability of the industry to adjust to price changes (Woodward *et al*., 1993). More important is the shifting and elastic nature of demand for crocodilian products. While there is little evidence that changing sentiments in the fashion industry, and consumer resistance to animal products are important, the general economic status of consuming countries is held to be a principal determinant of demand (Hutton *et al*., 2001). As luxury goods, products manufactured from crocodile leather are highly income-elastic, suggesting that demand is reliant on economic prosperity and higher incomes. In times of recession consumers are likely to defer or discontinue purchases of exotic leather, or substitute away from 'classic' crocodilian products towards relatively less expensive products such as caiman, ostrich or snake skin. The 1996 downturn was attributed to the Asian economic crisis, since Asia is the principal end-market for luxury crocodilian products. However, due to traditionally low supplies of saltwater crocodile skins (limiting stock accumulation by traders, tanners and manufacturers prior to the price fall in 1992) and the higher quality of saltwater crocodile skins, Australian producers were less severely affected (Hutton *et al*., 2001).

Australian exports skins to France, Italy, Japan and Singapore (MacNamara *et al*., 2003). Of the three major tanneries for exotic skins in France – Gordon Choisy and TCIM (owned and partly-owned by Hermes respectively), and France Croco – all can sell more skins than Australian producers supply. Although the market for first grade skins is highly dependent on Hermes demand, there are no indications that the historically constant demand will decline in the future. However, the market for second and third grade skins is limited due to the preference for a guaranteed supply of first grade Alligator skins. In Italy and Japan, even first grade skins face extensive competition and declining prices. This is driven by strong preferences for alligator leather in the United States, the major market for finished products from Italy, and competition from other crocodilian skins and alternative exotic species such as snake and ostrich, (MacNamara *et al*., 2003).

The largest concern of skin buyers is the undersupply of first-grade skins, as many fail to meet the grading requirements (Manolis *et al*., 2000). MacNamara *et al*. (2003) reported that 50 per cent of crocodiles currently produced meet first grade requirements, whereas Isberg *et al*. (2003) reported a figure around 30 per cent first grade. The pricing regime, as demonstrated in Tables 1 and 2, makes it apparent that farm revenue is dependent on producing a high proportion of first grade skins, as competition with other crocodilian species reduces demand for lower quality saltwater crocodile skins. Developing an economic selection index to select future breeders, allows the producer to address traits which impact farm revenue (Goddard, 1998). This would enable producers to take advantage of the strong demand for first grade skins. Given the large proportion of skins that are second or third grade, genetic traits that affect the costs of production should also be included as selection objectives in the economic selection index.

3. Theoretical Considerations

A genetic improvement program is founded upon the selection of future breeders for more than one trait (for example, growth rates and fertility), in order to improve the economic value of the herd (Smith, 1983). Selection of candidates is based on an economic selection index, where the overall profitability of a potential breeder is the weighted sum of the estimated breeding value for each selection objective, and the weights are the economic values (Bourdon, 2000).

$$H = v_1 EBV_1 + v_2 EBV_2 + ... + v_m EBV_m$$

where H = aggregate breeding value for profitability,
v_i = the economic value for the ith selection objective in the breeding program,
EBV_i = the estimated breeding value for the ith selection objective in the breeding program, and
m = the total number of selection objectives in the breeding program.

The economic values indicate the relative importance of a marginal change in the trait as a dollar value. When they are combined into the economic selection index for an individual, they weight the EBV for each selection objective. This produces the best estimate of the aggregate (true) breeding value of each candidate available for selection, in a single dollar value, which producers can use a decision tool in selecting future breeders.

Conventional methods for estimating economic values use profit functions that describe a linear relationship between the physical inputs, the genetic traits, and profit (Bright, 1991). This was due to the belief that profitability was a linear function of measurable genetic characteristics (Goddard, 1983), and that profit could be maximised through selection for these traits. Economic values were calculated as the partial derivative of the profit function at the mean values of the genetic traits, on the basis that rates of genetic change in livestock are low (Brascamp *et al*., 1985), and that for selection between genotypes (such as *Crocodylus porosus*) the profit function can be approximated as a linear curve (Goddard, 1998). A generally accepted extension of this method was proposed by Smith *et al*. (1986), who rescaled enterprise size to constrain output at its original level. They argued that economic values should only reflect a reduction in costs per unit of product, excluding any gains that could have been achieved by rescaling the size of the production system to match post-genetic improvement levels of output.

