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Harvest estimates of the Western Arctic caribou herd, Alaska

Bob Sutherland

Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, Alaska, USA 99518 (Robert_Sutherland@fishgame.state.ak.us).

Abstract: A generalized least squares regression model was developed to estimate local harvest of the Western Arctic caribou (*Rangifer tarandus granti*) herd. This model provides herd and community level harvest based on community size, proximity of the herd to the village. The model utilizes community harvest survey information from the Alaska Department of Fish and Game, Subsistence Division and cooperation from the nonprofit organizations Maniliq and Kawerak. The model will assist in an annual selection of communities to survey. The predicted local resident harvest of the Western Arctic caribou herd is 14 700 with 95% lower and upper confidence limits of 10 100 and 19 700 respectively.

Key words: generalized least squares, *Rangifer tarandus granti*, regression modeling.

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Introduction

Caribou (*Rangifer tarandus granti*) are important sources of food and material for families in northwest Alaska. Information on the local consumption of caribou is important for effective managing of the Western Arctic caribou herd (WAH). Harvest of the WAH in northwestern Alaska, until now, has been unknown. In 1999 the Alaska Department of Fish and Game (ADF&G) began community surveys to gather harvest information in Game Management Units (GMU) 22 (Seward Peninsula) and 23 (Kotzebue Sound). Combining this survey information with GMU 26A (Western North Slope) survey information available from the North Slope Borough and ADF&G, a generalized least squares model has been developed.

This model's prediction of harvest is a function of village population, the availability of the herd to the village, and GMU the village is within. Village population represents the idea the larger the village the higher the harvest. The availability measure is a set of 3 indicator variables (high, medium, and low) representing the availability of caribou to the village for harvest. High availability would indicate larger harvest and low availability would mean less harvest. The 3 GMUs are ADF&G geographic units containing villages sharing common interests and having a common heritage within each GMU. A map showing WAH seasonal ranges, villages, and GMUs is in Fig. 1.

A generalized least squares (GLS) (Pinheiro & Bates, 2000) modeling is necessary because of issues with spatial and temporal dependence of observations. GLS is a model for correlated observations or which have differing variances (Rencher, 2000; Waller & Gotway, 2004). Ordinary least squares regression requires independent observations for the proper estimation of the variance-covariance matrix. A correct variance-covariance matrix is essential for proper model selection, inference of equation coefficients, and confidence intervals of predictions.

The sets of GLS equations are used to estimate harvest for each community in GMUs 22, 23, and 26A, and provide GMU and herd-wide local harvest estimates with 95% confidence intervals.

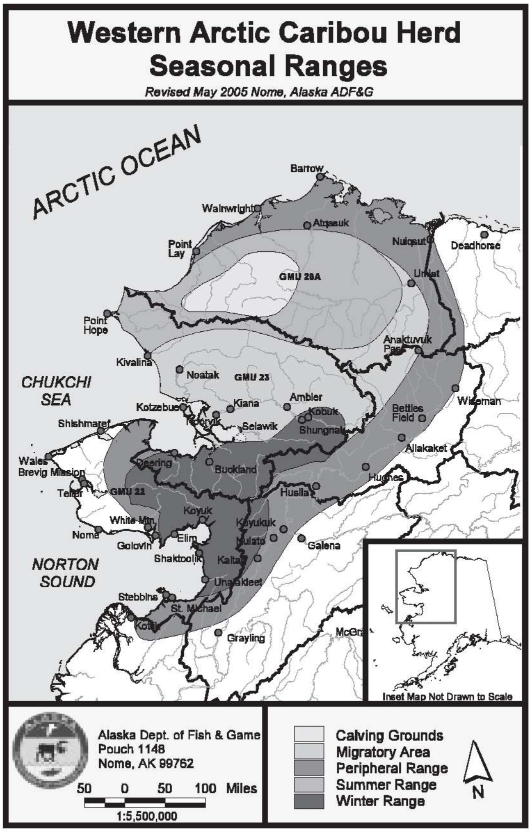

Fig. 1. Western Arctic Herd seasonal ranges.

