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The Impact of Hogget and Mature Flock Reproductive Success on Sheep Farm Productivity

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Abstract: Breeding hoggets (ewe lambs aged four to 16 months) at 8 to 9 months of age has a number of potential benefits, including increased lamb production and profitability. However, the majority of hoggets in New Zealand are not bred due to producer concerns regarding their variable reproductive success and increased feed demand. Simulation modelling was used to quantify effects of hogget breeding on sheep numbers, lamb production, sheep feed demand, and sheep enterprise cash operating surplus (COS) compared with a flock not breeding hoggets. Hogget weaning rate (HWR) was modelled at 0%, 60%, 80%, and 100% and combined with mature ewe flock weaning rates (FWR) of 132% and 150%, while maintaining total annual sheep feed demand. For each FWR, increased HWR reduced total sheep numbers, increased the proportion of sheep feed demand for lamb production, increased total numbers of lambs weaned, and increased COS. Therefore, achieving even a relatively low HWR of 60% can improve sheep enterprise profitability for a given FWR. However, COS was lower with FWR = 132% and HWR = 100% than with FWR = 150% and HWR = 0%. The results indicate farmers who do not currently breed their hoggets may wish to improve their FWR before considering HWRs.

Keywords: flock dynamics; system dynamics; bio-economic; profit; sheep; New Zealand; ewe lambs; profitability

1. Introduction

Hoggets (ewe lambs aged four to 16 months) have the potential to be successfully bred at 8 to 9 months of age and in New Zealand 32% of hoggets were presented for breeding in 2019 [1]. Stated production benefits from breeding hoggets include: (1) increased utilisation of pasture in spring, (2) increased numbers of lambs weaned, (3) more lambs available for sale providing additional income, (4) an additional selection tool for ewe replacements, (5) increased selection pressure for replacements if replacements are selected from those born to hoggets, (6) reduced generation interval if replacements are selected from those born to hoggets, and (7) reduced greenhouse gas emissions intensity on a per kg of product basis [2–12]. However, as indicated by the majority of New Zealand sheep farmers not breeding hoggets, there are producer concerns. These include: (1) variable hogget reproductive success, (2) increased total farm feed demand unless changes are made to numbers of other stock classes, (3) greater live weight targets at 8 to 9 months of age, (4) potential for negative consequences on future live weight and productivity, (5) potential lighter live weights and poorer survival to weaning of hogget progeny, (6) potential for increased expenses, and (7) the potential of increasing the mortality rates of hoggets [3,7,8,10–14].

Experimental data from New Zealand have indicated potential improvements to ewe lifetime reproductive success by hoggets being bred at 8 to 9 months of age [11,12,15]. If a hogget is bred successfully and rears her lamb(s) to weaning, modelling in Australia reported the potential to lift overall farm profitability [16,17]. However, the potential economic impacts of breeding ewe lambs on sheep and beef production systems under New Zealand conditions have not previously been analysed and quantified, and earlier research may no longer be relevant due to changes in sheep production levels. This knowledge would allow New Zealand farmers to make more informed decisions when considering hogget breeding. Bio-economic modelling can include both the potential benefits of hogget breeding, such as potential increases in income from additional weaned lambs, and potential negative impacts, such as increased feed demand and expenses. The first objective of this study was to use an established bio-economic system-dynamics model of a New Zealand sheep production enterprise [18,19] to quantify the potential net economic benefit of breeding hoggets. It has previously been established that improving the weaning rate of mature ewes can increase farm productivity and profitability in Australia [16,17] and New Zealand [20]. The New Zealand national average industry weaning rate was 132% in 2018 [21]. New Zealand farmers who do not breed their hoggets may wish to consider if it would be more profitable to aim for a higher mature ewe weaning rate or to breed hoggets. Furthermore, it is not known if the potential positive effects of hogget breeding are consistent across differing mature ewe weaning rates. Therefore, the second objective of the current study was to quantify the profitability of scenarios with combinations of varying hogget and mature weaning rates with consistent total annual sheep feed demand between scenarios.

2. Materials and Methods

The farm system under consideration was a New Zealand East Coast North Island Hill Country sheep and beef farm. Farm and ewe flock characteristics were based on average values from industry survey data for East Coast North Island Hill Country farms in the 2017/18 production year [21]. This farm system had both sheep and beef production enterprises, where sheep accounted for 60% of total feed consumed with the remainder mostly consumed by beef cattle [21]. The farm was 530 ha with a self-replacing flock of 2066 mature Romney ewes lambing annually in spring and extensively grazing pasture year-round. The sheep enterprise was the focus of this research, producing coarse wool (fibre diameter > 30 µm) and lambs for meat production, with the proportion of feed consumed by sheep used to estimate operating expenses and farm area applicable to the sheep enterprise. Total annual feed demand for sheep was maintained at 60% of total farm feed for all scenarios; therefore, it was assumed the on-farm beef enterprise was not affected by the modelled changes in sheep breeding policies.

The bio-economic system dynamics model used in this study was constructed using STELLA version 1.9.3 [22]. The model was the same as was previously used by [18,19] to quantify changes in the production and profitability of New Zealand sheep farming enterprises with various system changes. In the current research, component modules were flock dynamics for the self-replacing ewe flock (including lamb production), wool production, fortnightly and annual sheep feed demand, and sheep enterprise economics. More detail on the model's workings and changes between differing scenarios is given in the following subsections.