Alternative methods based on production theory advocate calculating economic values based on profit maximisation, using a production function describing a non-linear relationship between inputs and output (Bright 1991; Amer and Fox, 1992; Amer *et al*., 1994a). Amer and Fox (1992) incorporated genetic improvement into neoclassical production theory, and represented genetic improvement as a shift in the cost function. Bright (1991) and Amer *et al*. (1994a) used a generalised Cobb-Douglas function to represent genetic improvement in traits A and x_1, in Equations 1 and 2:

$$y = A x_1^{\alpha} x_2^{\beta} \tag{1}$$

$$y = A\left(1+\lambda_A\right)\left(\frac{x_1}{1-\lambda_1}\right)^{\alpha} x_2^{\beta} \tag{2}$$

In this way, both neutral $\left\{A \rightarrow A\left(1+\lambda_A\right)\right\}$ and non-neutral $\left\{x_1 \rightarrow \left(\frac{x_1}{1-\lambda_1}\right)\right\}$ genetic improvement were represented. Amer *et al*. (1997) emphasised the importance of a genotype-specific slaughter point for beef cattle. They optimised slaughter time before and after genetic improvement by equating marginal carcase revenue at time *t* to the marginal cost of keeping the animal in the system for a further unit of time, using a biological growth model to calculate carcase quality characteristics over time.

In comparing economic values estimated by these two methods, Amer *et al*. (1994a) concluded that depending on the size of the trait change, the relative differences in the values derived were significant enough to affect the efficiency of the selection index. Although the conventional methods could provide a useful approximation of the economic value for small trait changes, when larger changes or a time-frame beyond the short-run were considered, the simple profit function became less satisfactory (Bright, 1991). In recommending that the economic values be calculated, while continuously reoptimising decision variables, McArthur (1987) and Amer and Fox (1992) noted that the economic values would include the benefits from new production decisions that better use the genetically superior animals.

4. Empirical Model, Data and Procedures

A profit function (Equation 3) for farmed saltwater crocodiles was developed in the form of a bioeconomic model for determining optimal slaughter age. The model consists of output, revenue and cost functions that use simulated biological functions describing juvenile growth, survival, feed consumption and skin quality over time. The profit function is specified for the long-run, in which case the farm is maximising profit when economic profit equals zero, and all inputs are receiving a payment:

$$\pi = A.\left[\sum_{i=1}^{3} P_{i,t}.\theta_i(t)\right].S(t).W(t) - A\left[P_F.\overline{F}(t) + D(t).S(t) + K(t)\right] \tag{3}$$

The decision variable is slaughter age t. Output, in centimetres of belly width skin is dependent on A, the number of hatchlings per clutch; $S(t)$, juvenile survival; and $W(t)$, average juvenile belly width at time t. Juvenile survival in Equation 4 gives the proportion of juveniles surviving up until at least time t:

$$S(t) = \exp^{\left[-\left(t/\kappa\right)^{\rho}\right]} \tag{4}$$

The distribution for survival times is based on a hazard function describing the instantaneous risk of failure (death) at time t, given the individual is alive immediately prior to t (McCullagh and Nelder, 1989). The underlying Weibull hazard function has $0 < \rho < 1$ to describe a decreasing hazard with time, as mortality rates fall as juveniles mature. A benefit arising from simulating a survival function is that it is an alternative to estimating that non-surviving juveniles incurring 50 per cent of operating costs.

Average juvenile belly width is described by a logistic function in Equation 5 that follows the model used in Engel and Bassanezi (1997) for farmed Yacare caimans. The logistic function gives belly width as a constant proportion (w) of total length:

$$W(t) = w.\left[1 \Big/ \left(a + b\exp^{-ct}\right)\right] \tag{5}$$

Revenue earned per skin depends on the price received per centimetre belly width, $P_{i,t}$. Within a certain skin-width range and price bracket, average price is a weighted average, depending on the proportion of skins in each grade, θ_i, given in Equation 6:

$$\begin{aligned} \theta_1(t) &= \{1+\exp[-(\alpha_1-\beta t)]\}^{-1}; \\ \theta_2(t) &= \{1+\exp[-(\alpha_2-\beta t)]\}^{-1} - \{1+\exp[-(\alpha_1-\beta t)]\}^{-1}; \text{ and} \\ \theta_3(t) &= 1-\{1+\exp[-(\alpha_2-\beta t)]\}^{-1} \end{aligned} \tag{6}$$

