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Variation in meat pH in steers and association with other carcass attributes: analysis of a commercial database

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ABSTRACT

Measurements of meat pH on 16905 steer carcasses supplied to the Richmond Asian Beef Programme in the 1993/94 and 1994/95 seasons were analysed for variability between suppliers and associations between pH and other carcass attributes. Carcass measurements were made 12 hours or later after slaughter. Factors evaluated included carcass weight, carcass grade, marbling level, age of cattle, mob size, and use of growth promotants.

The frequency distribution of meat pH was highly skewed, with 92% of carcasses falling within the range of 5.2 to 5.8, and the remainder forming a long tail above 5.8, ranging to an extreme value of 7.1. For carcasses falling in the pH range of 5.2 to 5.8, pH showed a highly significant positive association with meat colour. As pH rose above 5.8, the slope of the relationship increased and the percentage of carcasses in the darkest meat colour category rapidly approached 100%.

In the range 5.2 to 5.8, pH showed highly significant negative ($P< 0.0001$) associations with degree of marbling and carcass weight. After adjusting for carcass weight and marbling score, pH showed a significant positive association with age of cattle. The percentage of carcasses with a pH above 5.6 was 38% for carcasses with a marbling score of 1. For every unit increase in marbling score (up to 5), the percentage of carcasses above a pH 5.6 specification declined by approximately 5%. However, the proportion of carcasses with pH above 5.8 showed little association with marbling. Similarly, effects of weight and cattle age on pH were much more apparent near the mean pH (5.61) than at pH values at and above 5.8.

Mob size had a small but highly significant($P<0.001$) effect on the frequency distribution of pH, with smaller mobs tending to have lower pH. The effect of smaller mob size was more evident near the high pH range than in the middle of the frequency distribution. For mobs of 15 or fewer cattle, 94% of carcasses had a pH of 5.8 or less. For mobs larger than 15, 91% of carcasses met this specification.

Keywords: meat pH; beef; carcass; variability.

INTRODUCTION

Between slaughter and the onset of rigor, meat pH usually declines from about 7.0 in living tissue to about 5.5 (the ultimate pH) as glycogen stored in muscle is converted to lactic acid. Muscle containing low levels of glycogen, due to strenuous exercise or exposure of animals to stress prior to slaughter, can result in meat with high ultimate pH. (Lawrie, 1985)

Meat with high (>5.8) pH is often described as dark-cutting or DFD (dark, firm and dry). In addition to its dark-purple colour (Renerre, 1990), meat with high pH has reduced keeping quality as bacterial putrefaction is accelerated (Newton and Gill, 1981). Meat with pH in the 5.8 to 6.2 range becomes less tender with the same amount of aging than meat with lower pH (Purchas, 1990; Anon, 1995). At pH above 6.2, meat becomes very tender with aging, but this is accompanied by poor texture and rapid spoilage.

Lawrie (1985) has reviewed various factors affecting the rate and extent of the decline of meat pH after slaughter. These include intrinsic factors such species of animal, breed, muscle type and between animal variability, and extrinsic factors such as environmental temparture and degree of stress. Young bulls are especially prone to stress and hence are more likely to have dark-cutting meat than steers. (Tarrant, 1981). Electrical stimulation of hot carcasses after slaughter can reduce much of the variability in meat by increasing the rate of pH decline (Renere 1990).

This report summarises measurements of meat pH made on prime steers processed in a commercial meat plant over a two year period Data were analysed to assess the extent of the problem in heavyweight, pasture fed New Zealand steers and to identify associations of meat pH with carcass weight and fatness, steer age, growth promotant treatment and mob size

METHODS

The population analysed in this report consisted of 16,905 steer carcasses supplied to the Richmond Asian Beef programme and slaughtered at the Richmond Pacific plant near Hastings between November 1993 and August 1995. Steers were supplied by 268 producers in a total of 1100 mobs. Mob size, as supplied to the plant, ranged from 1 to 73 with a median of 13. Carcass weight of this population averaged 331 kg. somewhat higher than the average New Zealand export steer carcass weights of 310 kg in 1993/94 and 306 kg in 1994/95 (B Spiers, NZ Meat and Wool Boards Economic Service, *pers comm.*).

Carcass measurements included carcass weight, carcass grade, meat colour and marbling score and pH.

