Size is everything

Because it lives longer a larger animal uses less energy per kilogram per day.

GENE TALK
Mark Young

My last two columns have examined how adult size impacts on the rate at which animals do things and their lifespan and also how tissue proportions change as animals grow from birth to maturity.

This final article considers how this all fits together and what it tells us about mammalian biology.

While larger animals live longer they do things at a slower rate. So one kilogram of tissue in a cow uses less energy a day than one kilogram of tissue in a sheep all other things being equal. The cow eats more overall a day because it is bigger but less per kilogram of body weight. Detailed experiments made many years ago proved this and showed that energy requirements of animals scale (are proportional) to adult body weight (A) to the power of 0.73 ($\propto A^{0.73}$).

The length of events scale to 0.27 ($\propto A^{0.73}$) – therefore total energy used by one kilogram of tissue over the animal's life scales to rate per day ($A^{0.73}$) times length of life ($A^{0.27}$). We do the algebra and find that $A^{0.73} * A^{0.27} = A^{0.73+0.27} = A^{1.00}$. In other words, the total energy an animal uses in its life is directly proportional to its size. Or, one kilogram of tissue uses the same amount of energy over the lifespan of an animal whatever the size of the animal is. But since it lives longer a larger animal uses less energy per kilogram per day.

Associated with a lower rate of energy use in larger animals, events occur less frequently. A heart beat is an event so larger animals have slower heart rates. This is entirely consistent with using energy at a slower rate per kilogram of tissue. But since they have longer lives, larger animals are predicted to have the same number of heart beats in their lifetime as smaller animals. Some estimates have this as 1.5 billion heart beats per lifetime.

So how does the algebra shown cope with this? If animals have a constant number of events per lifetime not affected by body size, this scales to $A^{0.00}$ (any number raised to the power of zero equals 1). Since lifespan scales to $A^{0.27}$, rates of events is a function of number of events per lifetime ($\propto A^{0.00}$) divided by lifespan ($\propto A^{0.27}$) so event rates are proportional to $A^{0.00} \div A^{0.27}$, which simplifies as $A^{0.00-0.27}$ and then to $A^{-0.27}$.

You can work out the algebra yourself to show that larger animals have a slower heart rate than smaller animals – *see Table 1.*

All animals have a similar life plan from conception then growth through birth to maturity and functioning as a reproductive adult before old age leads to death from natural causes.

This has led to a description of a standard lifespan for a mammal that has 2000 "metabolic days" (with unit of theta – θ). One "metabolic day" multiplied by $A^{0.27}$ gives us true "Earth days". Examples for a 65kg ewe and a 500kg cow are given in *Table 2.*

These show some animals have specialised by deviating from prediction. Pigs are born much smaller than 5% of adult size after a shorter pregnancy (about 114 days). This is because a sow can only carry a large litter if each piglet is a lot less than 5% of adult size.

Sheep are predicted to have 10.1 months between first giving birth and the end of lactation.

Table 1: Genetic scaling of animal performance traits to adult size (A)

Type of performance measure	Scales to	From	Comment
Number of events in life	$A^{0.00}$		Constant number (no effect of adult size)
Total metabolic activity in life eg: feed energy per lifetime	$A^{1.00}$		Constant amount per kilogram of tissue (no effect of animal size)
Periods for events	$A^{0.27}$		Shorter in smaller animals
Event rates	$A^{-0.27}$	$A^{0.00} \div A^{0.27}$	Faster in smaller animals
Rate of metabolic activity eg: feed energy per day	$A^{0.73}$	$A^{1.00} \div A^{0.27}$	Smaller animals require more energy per kilogram

Sheep have a slightly shorter pregnancy (about 147 days) than predicted possibly because they average more than one lamb a pregnancy. Cows have a slightly longer pregnancy (about 285 days) fitting this trend of shorter pregnancies for species with larger litters.

The predictions we get from genetic size scaling theory are not absolutes. However, they help explain general principles and, most importantly for animal science and animal breeding highlight unusual animal types deviating from our predictions or limitations to performance.

Sheep and beef cattle are farmed under more favourable conditions than those they evolved in.

With high levels of feeding and high-quality pasture ewes and cows can reach developmental targets faster than the theory predicts. However, the underlying biology because of genetic size scaling may limit opportunities to improve traits.

For example, sheep are predicted to have 10.1 months between first giving birth and end of the associated lactation (20.4-10.3) while for cattle this is 15.8 months (35.3-17.7). We are fighting against biology trying to shoehorn cattle into a repeated 365 day cycle for pregnancy and lactation.

Cattle have a cycle inherently longer than the 365 day "Earth year" dictated by motion of the Earth around the sun, while sheep can easily fit within our "Earth year" provided we can feed them what they require.

In summary, size matters.

You can give B+LNZ Genetics or SIL your thoughts on this topic by emailing: silhelp@sil.co.nz or by leaving a message on 0800-silhelp (0800 745 435).

- *[Mark Young is senior geneticist with B+LNZ Genetics and SIL.*

Table 2: Prediction of event times based on a standard lifespan of 2000 metabolic days (θ); convert to true time by multiplying θ by $A^{0.27}$; all ages are post conception.

Time of event, post conception	Age in metabolic days (θ)	True age for 65kg adult (ewe)	True age for 500kg adult (cow)
Birth (5% of adult size)	50	158 days	271 days
Reaches sexual maturity	100	10.3 months	17.7 months
End of first pregnancy	150	15.3 months	26.5 months
Reaches 70% of adult size	160	16.4 months	28.3 months
End of first lactation	200	20.4 months	35.3 months
Ceases growth	500	4.2 years	7.3 years
End of prime of life	700	5.9 years	10.3 years
Dies	2000	16.9 years	29 years