In the cost component of the model, the average amount of feed consumed depends on instantaneous feed consumed $f(t)$ (Equation 7) and the survival function $S(t)$. This gives the cumulative amount of feed consumed up to time t, $\overline{F}(t)$ in Equation 8. Feed price P_F was assumed constant:

$$f(t) = x - z\exp^{-ut} \tag{7}$$

$$\overline{F}(t) = \int_0^t f(t) S(t) dt \tag{8}$$

Operating costs including labour, $D(t)$, were assumed constant per unit of time and dependent on the number of juveniles in the system. Capital costs, $K(t)$, were assumed to be constant and dependent on A, the number of hatchlings per clutch (or the number of juveniles slaughtered with no mortality). Feed costs per breeding pair were excluded.

Prior to genetic improvement, profit is maximised with respect to t, as in Equation 9:

$$\frac{d\pi}{dt} = A \left\{ \begin{array}{l} \left[\sum_{i=1}^{3} P_{i,t} \theta_i'(t) \right] .S(t).W(t) + \left[\sum_{i=1}^{3} P_{i,t} \theta_i(t) \right] .S'(t).W(t) \\ + \left[\sum_{i=1}^{3} P_{i,t} \theta_i(t) \right] .S(t).W'(t) \end{array} \right\} \tag{9}$$
$$-A\left[P_F.S(t).f(t) + D.S'(t) + K \right] = 0$$

Genetic improvement in the selection objectives is affected through the alteration of parameters in the biological functions given in Equations 4, 5, 6 and 7. An improvement in the number of hatchlings per clutch (NoHatch) by one viable hatchling is represented as a shift in $A \rightarrow (A + \lambda_A)$. An improvement in juvenile survival (Surv) is represented by new values for ρ and κ in Equation 4 to give a one per cent increase in juvenile survival at time of slaughter. An increase in the proportion of skins that are first grade (%First) is represented by a shift $\beta \rightarrow (\beta - \lambda_\beta)$ in Equation 6. This slows the rate at which the proportion of first grade skins declines. A reduction in feed consumed per juvenile (FeedCons) by one gram per week is represented by $x \rightarrow (x + \lambda_x)$ in Equation 7. This shifts the instantaneous feed consumed function down by one gram for all values of t. An improvement in the selection objective slaughter age (CullAge) is represented by $c \rightarrow (c + \lambda_c)$ in Equation 5, which increases the slope of the function, and hence the growth rate of the juvenile crocodiles. Economic values were calculated as the change in profit following genetic improvement and the reoptimisation of slaughter age. Sensitivity analyses were carried out on the parameters of the biological functions and the management and marketing systems to determine the sensitivity of the economic values. Price changes and increasing production costs were assessed, as well as different phenotypic characteristics for the juveniles. These included a higher proportion of first grade skins, through adjusting β in Equation 6, and different growth rates and hatching lengths, through adjusting c and b respectively in Equation 5.

The importance of slaughter age as a decision variable is that average price declines with age, as the proportion of skins that are first grade falls, yet the price itself depends on the skin width, and hence age of the crocodile. Although crocodiles have high feed conversion efficiency, in terms of production per unit time, crocodiles are very inefficient, (Webb, 1989). Growing out a juvenile to the industry-preferred belly width takes an average of three years. Because of this, the largest component of the operating costs of crocodile farms is feed, (42-45% Treadwell *et al*., 1991). The other main component is labour, which is around 40% of operating costs (Treadwell *et al*., 1991). Other management controlled variables were not optimised because the quantities of the physical inputs used are dependent on what is needed to sustain a predetermined genetic level of performance (Tess *et al*., 1983), and the number of juveniles in the production system. Data were provided by Janamba Croc Fram in the Northern Territory, and the parameters of the model were specified to simulate a representative breeding pair of Janamba Croc Farm.