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Carcass weight was measured and fat depth grade (Anon, 1987) was assessed visually on hot carcasses after splitting into sides. Other meat quality measurements were made on chilled sides, 12 hours or more after slaughter. Meat colour and marbling were scored on rib-eye muscle (*M. longissimus dorsi*) cut between rib 9 and 10, 30 minutes or more after cutting. The scoring system for these visual assessments were based on Japanese Meat Grading Association standards (Anon, 1988), with meat colour scored on a scale of 1(light) to 7(dark) and marbling on a scale of 1 (no marbling) to 12 (high marbling). Meat pH was measured using a spear-type electrode (NWK Binär GmbH, Landsberg Germany) inserted into the rib-eye muscle to a depth of 2 cm.

Age of cattle and details of treatment with growth promotants were obtained from questionnaires completed by suppliers as part of the programme. These were completed by 194 suppliers on 770 mobs (12089 steers). In the 1994/95 season, growth promotant treatment, as indicated by ear tags, was also recorded in plant on all cattle.

The relative contribution of between supplier, between mob within supplier, and with mob variation to the total variation in meat pH, carcass weight and marbling score was assessed using nested analysis of variance, with all effects treated as random varibles. Variance components were estimated by equating observed mean squares to their expectations. A nested analysis of covariance was used to estimate the contribution of these random effects to the association between carcass variables.

Standard linear models were used to measure associations between meat pH and other carcass and mob variables. Meat colour score, marbling score, carcass weight, age at slaughter and mob size were ananlysed as interval variables, while carcase grade and hormonal growth promotant treatment were analysed as nominal variables. Meat pH was treated as the dependent variable. The other variables, with the exception of meat colour, were treated as predictor variables, first using simple, one factor models and secondly including all predictor variables in the model. In presenting results, simple (unadjusted) means rather than covariate-adjusted means are reported, since covariate adjustment had no substantive effect on modifying the trends observed in the unadjusted data.

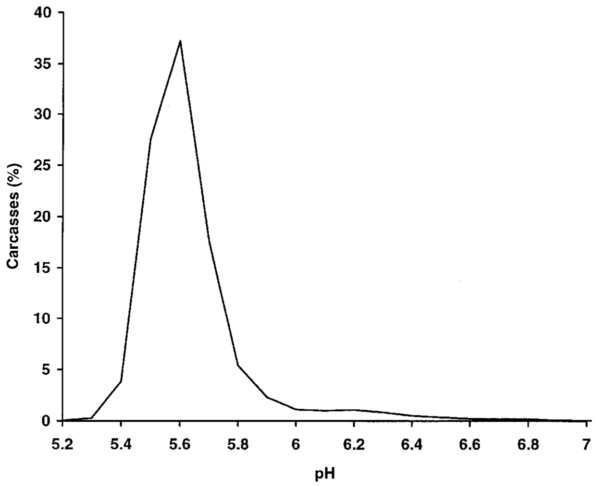
Parallel analyses were conducted using logistic models (Cox, 1970, McCullagh, 1980) to evaluate effects on the frequency distribution of meat pH and, in particular, on the probability of satisfying commercial meat pH specifications. In these logistic models, carcasses were classified as either passing or failing a pH specification and the logarithm of the odds ratio (ie., the ratio of the probability of failing to the probability of passing) was regressed against other carcass or mob variables. The binary classification variable was assumed to have a binomial error distribution.

RESULTS

Variability

The mean pH of the carcasses was 5.61 However, the distribution was not normal, with a long tail of high pH measurements extending to a maximum of 7.1 (Figure 1). Eight per cent of carcasses had a pH greater than 5.8 and 5% exceeded 6.0. Attempts to normalise the distribution using a logarithmic or inverse transformation were unsuccessful.

FIGURE 1: Frequency distribution of meat pH of steer carcasses slaughtered in the 1993/94 and 1995/96 seasons.



Variance components derived from a nested analysis of variance of between supplier, between mob within suppliers, and within mob effects are presented in Table 1. For comparison, variance components for marbling score and carcass weight are also presented. Most of the variation in pH was due to differences between steers within the same mob, with supplier effects accounting for only 3 to 4% of the total variance. This contrasts markedly with the analysis of carcass weight, an attribute that can be estimated by suppliers through liveweight measurement. Marbling score, a meat attribute that can be assessed by suppliers only by judgment of degree of finish, was intermediate.