Material and methods

Harvest data for the model are gathered from community harvest surveys gathered from households. The exception being Nome where harvest information will be gathered by a registration hunt. Initial approval for survey work from village tribal councils is obtained before the project begins. For GMUs 22 and 23, local residents are trained by ADF&G Subsistence Division staff in partnership with the regional nonprofit staff from their respective corporation (Kawerak or Maniliq). In Unit 26A, community harvest surveys were completed by the North Slope Borough Department of Wildlife Management, ADF&G/Subsistence Division, or S. R. Braund & Associates, Inc. Barrow was surveyed by S. R. Braund and Associates, Inc., in conjunction with the Institute of Social and Economic Research, University of Alaska. For modeling purposes, Anaktuvuk Pass was included in the GMU 26A village grouping because of their cultural, economic and political ties with the North Slope villages.

The household survey is used to gather information on caribou hunting for a 12-month period May through April. Survey data are expanded through the use of weights for the nonresponding households. At most 8% of the households did not respond for any village survey making many efforts at acquiring community harvest data a census rather than a sample. The Kotzebue and Barrow community surveys were stratified random samples of households. Table 1 lists the communities sampled by year.

Village population is obtained from State of Alaska Department of Community and Economic Development community database online.

The availability component represents the accessibility of the herd for harvest due to seasonal migrations, shifts in herd ranges, and the ability of villagers to approach the herd to hunt. The ability of villagers to hunt the herd could depend on several items, primarily adequate conditions to access the herd like adequate snow cover for snowmachine use or open water to operate boats. But it also could depend on other necessities like gas prices and having the right gear. Availability is a qualitative variable because of the difficulties measuring each of its components and is also a confounded variable.

ADF&G area management biologists select which of the availability states applies to each village. This information is based on examination of VHF and satellite collars locations, herd flyovers by biologists, reports from villagers, and an assessment of terrestrial conditions for allowing travel to hunt caribou.

Game management units provide a geographical means to separate villages. Each GMU usefully matches to a separate Alaskan Native for-profit regional corporation. GMU 22 corresponds with the Bering Strait Native Corporation; GMU 23 corresponds to the NANA Regional Corporation; and GMU 26A to the western portion of the Arctic Slope Regional Corporation. These regional corporations are composed of a relatively culturally homogeneous Native people formed under the Alaska Native Claims Settlement Act (PL 92-203, Sec. 7a). Within a GMU, villagers display similar subsistence traditions that are different between game management units (Georgette, pers. comm., 2000). Villages nearest each other are expected to exhibit similar harvest since they share caribou harvest, family members in separate villages often hunt together and they display common subsistence customs (Georgette, pers. comm., 2000).

Model construction relied on residual diagnostics to determine if violations of assumptions were made. Residuals were examined with partial regression plots, studentized residual plots, leverage, influential cases (Cook's distance, dffits, dfbetas) and spatial and autocorrelation (variogram analysis, inspection of residuals against time and the Durbin-Watson test).

Table 1. Villages, harvest survey dates and availability groupings.

Survey year	Community	GMU	Availability grouping			Village population	Village harvest
			High	Med	Low		
1987	Point Lay	26		1		121	157
1989	Golovin	22	1			169	40
	Shishmaref	22		1		472	197
	Barrow	26			1	3379	1656
	Wainwright	26	1			468	711
1990	Anaktuvuk[a]	26 (24)	1			314	592
1991	Kotzebue	23	1			2751	3782
	Anaktuvuk[a]	26 (24)	1			272	545
1992	Point Hope	23			1	699	225
	Kivalina	23		1		344	351
	Barrow	26			1	3908	1993
	Wainwright	26	1			584	748
	Atqasuk	26		1		237	262
	Nuiqsut	26			1	361	672
	Anaktuvuk[a]	26 (24)	1			270	566
1993	Wales	22			1	152	4
	Nuiqsut	26	1			361	672
	Anaktuvuk[a]	26 (24)	1			318	574
1994	Noatak	23	1			379	615
	Deering	23		1		147	142
	Nuiqsut	26			1	418	258
	Anaktuvuk[a]	26 (24)		1		318	322
1995	Shishmaref	22		1		560	342
1998	Koyuk	22	1			277	263
	Shaktoolik	22	1			235	167
	Shungnak	23	1			245	561
1999	Elim	22	1			306	227
	Stebbins	22			1	543	16
	St Michael	22			1	368	11
	Unalakleet	22		1		757	439
	Shaktoolik	22	1			216	125
	White Mtn	22	1			197	93
	Noatak	23		1		423	683
	Kiana	23		1		398	488
	Selawik	23	1			767	1289
	Nuiqsut	26		1		468	413
2000	Brevig	22		1		291	74
	Shishmaref	22		1		547	286
	Teller	22			1	281	21

[a] Anaktuvuk Pass is located in GMU 24, but because of its cultural and political ties to villages in GMU 26A, is used in GMU 26A modeling efforts.