2.1. Flock Dynamics

A simplified diagram of the flock dynamics module is shown in Figure 1. Ewes in each age ($_i$) class (Y_i) each year were the sum of ewes in the previous age class (Y_{i-1}) less ewes leaving the flock due to deaths (D_{i-1}) and culling (C_{i-1}) (Equation (1)). The ewe flock (F) was therefore the sum of ewes in six age classes (Equation (2)). Flock replacement requirements (R) were the sum of all ewes leaving the flock due to death and culling in order to maintain flock size (Equation (3)). Death rates of 5.2% for $Y_{2\ to\ 6}$ ewes were assumed [21] which included missing ewes, with a flock replacement rate of 25% assumed, which is typical of New Zealand sheep-breeding flocks [23]. All ewes in Y_6 were culled after their lambs were weaned. A death rate of 2% was assumed for Y_1 ewes when not bred [21], which was doubled to 4% for Y_1 ewes that lambed [11].

$$Y_i = Y_{i-1} - D_{i-1} - C_{i-1} \tag{1}$$

and

$$F = \sum_{i=1}^{6} Y_i \tag{2}$$

and

$$R = \sum_{i=1}^{6} [D_i + C_i] \tag{3}$$

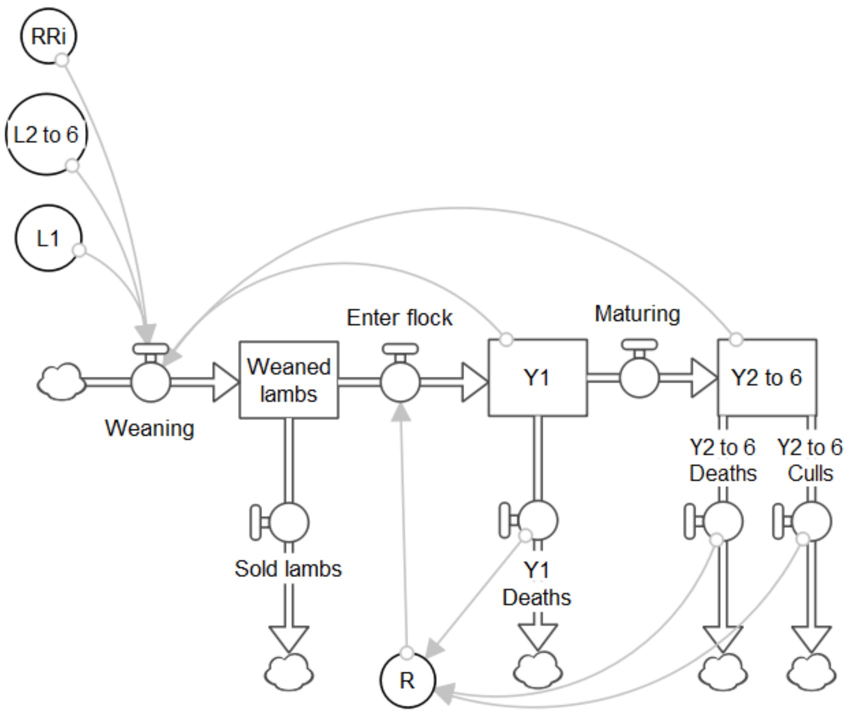


Figure 1. Simplified diagram of the flock dynamics module. Where numbers of Weaned lambs were a product of the numbers of ewes in each age ($_i$) class (Y_i) of the flock, the relative reproductive success (RR_i) of ewes in each age class, and weaning rate (L_i). Numbers of replacement ewe lambs entering the self-replacing flock (R) were determined by numbers of ewes leaving the flock due to deaths and culling (with no culling of Y_1 ewes assumed and all live Y_1 ewes entered the mature flock).

Numbers of lambs weaned (LW) were estimated from Equation (4) as a function of ewes of each age class presented for breeding (Y_i), L (weaning rate as lambs weaned per ewe presented for breeding), and relative reproductive success for each ewe age class (RR_i; RR_2 = 0.85, RR_3 = 0.98, RR_4 = 1.07, RR_5 = 1.12, and RR_6 = 1.09; as detailed in [18]). The flock weaning rate (FWR for $Y_{2\ \mathrm{to}\ 6}$ ewes) was modelled at two levels, firstly at 132% which was the average 2017/18 rate for the farm system under study [21]. In order to investigate the value of breeding hoggets for farms with a more productive flock, FWR was also modelled at 150%. This FWR of 150% was approximately the 90th percentile of weaning rates achieved in 2017 by flocks on New Zealand North Island Hill Country farms [24]. Hogget weaning rate (HWR) was varied to RR_1 = 0, 0.6, 0.8, or 1. Responses to a questionnaire sent to New Zealand sheep farmers who bred Y_1 ewes in 2002 suggested an average HWR of 60%, with 21% of the farmers achieving *HWR* of ≥80% and 6% achieving Y_1 weaning rates of ≥100% [25].

$$LW = \sum_{i=1}^{6} [Y_i \times L_i \times RR_i] \quad (4)$$

2.2. Wool Production

The flock had an average mature ewe greasy fleece weight (W) of 5.2 kg [26]. All lambs on-farm in January were assumed to be shorn along with the ewe flock, with total flock wool production estimated according to mature fleece weight (W in kg), an adjustment parameter for fleece weight of lambs and ewes in each age class (w_i; $w_{0.5}$ = 0.50 (lambs), w_1 = 0.95, w_2 = 1.01, w_3 = 1.08, w_4 = 1.05, w_5 = 1.01, and w_6 = 0.97) [27–29], and numbers of sheep in each age class (Y_i) in Equation (5).

$$WP = \sum_{i=0.5}^{6} [Y_i \times (W \times w_i)] \quad (5)$$

2.3. Sheep Feed Demand

Total annual sheep feed demand was maintained at 60% of total farm feed supply for all scenarios modelled, achieved through adjusting ewe flock size. Sheep feed demand was estimated in megajoules of metabolisable energy (MJ ME) and for daily maintenance energy (ME_m) was calculated from Equation (6) [30].

$$ME_m = \left[0.28 \times \frac{LW^{0.75} \times e^{-0.03 \times i}}{0.02 \times Q + 0.5}\right] \times 1.1 \quad (6)$$

where LW = liveweight (kg), i = sheep age (years), and Q = pasture quality measured as MJ ME/kg DM, assumed to be 10 MJ ME/kg DM which is considered a medium quality of pasture on New Zealand sheep and beef farms [31]. Mature ewe ($Y_{2 \text{ to } 6}$) average liveweight was 65 kg, losing 2 kg in spring during lactation which was regained prior to autumn breeding. The liveweight of replacement hoggets was assumed to average 80% of mature ewe liveweight when entering Y_1 at twelve months of age [32–35]. Liveweight values used to calculate maintenance demand for sheep younger than Y_2 were averages for that class of animal. For example, single-born prime lambs from mature ewes were weaned at 30 kg (Section 2.3 in manuscript) and sold for slaughter at a 44 kg liveweight; hence, demand for maintenance between weaning and slaughter was based on an average liveweight of 37 kg. Feed demand for liveweight gain was 55 MJ ME required for each kg of liveweight gain, and 35 MJ ME were converted from each kg of liveweight loss [36].