TABLE 1: Variance components derived from expectations of mean squares of nested analysis of variance of meat pH, marbling score and carcass weight.

Variance source	Variance					
	Meat pH		Marbling score		Carcass weight	
Total	0.0376	(100)[1]	1.043	(100)[1]	830	(100)[1]
Between suppliers	0.0013	(3.5)	0.147	(14.1)	209	(25.1)
Between mob within suppliers	0.0067	(17.7)	0.239	(23.0)	238	(28.7)
Between carcasses within mobs	0.0296	(78.7)	0.656	(62.9)	383	(46.2)

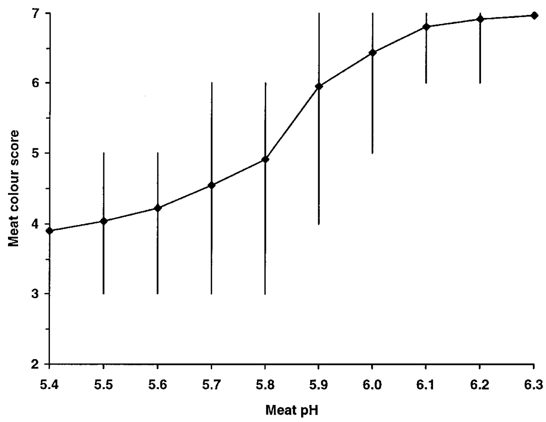
[1] Percent of total variance

Although differences between supplier <u>means</u> were small compared to the very wide range of variation in meat pH values observed within mobs, supplier differences in the frequency of high pH carcasses were highly significant. For the 107 suppliers contributing 50 or more cattle over the two year period, percentage of carcasses with pH > 5.8 averaged 8% but ranged from 0 to 35% (χ^2 for heterogeneity of suppliers = 483 with 106 df, p<0.0001).

Association of pH with other carcass and mob attributes

The association of high pH with darker meat colour was high, with a Pearson correlation coefficient of 0.69 (p<0.0001). The relationship between pH and meat colour is shown in Figure 2. Although change in meat colour with change in pH was greatest in the pH range of 5.8 to 6.0, an association of pH effects on meat colour was apparent at both lower and higher pH. For example, 17% of carcasses with a pH of 5.5 had a meat colour score of 5 or higher compared to 30% of carcasses with a pH of 5.6.

FIGURE 2: Relationship between meat pH and meat colour score. Data points represent mean meat colour scores at each pH. Vertical bars represent the 5-95% interquantile range.



Meat pH showed small but significant negative correlations with marbling score (r = -0.068, p < 0.0001) and carcass weight (r = - 0.048, p<0.0001). As marbling score increased from 1 to 5, mean pH decreased by 0.06 units (Table 2). Examination of the frequency distribution of meat pH at different marbling scores (Figure 3) indicated that the main effect of marbling was at low to moderate levels of pH, with little effect on the frequency of carcasses with extremely high pH values. Defining the pH 5.6 odds ratio as $P_{5.6}$ /(1- $P_{5.6}$) where $P_{5.6}$ is the proportion of carcasses with a pH > 5.6, each unit increase in marbling score reduced the odds ratio by the multiplicative factor 0.80. This change in the odds ratio is illustrated in Figure 2 as the vertical displacements of the cumulative distribution curves at pH 5.6. However, the effect of marbling on the pH 5.8 odds ratio was much smaller, and the χ^2 test for significance had a probability level of 0.17. Covariate adjustment for other significant factors indicated that the effect of marbling score could not be explained by other associated carcass variables such as weight or fatness grade.

Increasing carcass weight was associated with a small but highly significant decline in pH (Table 3). Each 10 kg increase in carcass weight was associated with a 0.003 decrease in mean pH and with an increase in the pH 5.6 odds ratio of 0.996^{10} = 0.96. However, unlike marbling, the effect of carcass weight on the proportion of carcasses meeting specific criteria was statistically significant at the high pH end of the frequency distribution as well as at the median. Carcasses under 300 kg appeared to be particularly susceptible to high pH. These trends were still significant after adjusting for marbling score, fatness grade, age and mob size.