5. Results

The economic values (EVs) for the base case are displayed in Table 3. In the base case, optimal slaughter occurs immediately juveniles reach the industry preferred belly-width range of 35-45 centimetres. In all scenarios assessed, the optimal slaughter age coincided with a lower limit of the belly width range in a price bracket, as the increasing width of skins with *t* failed to compensate for the declining proportion of first grade skins, and the accompanying decline in average price. In the base case, profit per breeding pair was $1025.43. In terms of relative importance, CullAge contributed most to the economic selection index (43 per cent), indicating the importance of productive efficiency per unit of time. The EV of $111.50 represents the cost savings from reducing the production period by one week, and the gains in revenue from selling skins for a higher average price, due to the marginally higher proportion of first grade skins at the earlier age. %First was second in relative importance (30 per cent) with an EV of $77.84 for an improvement in the proportion of first grade skins by one per cent, indicating the increase in profit as producers receive a higher average price. The EV of $32.81 for NoHatch reflects the profit from increasing the number of viable hatchlings by one per clutch. The EV of $30.34 for Surv includes the benefits of reduced mortality costs, which are the costs of raising an animal for no economic return, in addition to the revenue from increased output. The EV for FeedCons of $4.75 is small, but this is due to the magnitude of the improvement considered, namely a reduction of one gram per week. Additionally, the high feed conversion efficiency of crocodiles suggests that further improvement would not be as valuable as improvements in other traits that are less efficient.

Table 3: Economic values for the base case

Optimal Slaughter Age	π per Breeding Pair ($)	Economic Values: NoHatch	CullAge	Surv	FeedCons	%First	Reoptimized Slaughter Age
141.57	1025.43	32.81	111.50	30.34	4.75	77.84	140.69
		0.13	0.43	0.12	0.02	0.30	

Harris and Freeman (1993) argue that economic values derived for current prices and costs are valid only if production and market conditions are expected to be stable into the future. Yet Smith (1983) concluded that frequent revision of economic values to accommodate small changes arising from new husbandry techniques, changes in market conditions or the increased productivity of the improved livestock was unnecessary, as the effect on efficiency would be small. The view that the efficiency of the selection index is not sensitive to small changes in the economic values is arguably better for the genetic improvement program for saltwater crocodiles, because of the time required for genetic improvements to be expressed. To confirm this, sensitivity analyses were conducted on the economic parameters, production costs and productive. Although profit per breeding pair and the magnitudes of the economic values were sensitive to these changes, their relative importance was largely unaltered for the less extreme of the changes considered. Scenarios that affect price received by producers are displayed in Table 4. NoHatch had the largest change in relative importance, falling to five per cent following a 10 per cent appreciation. This was sufficient to increase the relative importance of CullAge and %First, even though their EVs were reduced in value.

Table 4: Economic values under conditions that affect price received by producers

	Optimal Slaughter Age	π per Breeding Pair ($)	Economic Values					Reoptimised Slaughter Age
			NoHatch	CullAge	Surv	FeedCons	%First	
Exchange Rate								
+5%	141.57	681.79	21.82	108.69	26.77	4.75	74.17	140.69
			0.09	0.46	0.11	0.02	0.31	
-5%	141.57	1405.23	44.97	114.61	34.29	4.75	81.94	140.69
			0.16	0.41	0.12	0.02	0.29	
+10%	141.57	369.40	11.82	106.13	23.52	4.75	70.77	140.69
			0.05	0.49	0.11	0.02	0.33	
Price US$								
+5%	141.57	1386.24	44.36	114.45	34.09	4.75	81.74	140.69
			0.16	0.41	0.12	0.02	0.29	
-5%	141.57	664.61	21.27	108.55	26.59	4.75	73.95	140.69
			0.09	0.46	0.11	0.02	0.31	

Different cost conditions were also considered at Janamba Croc Farm and all operating costs were increased by five and ten per cent in Table 5. As expected, profit was most sensitive to increases in feed costs, which Treadwell *et al*. (1991) had indicated were the main component of the operating costs. The relative importance of the EVs was not greatly affected by increases in any of the operating costs.