Mature ewes began lambing September 1, the average date for East Coast flocks [37] and hoggets began lambing a month later [8]. Feed demand for gestation (ME_G) was estimated on a per foetus basis for the entire gestation according to Equation (7) [36]. The average New Zealand lamb foetal loss rate (from ultrasound pregnancy scanning to weaning) of 15% [38] was used for foetuses from mature ewes alongside the FWR to estimate numbers of foetuses for gestation feed demand calculations. Therefore, when FWR = 132%, estimated feed demand for gestation from Equation (7) was for 1.55 foetuses per mature ewe. A lamb foetal loss rate of 25% was used in estimation of the gestation requirements of lambs weaned from hoggets [32,34,35,39,40]. Therefore, when HWR = 100%, estimated feed demand for gestation of foetuses from hoggets was for 1.33 foetuses per hogget. Feed demand for lactation (ME_L) was estimated per ewe for the entire lactation according to Equation (8) [36].

$$ME_G = 49 \times b + 7 \quad (7)$$

and

$$ME_L = N \times [51.4 \times WW + 134.7 \times \alpha - 1808] \quad (8)$$

where b is lamb birthweight (kg), N is the adjustment parameter for birth rank (N = 1 for single-born lambs and N = 1.35 for multiples) [30], WW = lamb liveweight at weaning (kg), and α = lamb age at weaning in weeks. Lamb birth weights were 5.5 kg for single-born lambs from mature ewes and 4.5 kg for multiple-born lambs from mature ewes [15,32,33]. Lambs from hoggets weighed 4.5 kg and 3.9 kg for single– and multiple-born lambs at birth, respectively [32,34,39,40]. Lambs from mature ewes were weaned at 12 weeks of age weighing 30 kg and 28 kg for single- and multiple-born lambs, respectively [41,42]. Lambs from hoggets were weaned at 10 weeks of age weighing 23 kg and 17.4 kg for single- and multiple-born lambs, respectively [35,43,44]. Flock average greasy fleece weight (5.2 kg) [26] was used to calculate flock daily wool growth (G) in g/sheep/day. Daily feed demand for wool growth (ME_w) was estimated using Equation (9) [30].

$$ME_w = 0.13 \times (G - 6) \tag{9}$$

2.4. Lamb Sale Policies

Lambs from mature ewes were sold in three groups, with two groups sold prime (direct to slaughter) and the third sold store (to another farmer to grow for slaughter). Prime lambs were assumed to have an average carcass weight of 18 kg at sale [21] and carcass dressing rate of 41% [45]. The first group of prime lambs were sold in early February and the second group in mid-February according to an estimated average post-weaning growth rate of 100 g/day [23,46,47]. Store lambs from mature ewes were also sold mid-February with a liveweight of 30 kg, lighter than would typically be sold prime [48]. Lambs from hoggets were assumed to all be sold store in mid-December, within a fortnight of their weaning with an average liveweight of 24 kg, assumed to also have average post-weaning growth rates of 100 g/day [23,46,47].

2.5. Economics

Annual sheep enterprise cash operating surplus (COS) was used as an indicator of changes in profit and was estimated from gross sheep enterprise cash income (sheep and wool sales) and sheep-related operating expenses. All economic values in this analysis were in New Zealand dollars (NZD). Sheep enterprise COS was expressed on a per ha basis, with the COS therefore divided across the sheep proportion of the 530 ha farm area [21]. As total annual sheep feed demand was maintained at 60% of farm feed, the beef enterprise COS was assumed not to change between modelled scenarios. Prices for cull ewes and all sold lambs were from 2017/18 values, shown in Table 1, which were combined with numbers of sheep sold in the flock dynamics module to estimate total annual income from sheep sales. Prices for store lambs and culled ewes were per head values from industry survey data [21]. Prices for prime lambs were from weekly 2018 published schedule prices, a weighted average price (per kg carcass weight) from lamb sales across the North Island [48]. A 2017/18 farmgate wool price of NZD 2.15 per kg greasy wool [21] was combined with wool production in Equation (5) to estimate income from wool sales.

Table 1. Prices for sold sheep in 2017/18, ewes of various age classes (Yi), and lambs sold either prime (direct to slaughter) or store (to another farmer to grow for slaughter), with lambs from hoggets sold store after their weaning.

Sheep Class	Timing of Sale	Value (NZD /Head) [1]	Price Data
$Y_{3\ to\ 6}$ ewes	Early December [2]	113.73	[21]
Y_2 ewes		134.64	
Prime lambs	Early February	107.44	[48]
	Mid-February	107.10	
Store lambs	Mid-February	84.00	
Lambs from hoggets	Mid-December	67.00	[21,48]

[1] Prices per head for lamb sales were estimated from weekly schedule prices per kg of carcass weight and their weight at sale. [2] The majority of ewes were culled in early December at weaning, with a small proportion culled in June at pregnancy scanning.