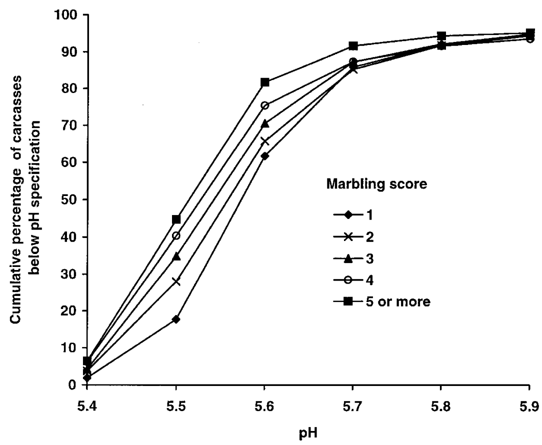
TABLE 2: Change in meat pH with change in marbling score.

Marbling score	N	Mean carcass weight (kg)	pH Mean	pH SD	Carcasses with pH above criterion (%) pH>5.6	pH>5.8
1	1523	324	5.64	0.18	38.3	7.9
2	6830	328	5.62	0.19	34.2	8.3
3	5603	333	5.61	0.20	29.5	7.9
4	2233	337	5.60	0.20	24.7	8.4
5	500	341	5.58	0.17	19.6	6.4
• 6	216	347	5.57	0.18	15.3	4.2

	Linear regression coefficient	Logistic model odds ratio pH> 5.6	pH> 5.8
Parameter estimates			
Single factor model	-0.0128 ***	0.796 ***	0.962 ns
Multiple factor model[1]	-0.0084 ***	0.830***	1.027 ns

[1] Adjusting for weight, grade, age and mob size effects.

FIGURE 3: Changes in cumulative distribution of meat pH with marbling score.



Carcass grade, a classification based on subcutaneous fat depth, also showed significant effects on meat pH (Table 4). As with the trend observed for increases in carcass weight, increasing fat cover was associated with decreasing mean pH and with fewer carcasses exceeding a pH 5.8 criterion. Fat cover remained a significant predictor of pH even after covariate adjustment for carcass weight, marbling score and age.

Analysis of covariance was used to partition the correlations between meat pH, marbling score and carcass weight into supplier, mob and carcass components (Table 5). Although the main source of variability of meat pH was differences between carcasses within mobs (Table 1), the association between pH and weight and marbling was due mainly to supplier and mob effects.

TABLE 3: Change in meat pH with change in carcass weight.

Carcass weight (kg)	N	pH Mean	pH SD	Carcasses with pH above criterion (%) pH>5.6	pH>5.8
<300	2048	5.64	0.21	38.1	10.18
300-325	5884	5.62	0.19	31.5	7.87
325-350	5487	5.61	0.19	29.9	7.56
350-375	2427	5.61	0.20	30.2	8.42
375-400	879	5.60	0.20	27.0	6.84
400-425	308	5.60	0.18	25.1	7.49
>425	98	5.58	0.15	20.4	6.12

	Linear regression coefficient	Logistic model odds ratio pH> 5.6	pH> 5.8
Parameter estimates for carcass weight			
Single factor model	-0.000324 ***	0.996 ***	0.997 *
Multiple factor model[1]	-0.000379 ***	0.995 ***	0.997 ns

[1] Adjusting for age, marbling, grade and mob size effects.

Older cattle tended to have higher mean pH and a greater frequency of carcasses with pH > 5.6 then younger cattle (Table 6). However, there was no association of age with the frequency of carcasses with pH > 5.8. The increase in pH with age occurred despite the higher carcass weights and increased marbling of older cattle, factors that were associated with lower pH.

Cattle treated with growth promotants had a similar pH distribution to cattle that were not treated (Table 7). Cattle treated with growth promotants tended to be heavier (averaging 332 kg versus 327 kg for untreated), but younger (17% under 24 months versus 7% for untreated) and with lower marbling score (averaging 2.53 versus 2.81 for untreated). Analysis of the effects of growth promotant treatment after covariate adjustment for weight, marbling and age effects gave similar results to the simple analysis of unadjusted effects. At the same weight, marbling and age, growth promotant treatment had no effect on either mean pH or proportion exceeding a pH 5.8 specification. but did gave a slight increase (p<0.0001) in proportion of carcasses below pH 5.6.