Table 5: Economic values under increased production cost conditions

	Optimal Slaughter Age	π per Breeding Pair ($)	Economic Values NoHatch	CullAge	Surv	FeedCons	%First	Reoptimised Slaughter Age
Labour								
+5%	141.57	910.78	29.15	112.19	29.15	4.75	77.84	140.69
			0.12	0.44	0.12	0.02	0.31	
+10%	141.57	796.14	25.48	112.88	27.96	4.75	77.84	140.69
			0.10	0.45	0.11	0.02	0.31	
Fed Costs								
+5%	141.57	873.99	27.97	113.17	29.75	4.98	77.84	140.69
			0.11	0.45	0.12	0.02	0.31	
+10%	141.57	722.55	23.12	114.85	29.15	5.22	77.84	140.69
			0.09	0.46	0.12	0.02	0.31	
Operating Costs								
+5%	141.57	982.41	31.44	111.76	29.89	4.75	77.84	140.69
			0.12	0.44	0.12	0.02	0.30	
+10%	141.57	939.39	30.06	112.02	29.45	4.75	77.84	140.69
			0.12	0.44	0.12	0.02	0.31	

It was reported in Manolis *et al*. (2000) that the undersupply of first grade skins was a major problem faced by the industry. In this paper an estimate of 45 per cent first grade skins was used. This was varied by five, 10, 20 and 30 per cent in Table 6. Profit per breeding pair is highly dependent on the proportion of first grade skins. The key result is that when the proportion of first grade skins reached 20 and 30 per cent, it becomes profitable to keep juveniles in the system longer, in order to reach the +40 centimetre belly widths and accompanying higher price brackets. At the new slaughter age of 159.5 weeks, output and price received for first grade skins had increased, and the farm was maintaining a proportion of first grade skins close to 60 per cent.

For increases in the percentage of first grade skins of 10 per cent and more, the relative importance of NoHatch and CullAge was significantly altered, which might compromise the efficiency of the selection index. Changes to this extent in the production system warrant revised EVs, as those calculated in the base case would no longer indicate the value of an improvement in a particular trait, distorting the direction of selection. In this case, reducing slaughter age is the most profitable genetic improvement when the proportion of first grade skins is low, as a shorter production period can increase average price. However, when the farm is producing a high proportion of first grade skins, and consequently receiving a high average price per centimetre belly width, increasing output gains importance, while the benefits of reducing slaughter age are relatively unchanged.

Table 6: Economic values with different proportions of first grade skins

	Optimal Slaughter Age	π per Breeding Pair ($)	Economic Values					Reoptimised Slaughter Age
			NoHatch	CullAge	Surv	FeedCons	%First	
Change % 1st Grade Skins								
+5%	141.57	1409.33	45.10	107.17	34.33	4.75	72.82	140.69
			0.17	0.41	0.13	0.02	0.28	
-5%	141.57	631.71	20.21	115.16	26.25	4.75	74.33	140.69
			0.08	0.48	0.11	0.02	0.31	
+10%	141.57	1772.48	56.72	102.42	38.11	4.75	77.61	140.69
			0.20	0.37	0.14	0.02	0.28	
+20%	159.50	2600.78	83.23	126.74	56.13	5.33	122.13	158.51
			0.21	0.32	0.14	0.01	0.31	
+30%	159.50	3929.69	121.90	109.71	70.93	5.33	122.80	159.00
			0.28	0.25	0.16	0.01	0.29	

The biological function in Equation 5 was simulated to reflect conditions at Janamba Croc Farm. Parameters were adjusted to simulate alternative juvenile growth rates and hatching lengths in Table 7. These parameters were the primary determinants of the time taken to reach 35 centimetre belly widths. Increasing juvenile growth rate $c \rightarrow c + \lambda_c$ increased profit per breeding pair to $1536.89, as well as the EVs of NoHatch and Surv, as juveniles slaughtered earlier had a higher proportion of first grade skins, and incurred lower production costs. Optimal slaughter age was also reduced to 136.45 weeks, which reduced the EV of CullAge, as the benefits of reducing the production period increase with *t*, as feed consumed per week increases with juvenile age. Slower growth rates increase operating costs per juvenile but reduce average price. Adjusting hatching length $b \rightarrow b +/- \lambda_b$ had a more extreme impact on profit per breeding pair, optimal slaughter age and the relative importance of the EVs.