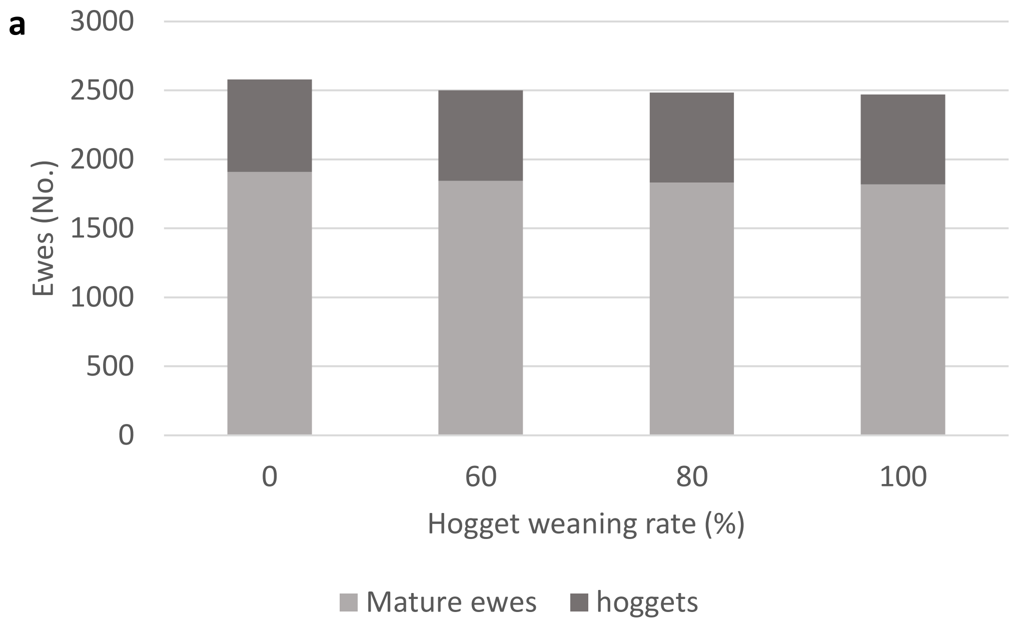
Animal health expenses were assumed to be NZD 6.00 per sheep stock unit and other operating expenses were assumed to be NZD 47.80 per sheep stock unit [21]. Operating expenses were comprised of variable costs and the enterprise share of fixed costs (including costs of repairs and maintenance, vehicles, administration, ACC (Accident Compensation Corporation levy), and insurance) while excluding drawings, tax, interest, depreciation, and rent [49]. Wintered sheep stock units included ewes, rams, and replacement lambs. A stock unit is the equivalent of one 55 kg ewe weaning one 28 kg lamb, equal to an annual feed consumption of 550 kg dry matter (DM) [50]. The stock unit value per ewe and hogget varied according to their weaning rate and liveweight [51]. The ewe flock ($Y_{1\ to\ 6}$) had shearing expenses per head of NZD 10.98 (consisting of expenses of NZD 4.89 for a full summer shear, NZD 4.09 for a second winter shear, and NZD 2.00 for a full crutch of the belly and breech) and lambs had shearing expenses of NZD 3.71 per head [52]. Breeding expenses for the mature flock ($Y_{2\ to\ 6}$), including for ram purchases, were assumed to be included in the general operating expenses. Expenses from purchases of rams for hogget breeding were calculated separately, with breeding ratios of one pre-breeding teaser ram per 75 hoggets and one breeding ram per 50 hoggets [11,53,54]. Teaser rams are vasectomised rams exposed to hoggets prior to breeding to improve pregnancy rates [11]. Rams were assumed to be purchased for NZD 800 per head, where the value of teaser rams included their vasectomisation, and were assumed to each be used for three years so the expense per ram was NZD 267 per year [52]. It was assumed purchases of additional rams and increased hogget stock units (as hogget stock units increased with their weaning rates) were the only increased expenses with hogget breeding.

3. Results and Discussion

The results are presented and discussed for modelled scenarios combining FWRs of either 132% or 150%, with HWRs of 0%, 60%, 80%, or 100%. Total annual sheep feed demand was maintained at 60% of total farm feed for all scenarios.

3.1. Sheep Numbers

Feed demand on a per ewe basis was greater with FWR = 150% and HWR = 0% than with FWR = 132% and HWR = 0%, due to additional feed demand for the gestation, lactation, and post-weaning growth of additional lambs [36]. Therefore, to maintain the overall total annual sheep feed demand with FWR increased to 150%, there were fewer ewes in the flock. For example, with HWR = 0%, there were 2580 total $Y_{1\ to\ 6}$ ewes with FWR = 132% and 2500 total $Y_{1\ to\ 6}$ ewes with FWR = 150% (Figure 2). Similarly, as the HWR increased there was increased per hogget feed demand for the production of their lambs, so total ewe numbers were reduced by up to 115 ewes when HWR increased from 0% to 100% (Figure 2).