As mob size increased from 1 to 20 there was small but significant increase in mean pH, with a leveling off of the trend as mob size increased further (Table 8). Unlike, other factors affecting meat pH, mob size appeared to affect the frequency of high pH outliers more than it affected the modal region of the pH distribution. Using the logarithm of mob size as the predictor variable, the estimated effect of mob size on the pH 5.8 odds ratio was greater than its effect on the pH 5.6 odds ratio (χ^2 test for differences in slope =18.4 with 1 df, p< 0.0001). For each doubling of mob size, the pH 5.8 odds ratio increased by the multiplicative factor 1.3. This effect of mob size on the proportion of carcasses with pH above 5.8 was still highly significant after adjusting for carcass weight, marbling score, fat cover score and age at slaughter.

TABLE 5: Supplier, mob and carcass effects on the association between pH, marbling and weight.

Covariance source	Correlations calculated from covariance components: pH & marbling	pH & weight	Weight & marbling
Total	-0.0677	-0.0481	0.1480
Between suppliers	-0.3074	-0.1102	0.4794
Between mobs	-0.2363	-0.0771	0.1255
Between carcasses within mobs	0.0024	-0.0338	0.0481

DISCUSSION

The incidence of carcasses with pH > 6.0 recorded here (5%) is similar to that reported elsewhere. For example, Munns and Burrell (1966) reported that of 3.4% of USDA ‘Choice’ steers had a pH>6.0. In a review of data from several countries, Tarrant (1981) reported that 1-4% was a typical range for the incidence of dark cutting steer carcasses, with dark cutting defined as pH in excess of 5.8 to 6.2 depending on the researcher involved.

The shape of the pH frequency distribution indicated that although variation in pH was continuous, high pH carcasses appeared as extreme outliers from the ‘normal’ range of pH. This impression of two different populations prompted the suspicion that factors affecting the frequency of very high pH levels were different from those associated with ‘normal’ variation about the median pH level of 5.6. Analysis of different factors associated with variation

TABLE 4: Changes in meat pH with change in carcass fatness grade.

Grade	Nominal fat depth (mm)	N	Mean carcass weight (kg)	pH Mean	pH SD	Carcasses with pH above criterion (%) pH > 5.6	pH > 5.8
L	1-3	105	305	5.68	0.19	56.2	13.3
P	4-7	8082	325	5.63	0.20	33.7	9.0
K	8-12	2337	329	5.61	0.20	31.0	7.5
G	13-18	5630	337	5.60	0.18	27.6	7.2
T	19-24	320	355	5.59	0.17	25.1	5.4

	Linear model	Logistic model pH> 5.6	pH> 5.8
Significance level for test of grade effect			
Single factor model	0.0001	0.0001	0.0001
Multiple factor model1	0.0004	0.0003	0.05

1 Adjusting for weight, marbling score, age and mob size effects.

TABLE 6: Change in meat pH with age of cattle.

Age class (Years)	N	Mean carcass weight (kg)	Mean marbling score	pH Mean	pH SD	Carcasses with pH above criterion (%) pH>5.6	pH>5.8 score
1	1419	319	2.44	5.61	0.21	26.6	8.5
2	8145	330	2.63	5.61	0.18	31.7	7.5
3	1963	341	2.72	5.63	0.19	34.9	8.3
				Linear regression coefficient		Logistic model odds ratio pH> 5.6	pH> 5.8
Parameter estimates for age (in years)							
Single factor model				0.0124 **		1.205 ***	1.003 ns
Multiple factor model[1]				0.0120 ***		1.341 ***	1.066 ns

[1] Adjusting for marbling score, weight, grade and mob size effects.

TABLE 7: Differences in meat pH associated with treatment with growth promotants.

Growth Promotant	N	Mean carcass weight (kg)	pH Mean	pH SD	Carcasses with pH above criterion (%) pH> 5.6	pH>5.8
No	6165	327	5.61	0.19	31.7	7.8
Yes	8489	333	5.61	0.19	29.8	7.7
			Difference in means		Difference in proportion pH> 5.6	pH> 5.8
Significance level			ns		0.02	ns

TABLE 8: Change in meat pH with change in mob size.