In Table 8, different scenarios are offered that may reflect saltwater crocodile production at Janamba Croc Farm. The first scenario, which increases hatching length and reduces growth rate extended the production period. The second and third scenarios are similar to the base case, in terms of profit per breeding pair, length of the production period, and the relative importance of the EVs. The EV of CullAge was reduced in both scenarios, as reoptimising slaughter age only slightly changed optimal slaughter age and average price received. However, it would appear that the efficiency of the selection would not be reduced by small changes in the parameters of Equation 5.

Table 7: Economic values under alternate growth parameters

	Optimal Slaughter Age	π per Breeding Pair ($)	Economic Values: NoHatch	CullAge	Surv	FeedCons	%First	Reoptimised Slaughter Age
Change Growth Rates								
↑ rate	137.28	1536.89	49.18	105.07	33.88	4.62	73.68	136.45
			0.18	0.39	0.13	0.02	0.28	
↓ rate	146.13	447.66	14.32	118.28	25.80	4.91	81.76	145.2
			0.06	0.48	0.11	0.02	0.33	
Change Hatching Length								
↑ length	136.13	1669.98	53.44	106.15	34.73	4.59	72.49	135.28
			0.20	0.39	0.13	0.02	0.27	
↓ length	146.57	408.45	13.07	115.97	25.52	4.91	82.1	145.66
			0.05	0.48	0.11	0.02	0.34	

Table 8: Economic values under different growth scenarios

	Optimal Slaughter Age	π per Breeding Pair ($)	Economic Values: NoHatch	CullAge	Surv	FeedCons	%First	Reoptimised Slaughter Age
Decrease Growth Rate and Increase Hatching Length								
↓ rate ↑ length	145.20	565.30	18.09	120.21	26.76	4.88	81.01	144.24
			0.07	0.48	0.11	0.02	0.32	
Increase Growth Rate and Decrease Hatching Length								
↑ rate ↓ length	141.81	1002.94	32.09	69.67	30.20	4.75	78.07	141.04
			0.15	0.32	0.14	0.02	0.36	
Further Increase Growth Rate and Further Decrease Hatching Length								
↑ rate ↓ length	140.55	1148.73	36.76	98.41	31.24	4.71	76.90	139.82
			0.15	0.40	0.13	0.02	0.31	

6. Policy Implications

In this paper, genetic improvement was expressed as a change or shift in the slopes of simulated biological functions describing crocodile growth, survival, instantaneous feed consumed and the proportions of skins in each grade over time. Profit was maximised with respect to slaughter age, which was reoptimised after genetic improvement to allow producers to take advantage of superior juveniles. Although the reoptimised slaughter age was not significantly different from the pre-improvement slaughter age, following improvement in the selection objective slaughter age reoptimisation did increase the magnitude of its economic value. The driver of this reoptimisation was the pricing regime in the market for crocodilian skins, which awards higher prices for first grade skins within larger belly width ranges. Because crocodile skin quality was simulated to decline with age (and hence the proportion of skins that are first grade), producers maximised profit by slaughtering juveniles immediately they reached the price bracket for the "handbag" market. Otherwise, if juveniles were retained in the production system, the increase in output as juveniles grew failed to compensate for the decline in average price.

As an emerging industry, saltwater crocodile skin producers face a number of constraints that hinder the further development of the industry. The characteristics of saltwater crocodiles that distinguish them as production units impose costs on producers, and can reduce farm profitability. Technical change, through genetic improvement, provides the means by which producers can improve the quality of their stock. The economic values indicate that producers should direct selection towards genetic improvement that reduces slaughter age, increases the percentage of first grade skins, and increases the number of viable hatchlings per clutch. However, it should be noted that the true value of a selection objective also depends on the genetic gain from selection (its EBV) and the candidate breeder's own merit.

The sensitivity analyses confirm that the economic values are stable for small changes in the production and marketing systems, such as changes in the price received and increases in production costs. However, for larger changes such as 10 per cent and greater increases in the proportion of skins produced that are first grade, the economic values estimated in the base case are likely to compromise the efficiency of the selection index. Nevertheless, the economic values estimated here can aid in the establishment of a breeding stock that better meet the needs of producers, while it is to be expected that future revision will be required as husbandry techniques are further advanced.