Most often violations were outliers resulting from misplacement of a village in a availability grouping, influential cases due to Barrow and Kotzebue, and nonconstant variances. To gauge the effect of the possible influential cases of Barrow and Kotzebue, equations were fit with the two villages left out and reported harvest was perturbed by 5, 10, and 20 percent. Variance functions were used to model the variance structure of the within group errors. Akaike information criterion (AIC) was used as a guide to choose the best model when there were several candidates.

Community harvest levels are predicted for each community based on the GLS regression equations. Confidence intervals were calculated using the prediction of a new response.

Caribou harvested in GMU 26A can be harvested from three different herds, the WAH, the Teshepuk Herd and the Central Arctic Herd. The percentage of total harvest comprised of WAH caribou is estimated based on the distribution of collared caribou in each herd. Although there is uncertainty associated with assigning harvest levels to individual caribou herds where they mix, we felt this approach was better than ignoring mixing of herds altogether. (Dau, 2003; G. Carroll, ADF&G, pers. comm., 2001) The variances and the upper and lower limits of the confidence intervals are also proportionally reduced for each community.

Total local harvest of the WAH is the sum of the predictions for each community. Confidence limits for individual communities were summed to produce an interval around total harvest.

The availability groupings were randomly altered for each of the three GLS regression models as a simple way to study what effect the change in availability grouping would have on harvest for each GMU. However, for Kobuk, Ambler and Shungnak the high availability grouping was not permuted because of their proximity to the WAH migrations through Onion Portage. The GMU 23 villages located outside any WAH range (Wales, Brevig Mission, Teller, Shishmaref, and Nome) were limited to permutations of low and medium availability.

The availability groupings were randomly permuted 1000 times for each of the three GMUs. The total local harvest was calculated for each of the permuted groupings and summary statistics are produced.

Results

The GLS regression equation for GMU 22 contains both an intercept and slope for each availability group. This is commonly known as an interaction model of Analysis of Covariance. Modeling the variance–covariance matrix is needed. A model was specified in which the variance increases linearly with the fitted values.

Table 2. Predicted local harvest of Western Arctic Herd caribou by game management unit (GMU).

GMU	Estimated harvest	95% Confidence interval	
		Lower	Upper
22	2300	1600	3000
23	10800	8100	13400
26A	1600	400	3300

A data plot and regression lines for GMU 22 are in Fig. 2. Regression equations, AIC, and ANOVA table are in Table 3. Predicted harvest and 95% confidence intervals for each village in the GMU is presented in Fig. 3.

The low availability group slope and intercept coefficients are not significantly different from 0. This implies a model could be built without the low availability grouping, however, without it residual diagnostics show an unequal variance problem. Inclusion of this group of villages in the model makes sense because those villages are part of the herd harvest.

The GMU 22 model predicts 2300 caribou will be harvested annually by local residents, with 95% lower and upper confidence interval limits of 1600 and 3000 caribou harvested respectively.

The GLS regression equation for GMU 23 is a classic analysis of covariance model with one slope for all availability levels and a separate intercept for each availability state. Modeling the variance–covariance matrix is needed. A model was specified in which the variance increases linearly with the fitted values.

A data plot and regression lines for GMU 23 are in Fig. 4. Regression equations, AIC, and ANOVA table are in Table 4. All terms are significant and should be included in the model. Predicted harvest levels and 95% confidence intervals for each village in the GMU is presented in Fig. 5. Kotzebue is not shown in the figure because it would render it unreadable. Kotzebue predicted harvest is 4200 caribou with a confidence interval of between 3800 and 4600 caribou.

The GMU 23 model predicts 10 800 caribou will be harvested annually by local residents, with 95% lower and upper confidence limits of 8100 and 13 400 respectively.

The GLS regression equation for GMU 26A is a classic analysis of covariance model with one slope for all availability levels and a separate intercept for each availability state. Modeling the variance–covariance matrix is needed. A model was specified in which the variance increases linearly with the fitted values.

Table 3. Game Management Unit 22 regression equations and ANOVA table.