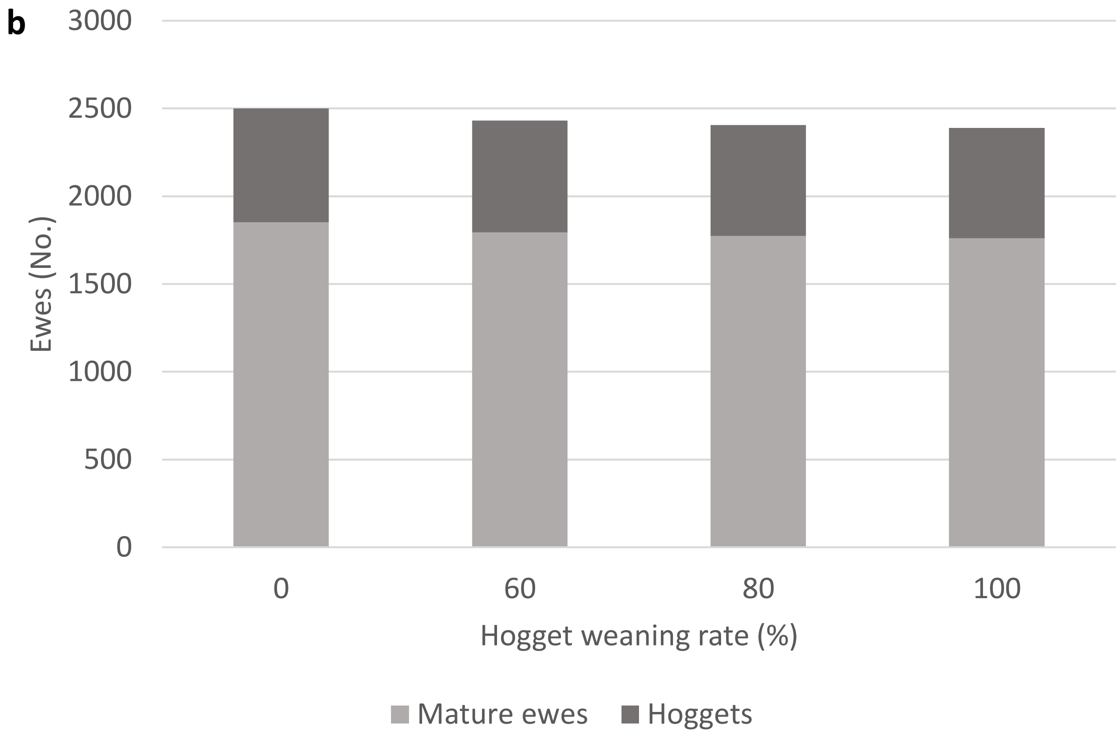


Figure 2. Numbers of ewes in the ewe flock that are mature ewes (aged two to six years) and hoggets, with varying hogget weaning rates and with mature ewe weaning rates of (**a**) 132% and (**b**) 150%.

3.2. Lamb Production

Hogget breeding always increased total flock numbers of lambs weaned (Figure 3) despite reductions in total ewe numbers (Figure 2). In the scenario with FWR = 132% and HWR = 100%, 524 more lambs were weaned than with FWR = 132% and HWR = 0% (Figure 3). With HWR of 100%

the proportion of total weaned lambs that were weaned from hoggets was 21% and 19% with FWRs of 132% and 150%, respectively. In the scenario with FWR = 132% and HWR = 60% 2834 lambs were weaned in total, only slightly higher than the 2780 total lambs weaned by the flock with FWR = 150% and HWR = 0%.

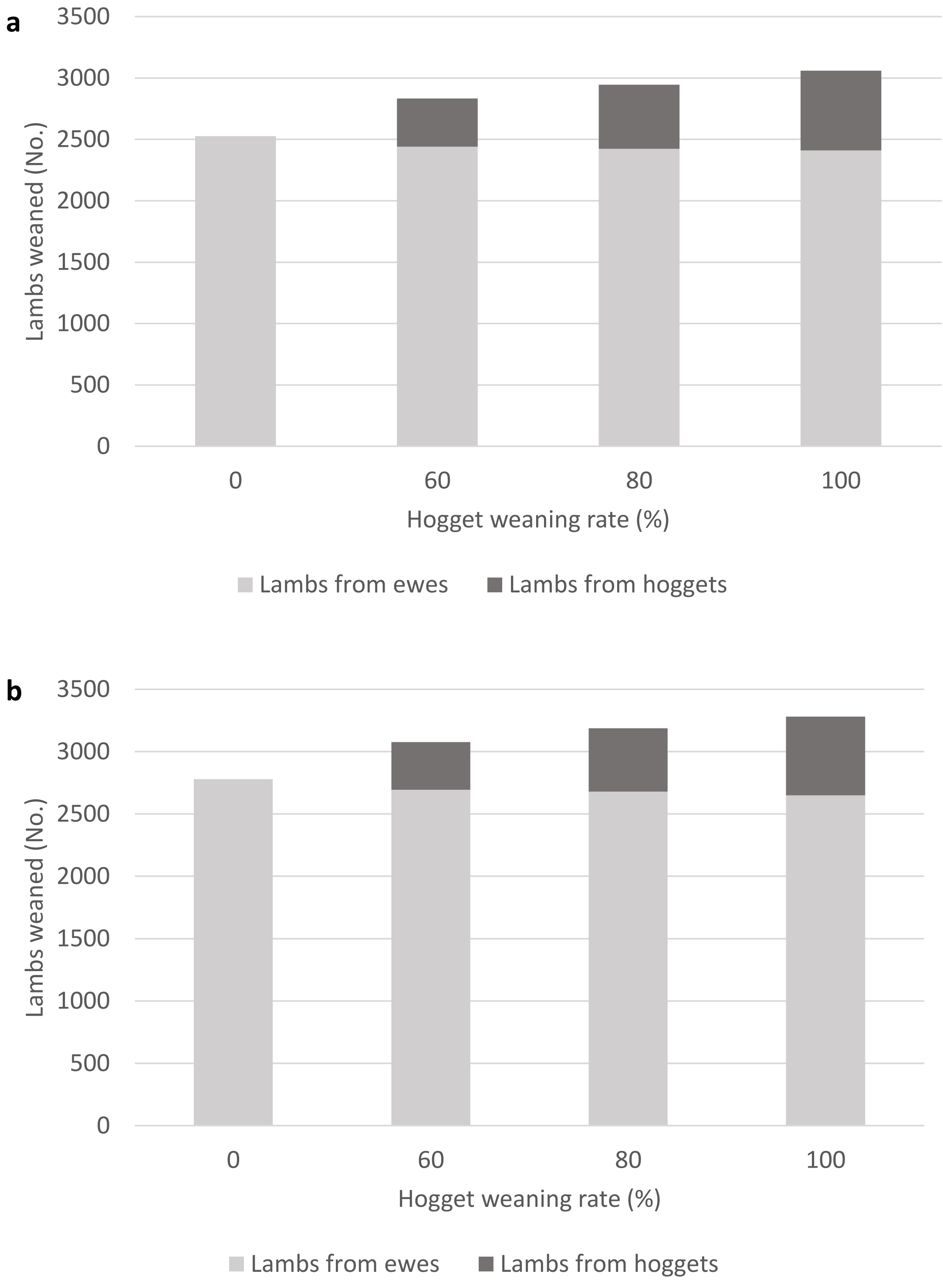


Figure 3. Numbers of lambs weaned from mature ewes (from ewes aged two to six years) and hoggets, with varying hogget weaning rates and with mature ewe weaning rates of (**a**) 132% and (**b**) 150%.