Smith (1983) stressed that whole life-time productive efficiency should be considered when defining the breeding objective. If an important trait is left out, the likelihood that the index efficiency is compromised increases. Such a trait may be related to the reproductive life of female crocodiles. Furthermore, the breeding objective did not include meat production as a selection objective, as meat is a currently regarded as a by-product of skin production. The inclusion of characteristics for meat production may induce a movement towards saltwater crocodiles as dual purpose production units, and lessen reliance on the markets for skins. The selection objectives were predominantly related to the production side of the saltwater crocodile industry, in that they aimed to reduce production costs and increase output. There is also scope for the economic selection index to anticipate future market conditions by addressing characteristics related to the final product, so as to produce a skin that better meets the needs of end users, in this instance, the fashion industry. The market does not currently award premiums or discounts for attributes that set skins apart within a grade, such as the regularity of the scale pattern. MacNamara *et al*. (2003) suggested that Hermes would begin to grade harder when supply reached 15,000 skins per annum, and that price levels would be affected when supply reached 20,000 skins per annum. Thus, selection objectives that rewarded the superior skins within a grade with a premium, and discounted borderline skins, would prepare producers for stricter grading specifications.

The consensus is that prices for first grade saltwater crocodile skins will be stable into the future. McNamara *et al*. (2003) investigated the demand for skins in France and noted that there was no indication that an increase in the supply of first grade skins would depress prices. However, unforseen shifts in demand, such as a backlash against animal leather by consumers, might drastically reduce the prices of crocodile skins. It is evident from Table 4 that a fall in the price of crocodile skins can affect farm viability. When the implications of a large demand shift are combined with the sensitivity of economic profit to exchange rate appreciations and the proportion of first grade skins produced, industry vulnerability is evident. This is further compounded by the heavy dependence of the crocodile industry on fashion based demand for crocodile leather, as the end use of skins is essentially confined to the manufacture of luxury leather items.

Developments in the Australian industry may also curtail the usefulness of the economic values calculated in this paper. Growth in value adding in the domestic industry, especially through the expansion of tanning capabilities and the development of a branded product (MacNamara *et al*., 2003), might significantly affect farm revenue. Product diversification in terms of niche markets for meat and other by-products would require further traits to be included in the breeding objective, as producers earned a relatively larger proportion of income from sources other than skins.

A final consideration for producers and the Australian saltwater crocodile industry is the feasibility of the genetic improvement program. Before genetic improvement programs are undertaken to improve breeding stock, it is necessary to determine if the program is in the best interest of the farm. A benefit cost analysis can be used to compare the costs and benefits of the breeding program with those associated with the normal operations of the farm. The costs associated with normal farm operations will include the purchasing costs of replacement breeders. The additional costs incurred through the genetic improvement program include the measurement costs, as the economic values do not provide information on the costs associated with achieving the desired genetic change (Goddard, 1998). There are also costs associated with maintaining the future breeders until they reach sexual maturity. The benefits associated with the genetic improvement program are the lower production costs and augmented income stream from increased productivity, and possibly from more first grade skins. By comparing the two scenarios over a suitable time period it would be possible to determine whether or not it was in a farm's best interest to invest in a genetic improvement program.

7. Concluding Comments

The economic values calculated in this paper clearly demonstrate that farm profit can increase if producers improve the genetic attributes of their stock in a genetic improvement program. Moreover, producing genetically superior crocodiles would allow producers to take advantage of strong demand for first grade skins, and increase the competitiveness of the industry. This is important, given the industry's vulnerability to reductions in the price received. Finally, through the use of biological functions that describe juvenile growth within a profit maximisation framework, the true value of genetic improvement in saltwater crocodiles might be more closely approximated.

REFERENCES

Amer, P.R. and Fox, G.C. (1992), 'Estimation of economic weights in genetic improvement using neoclassical production theory: an alternative to rescaling', *Animal Production* 54, 341-350.

Amer, P.R., Fox, G.C. and Smith, C. (1994), 'Economic weights from profit equations: appraising their accuracy in the long run', *Animal Production* 58(1),11-18.

Amer, P.R., Emmans, G.C. and Simm, G. (1997), 'Economic values for carcase traits in UK commercial beef cattle', *Livestock Production Science* 51, 267-281.

Barker, S.G. (2003), Personal communication.

Bourdon, R. M. (2000), *Understanding Animal Breeding*, 2nd edn, Prentice Hall, New Jersey.

Bright, G. (1991), 'Economic weights from profit equations: appraising their accuracy', *Animal Production* 53(3), 395-398.