Low availability: (village) harvest = 3.097 + 0.029 (village) population
Medium availability: harvest = -167.361 + 0.828 population
High availability: harvest = -240.007 + 1.682 population

AIC	logLik
131.0473	-58.523671

Coefficients:

	Value	Std. Error	*t*-value	*P*-value
Slope Low	0.02947	0.02579	1.142949	0.2826
Slope Med	0.82787	0.08308	9.964230	<0.0001
Slope High	1.68217	0.20823	8.078300	<0.0001
Inter Low	3.09701	8.24228	0.375747	0.7158
Inter Med	-167.36064	37.41956	-4.472544	0.0015
Inter High	-240.00730	43.80178	-5.479396	0.0004

Residual standard error: 2.048057
Degrees of freedom: 15 total; 9 residual

A data plot and regression lines for GMU 26A are in Fig. 6. Regression equations, AIC, and ANOVA table are in Table 5. All terms are significant and should be included in the model. Predicted harvest levels and 95% confidence intervals for each village in the GMU is presented in Fig. 7. Barrow is not shown in the figure because it would render it unreadable. Barrow predicted caribou harvest is 2300 with a confidence interval of between 800 and 3700 caribou.

The percent of caribou harvested, by GMU 26A communities, made up of WAH caribou:

Village	Percent
Anaktuvuk Pass	80
Atqasuk	40
Barrow	30
Nuiqsut	10
Point Lay	80
Wainwright	40

The GMU 26A model predicts 4700 caribou will be harvested annually by local residents, with 95% lower and upper confidence interval limits of 1100 and 9600 respectively. The local harvest of WAH caribou is predicted to total 1600 by GMU 26A residents, with 95% lower and upper confidence interval limits of 400 and 3300 respectively.

Total local harvest of the WAH is 14 700 caribou with a 95% confidence interval of between 10 100 and 19 700 caribou. Examination of Table 2 shows almost 11 000 of the nearly 15 000 caribou harvested annually have been by GMU 23 residents.

Random permutations of availability groupings produced a mean harvest of WAH caribou of 15 700 with a minimum harvest of 10 900 caribou and a maximum harvest of 20 700 caribou. The GMU 22 random permutations of availability groupings produced local harvest counts from 400 to 3900 with a mean of 2000 and a standard deviation of 649. For GMU 23, random permutations of availability

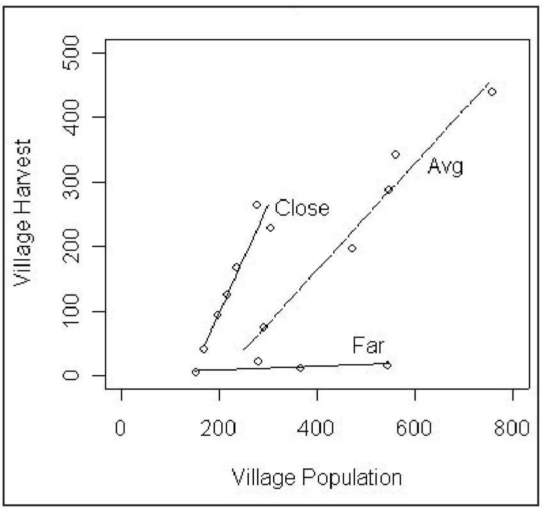

Fig. 2. GMU 22 regression model.

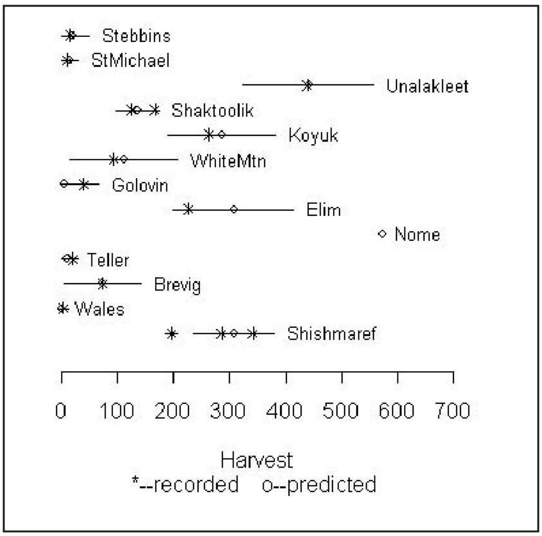

Fig. 3. GMU 22 WAH harvest and CI by village.