Mob size	N	Mean carcass weight (kg)	pH Mean	pH SD	Carcasses with pH above criterion (%) pH>5.6	pH>5.8
1-5	613	328	5.58	0.15	27.9	4.2
6-10	1960	332	5.60	0.17	26.8	6.4
11-15	3088	329	5.60	0.17	29.1	5.5
16-20	2741	329	5.62	0.21	31.0	9.0
21-25	1927	333	5.61	0.19	27.8	7.7
26-30	2875	332	5.64	0.22	35.9	10.3
31-35	2116	330	5.63	0.20	34.8	9.8
36-40	1173	321	5.63	0.20	33.6	8.3
> 40	412	341	5.61	0.22	27.4	9.7
			Linear regression coefficient		Logistic model odds ratio pH> 5.6	pH> 5.8
Parameter estimates for $\log_2$(mob size)						
Single factor model			0.0134 ***		1.124 ***	1.301 ***
Multiple factor model[1]			0.0066 **		0.963 ns	1.204 ***

[1] Adjusting for marbling score, carcass weight, grade and age.

in pH supports this notion. Factors such as weight, marbling, fat grade and age appeared to be more closely associated with variation about the median, while mob size was more closely related to the proportion of carcasses with very high pH. However, the distinction between factors associated with normal versus abnormal variation was not clear-cut, as carcass weight and grade did have a small but significant association with the proportion of high pH carcasses.

The negative associations of pH with carcass weight, marbling and fat depth grade reported here are consistent with other reports (Poulanne and Aalto, 1981; Munns and Burrell,1966; Murray, 1989; Jones and Tong, 1989). Shorthose and Harris (1991) have concluded that these effects of carcass weight and fatness on pH indicate that 'animals on lower planes of nutrition are more susceptible to stress than well-fed animals'. They suggest the glycogen sparing activity of fatty acid oxidation as an explanation for the greater resistance of well-conditioned animals to pre-slaughter stress.

Carcass fatness and weight may also influence meat pH and other meat attributes through a temperature effect - ie, smaller carcasses with a thinner layer of insulating fat may cool down more quickly in the chiller, thus reducing the rate of postmortem glycolysis. Murray (1989) considered this to be a major cause of the negative relationship between weight and pH and cautioned against the evaluation of dark-cutting meat prior to the attainment of ultimate pH at 30 to 48 hours post-slaughter. However, if postmortem rates of chilling were the most important factor, then within-mob effects should make a major contribution to the association between pH and weight and fatness variables. That is, the heavier and fatter carcasses within a mob would tend to cool down more slowly than lighter carcasses from the same mob and this would be associated with lower pH. Within-mob variation for pH, marbling and carcass weight made up a large proportion of the total variation in these attributes (Table 1). For example, the average within mob-standard deviation for carcass weight was 19.6 kg. Nevertheless, the associations between weight, marbling and pH were largely due to mob and supplier effects (Table 5) rather than within-mob effects.

Although carcasses from older steers tended to be heavier and have more marbling than those from younger steers, they had higher average pH. Thus, the importance of weight and fatness may depend on growth pathway - ie, the rate and continuity of growth. Speculatively, either age itself or periods during which growth is limited by poor nutrition or ill health may affect the ability of muscle tissue to maintain glycogen levels in response to stress. In the two years data examined in this report, most three year old cattle were supplied in October and November (D Smith, unpublished data). The effect of age may reflect a residual effect of the relatively poor nutrition and cold stress experienced over the preceding winter. Another possible explanation is that older animals were finished on more extensive properties, were handled less frequently during their lives, and thus were more excitable at mustering and during transport to the plant.

Mob size effects on the frequency of carcasses with very high pH indicate that the social effects increase susceptibility to pre-slaughter stress. A direct effect of mob size on agonistic behaviour and increased stress is one possibility. The effect of mob size may also reflect mixing of social groups; that is, the larger mobs, as supplied to the plant, may have been from two or more mobs, with little time to adjust to their new social grouping. This effect of mixing unfamiliar cattle, has been reported for bulls by Price and Tennessen (1981), who considered it to be a major cause of dark cutting and for steers by Jones and Tong (1989). Finally, the effect of mob size may be related to intensity of management, with larger mobs coming from more extensive properties and thus less used to handling.

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