Brascamp, E.W., Smith, C. and Guy, D.R. (1985), 'Derivation of economic weights from profit equations', *Animal Production* 40, 175-180.

Department of Transport and Regional Services (DOTRS), (2001), Crocodile farming, in *Investing in Northern Australia: Key Opportunities-Emerging Industries Sectors*, Canberra. [http://www.dotrs.gov.au]

Eady, S.J. and Prayaga, K.C. (2000), 'Rabbit farming for meat production in Australia: profitability in the industry and economic values for production traits. *7th World Rabbit Congress*, July 4-7, Valencia (Spain), Vol A pp 361.

Engel, A.B. and Bassanezi, R.C. (1997), 'A cybernetical strategy for optimal farming: on the growth of *Caiman Crocodylus Yacare*', *Kybernetes*, 26(3), 306-315.

Goddard, M.E. (1983), 'Selection indices for non-linear profit functions', *Theoretical Applied Genetics* 64, 339-344.

Goddard, M. E. (1998), 'Consensus and debate in the definition of breeding objectives', *Journal of Dairy Science* 81(2), 6-18.

Harris, B.L. and Freeman, A.E. (1993), 'Economic weights for milk yield traits and herd life under various economic conditions and production quotas', *Journal of Dairy Science* 76, 868-879.

Hutton, J., Ross, P. and Webb, G. (2001), 'Using the market to create incentives for the conservation of crocodilians: a review', *Using the Market: IUCN/SSC Crocodile Specialist Group*, September 2001.

Isberg, S.R., Nicholas, F.W., Thomson, P.C., Barker, S.G., Manolis, S.C. and Moran, C. (2003), 'Defining breeding objectives for saltwater crocodile genetic improvement programs', In *Proceedings of the Association for the*

Advancement of Animal Breeding and Genetics, Melbourne, Australia, 6-11 July 2003, Vol. 15, pp. 166-169.

Isberg, S.R., Thomson, Nicholas, F.W., P.C., Barker, S.C. and Moran, C. (2003), "Farmed saltwater crocodiles-A genetic improvement program', RIRDC – Publ. No 04/147, Canberra.

MacNamara, K., Nicholas, P., Murphy, D., Riedel, E., Goulding, B., Horsburgh, C., Whiting, T. and Warfild, B., (2003), 'Markets for skins and leather- from goat, emu, ostrich, crocodile and camel industries', RIRDC – Publ. No 02/142, Canberra.

Manolis, S.C., Webb, G. and Richardson, K. (2000), 'Improving the quality of Australian crocodile skins', RIRDC – Publ. No 00/21, Canberra.

McArthur, A.T.G. (1987), 'Weighting of breeding objectives- an economic approach', *Proceedings of the Australian Association of Animal Breeding and Genetics* 6, 179-187.

McCullagh, P. and Nelder, J.A. (1989), *Generalized Linear Models*, 2nd edn, Chapman and Hall, London.

Smith, C. (1983), 'Effects of changes in economic weights on the efficiency of index selection', *Journal of Animal Science* 56(5), 1057-1064.

Smith, C., James, J.W. and Brascamp, E.W. (1986), 'On the Derivation of Economic Weights in Livestock Improvement', *Animal Production* 43, 545-551.

Tess, M.W., Bennett, G.L. and Dickerson, G.E. (1983), 'Simulation of genetic changes in life cycle efficiency of pork production. 1. A bioeconomic model', *Journal of Animal Science* 56(2), 336-349.

Thorbjarnarson, J. (1999), 'Crocodile Tears and Skins: International Trade, Economic Constraints, and Limits to the Sustainable Use of Crocodilians', *Conservation Biology* 13(3), 465-470.

Treadwell, R., McElvie, L and Maguire, C.B. (1991). 'Profitability of selected aquaculture species', ABARE discussion paper 91.11.

Webb, G. (1989), 'The crocodile as a production unit', Intensive Tropical Animal Production Seminar, Queensland, 19-20 July.

Woodward, A.R., David, D.N. and Degner, R.L. (1993), "The rise and fall of classic crocodilian skin prices: where do we go from here?', *Proceedings of the 2nd Regional Meeting of the Crocodile Specialist Group*, The World Conservation Union, Gland, Switzerland.