3.3. Sheep Feed Demand

Figure 4 shows total annual sheep feed demand, irrespective of scenario, was maintained to approximately 19 million MJ ME. This was achieved through reductions in total ewe numbers as the HWR increased from 0% to 100%. Therefore, the proportion of the total sheep feed demand accounted for by mature ($Y_{2\ to\ 6}$) ewes (mostly for their maintenance) decreased from 49% to 46%. The proportion of sheep feed demand accounted for by post-weaning growth of lambs destined for sale displayed only small increases (up to approximately 70,000 MJ ME), as lambs from hoggets were sold store soon after weaning, rather than being grown to heavier sale weights. Feed demand for the gestation and lactation of lambs from hoggets was relatively low compared to lambs from mature ewes due to differences in birth and weaning weights and the weaning age of their lambs [36]. Therefore, with FWR = 132% and HWR = 100%, the overall proportion of sheep feed demand for reproduction (gestation and lactation) was 24% (approximately 4.87 million MJ ME), only 1% higher than with FWR = 132% and HWR = 0% (25% and approximately 4.57 million MJ ME). Ram feed demand doubled from approximately 90,000 MJ ME with HWR = 0% to approximately 180,000 MJ ME with hogget breeding, as ram numbers increased from 19 to 41. With FWR = 150% and HWR = 0% there were fewer ewes, a lower proportion of sheep feed demand for mature ewe maintenance (48%), and a higher proportion of feed demand for reproduction (gestation and lactation; 25%). With FWR = 132%and HWR = 0%, the proportions of feed demand for mature ewes and reproduction were 49% and 24%, respectively.

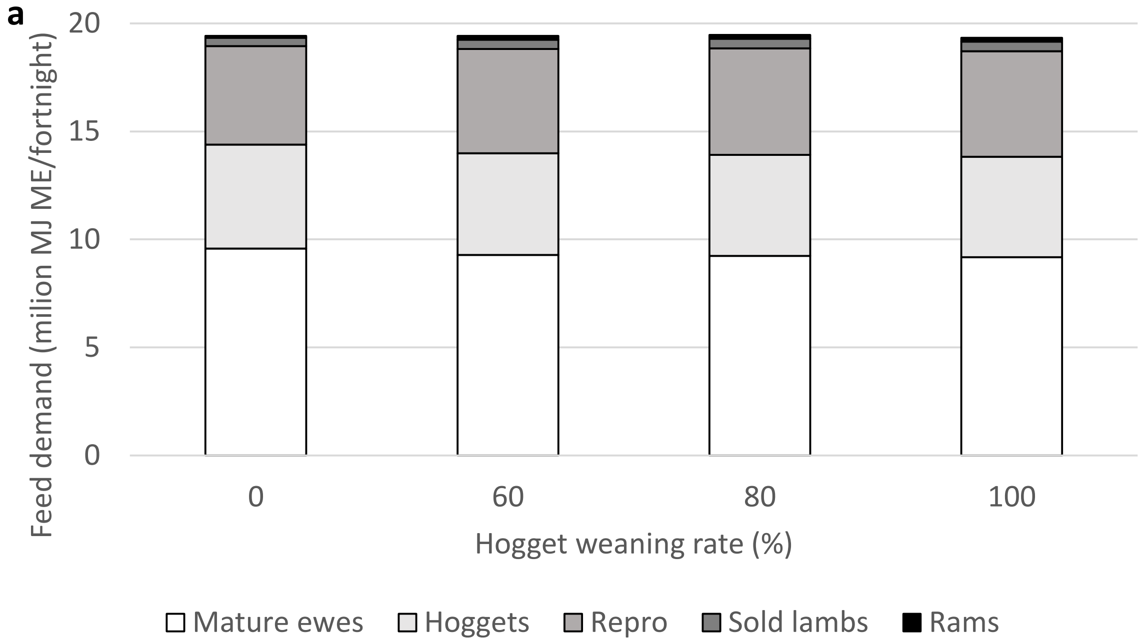


Figure 4. *Cont.*

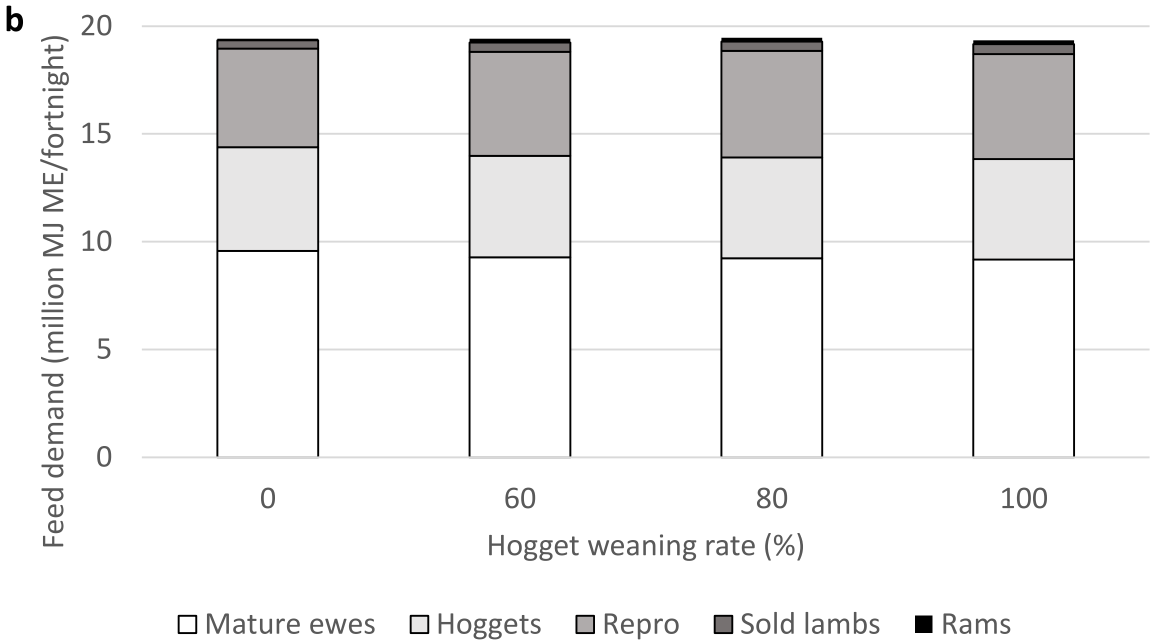


Figure 4. Total annual feed demand for mature ewes (aged two to six years), hoggets, reproduction (gestation and lactation for lamb production), sold lambs, and rams, with varying hogget weaning rates and with mature ewe weaning rates of (**a**) 132% and (**b**) 150%.

Scenarios with higher HWR weaned more total flock lambs while maintaining the same total sheep feed demand (Figures 3 and 4). With FWR = 132% and HWR = 0%, 130 lambs were weaned per million MJ ME of sheep feed demand, and with FWR = 132% and HWR = 100%, 158 lambs were weaned per million MJ ME of sheep feed demand. This indicated that hogget breeding improves the efficiency of feed use for lamb production, supporting the findings of [9]. There was an increased proportion of total feed demand for reproduction and growth of lambs destined for sale, rather than for maintenance of the mature ewe flock. Similarly, with FWR = 132% and HWR = 0%, there were 130 lambs weaned per million MJ ME of sheep feed demand. However, with FWR = 150% and HWR = 0%, 145 lambs were weaned per million MJ ME of sheep feed demand (Figures 3 and 4). Greenhouse gas emissions intensity (kg carbon dioxide equivalent emitted per unit of product) is reduced in animal production systems when a higher proportion of feed is used for production rather than maintenance [9]. This has been identified as occurring with changes in age at first lambing and higher weaning rates [9,55]. Therefore, hogget breeding is a potential option to improve the efficiency of, and reduce the greenhouse gas emissions intensity of, lamb production.

Though not presented, in the current analysis, hogget breeding increased fortnightly sheep feed demand during late gestation and lactation (in spring), and decreased sheep feed demand during late summer, autumn, and winter. These changes in the sheep feed demand profile were relatively small. Increasing the FWR from 132% to 150% also increased sheep feed demand in spring for reproduction. The fortnightly feed demand results support previous findings that breeding hoggets and improving flock weaning rates can improve the utilisation rates of spring pasture [11].

3.4. Economics

As HWR increased, income from wool sales decreased alongside decreasing ewe numbers, from a base level of 13% of total sheep enterprise income to 11% (Figure 5). With FWR = 132% and HWR = 0%, income from sheep sales was NZD 193,395, of which the majority was derived from lamb sales. Sheep sale income increased by NZD 18,064 with FWR = 132% and HWR = 60% and by NZD 31,357 with FWR = 132% and HWR = 100% (Figure 5a). Sheep enterprise expenses increased with increasing HWR due to purchases of additional rams, costing NZD 5867 annually, and increased hogget stock units. These increases, as a proportion of total expenses, were relatively small. For example, with FWR = 132% and HWR = 0% sheep enterprise expenses were NZD 193,395, and sheep enterprise expenses increased to NZD 204,952 with FWR = 132% and HWR = 100%, an increase of 6%.

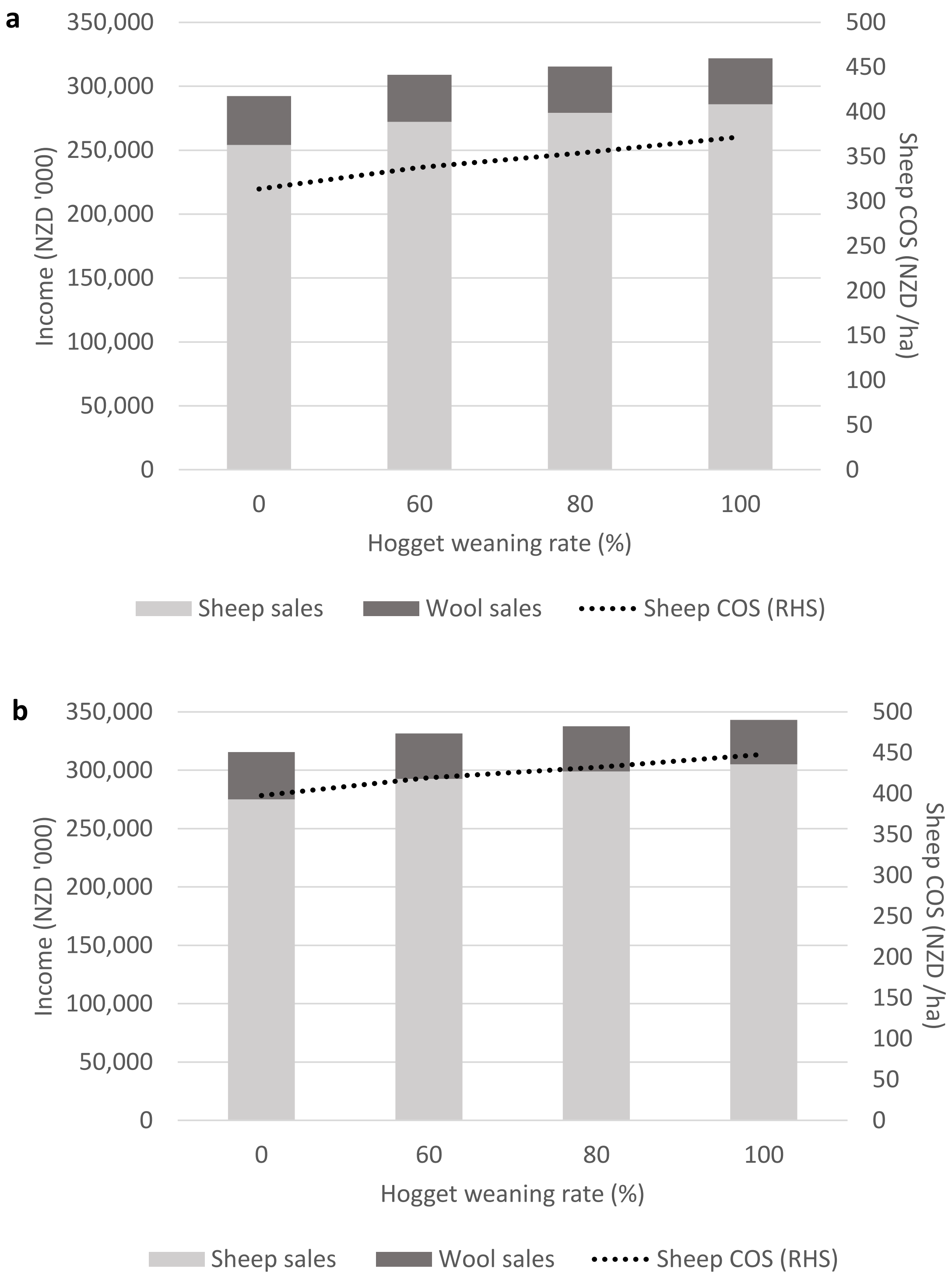


Figure 5. Sheep enterprise income from sheep and wool sales and sheep enterprise cash operating surplus (COS) with varying hogget weaning rates and with mature ewe weaning rates of (**a**) 132% and (**b**) 150%.

Given the relatively larger increases in income compared with increases in expenses, it was expected that COS would increase with increasing HWR. With FWR = 132% and HWR = 0% sheep enterprise COS was NZD 314/ha (Figure 5a). With FWR = 132% and HWR = 60% COS increased 8% to NZD 338/ha, and with FWR = 132% and HWR = 100% = COS increased 17% to NZD 369/ha. When a higher mature ewe flock reproductive performance was achieved a similar trend occurred. For example, with FWR = 150% and HWR = 0% sheep enterprise COS was NZD 397/ha and this COS increased with FWR = 150% and HWR = 100% to NZD 449/ha, an increase of 13% (Figure 5b). Ref. [56] used bio-economic modelling to identify the economic benefit of hoggets in New Zealand achieving puberty in their first year of life and their increased subsequent reproductive success. The analysis did not include hogget breeding; however, increases in feed demand associated with hoggets achieving puberty in their first year of life were modelled and mitigated some of the economic benefit. Similarly, the current analysis included the effect of increased feed demand when breeding hoggets on other stock classes, as ewe numbers decreased. Both studies found improving hogget reproductive success (either achieving puberty or being bred) was economically beneficial despite associated increases in their feed demand and is therefore a profitable option for farmers to consider.

With HWR = 0%, sheep enterprise COS was NZD 314/ha with FWR = 132% and increased to NZD 397/ha with FWR = 150% (Figure 5). These results support previous research findings that improved FWR increases sheep farm profitability in pastoral systems in New Zealand [20], Ireland [57], and Australia [17]. The average New Zealand FWR was 102% in 1990 and increased to 133% in 2019 [26]. These improvements in FWR were achieved through selection and changes in management practices such as pregnancy scanning, body condition assessment, preferential feeding of pregnant ewes bearing multiple lambs, and whole flock health plans [41,58].

Although sheep enterprise COS always increased with additional income from breeding hoggets, COS was lower with FWR = 132% and HWR = 100% compared with the scenario with FWR = 150% and HWR = 0% (Figure 5). This was due to a relatively greater difference in expenses (NZD 13,425 greater for the scenario with FWR = 132% and HWR = 100%) than income between the scenarios (NZD 5797 greater for the scenario with FWR = 132% and HWR = 100%). Previous bio-economic modelling of Australian sheep production systems suggested breeding replacement ewe lambs (hoggets) to lamb at one year of age could potentially lift profit by up to AUD 100/ha (Australian dollars) with HWRs of ≥83% [16]. However, the same study identified breeding hoggets to be a 'second-order' critical control point, less important than lamb sale policies and optimising pasture utilisation, and not economically beneficial for all types of sheep production systems. In a later analysis using the same model, improving hogget reproductive success was again suggested as a secondary priority for increasing Australian sheep industry revenue, less important than improving the survival of twin-born lambs from mature ewes [17]. The findings of [16,17] support those of the current analysis where improving FWR from 132% to 150%, with no hoggets bred, achieved greater increases in sheep enterprise COS than scenarios breeding hoggets (Figure 5). This suggests that lifting FWR to 150% from the industry average of 132% should receive relatively more attention from sheep producers and may be a more valuable use of feed for farmers considering breeding their hoggets. Furthermore, improving FWR would likely be easier than improving HWR due to the low and variable reproductive success reported for hoggets and potential long-term negative consequences in New Zealand conditions [11,59].

Continued improvements in FWR have occurred in New Zealand flocks [26] alongside increased hogget breeding. In 1990 only 16% of 8 to 9 months old hoggets were presented for breeding, this increased to 30% in 2010 and to 32% by 2018, with HWR (of hoggets presented for breeding) increasing from an average of 40% in 2010 to 60% in 2018 [1]. Industry production data from New Zealand East Coast North Island Hill Country report that, on average, 7% of weaned lambs were from hoggets in the 2017/18 production year [21]; however, those data include farms that do not breed hoggets. In the current analysis with FWR = 132% and HWR = 60%, current average industry weaning rates [21,25], 14% of total weaned lambs were weaned from hoggets (Figure 3). Therefore, the assumptions of HWRs and FWRs included in the current analysis were representative of those currently achieved in New Zealand sheep production systems.

4. Conclusions

Hogget breeding in all scenarios increased expenses but there was a relatively greater increase in income from sales of their lambs. Hogget breeding always increased sheep enterprise COS (sheep enterprise cash operating surplus) with the modelled HWRs (hogget weaning rate) of 60% and higher compared with a flock not breeding hoggets. Therefore, hogget breeding increased profit even with a relatively low HWR for a given FWR. These increases in COS were achieved while maintaining a constant total annual sheep feed demand. However, COS was higher with FWR (ewe flock weaning rate) = 150% and HWR = 0% than with FWR = 132% and HWR = 100%. The results indicate farmers who do not currently breed their hoggets may wish to improve their FWR before considering HWRs.

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