Table 4. Game Management Unit 23 regression equations and ANOVA table.

Low availability: harvest = -747.692 + 1.392 population
Medium availability: harvest = -75.587 + 1.392 population
High availability: harvest = 155.962 + 1.392 population

AIC	logLik
83.2502	-36.6251

Coefficients:

	Value	Std. Error	*t*-value	*P*-value
Slope Pop	1.3915	0.05729	24.290566	<.0001
Inter Low	-672.1048	50.30333	-13.361039	<.0001
Inter Med	-75.5868	27.81702	-2.717288	0.0419
Inter High	231.5488	41.21232	5.618437	0.0025

Residual standard error: 2.538328
Degrees of freedom: 9 total; 5 residual

groupings produced local harvest counts ranging from 6600 to 11 700 with a mean of 9200 and standard deviation of 973. For GMU 26A, random permutations of availability groupings produced harvest counts ranging from 3900 to 5100 with a mean of 4500 and a standard deviation of 333.

Discussion

A generalized least squares regression model has been presented relating village caribou harvest to village population size and herd availability for a village within each of 3 game management units.

Regression equations for the GMUs 23 and 26A are similar and represent analogous harvest patterns. Caribou historically have been available for these villages since many of them lie in WAH summer or migratory ranges. Caribou are considered a staple in their diet (Georgette, pers. comm., 2000). The regression equations reflect this with a common slope (for population) but separate intercepts for the 3 availability groups, indicating each could be thought of as a level or degree of harvest.

The regression model for GMU 22 is an interaction model for which each availability state is represented by a distinct equation with an individual slope and intercept for each state. The model for GMU 22 indicates each availability state has a different harvest regimen.

The villages in the low availability state are outside or near the fringe of the range of the herd. Harvest from this group is negligible as noted by the near zero statistically nonsignificant slope coefficient for population. The medium availability state is composed of villages nearby or within the outer or winter ranges but villages close enough to harvest WAH caribou when accessible. The importance of the harvest from this group is suggested by the statistical significance of the slope coefficient for population. The villages in the high availability state are within the winter range. The slope coefficient for population is double the same coefficient of the medium availability grouping suggestive of increased dependence on caribou by the high availability group.

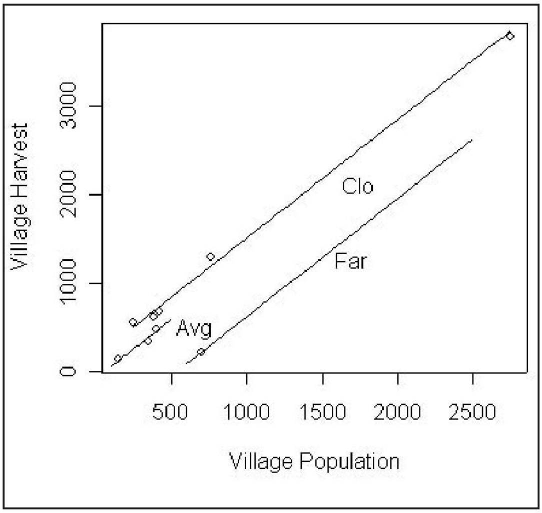

Fig. 4. GMU 23 regression model.

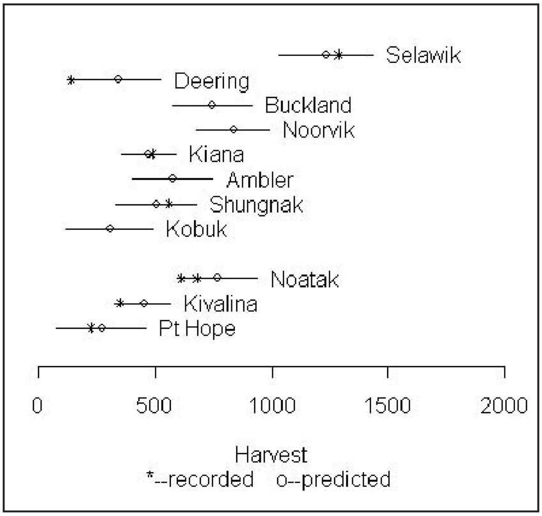

Fig. 5. GMU 23 WAH harvest and CI by village.

Table 5. Game Management Unit 26A regression equations and ANOVA table.

Low availability: harvest = 59.151 + 0.491 population
Medium availability: harvest = 140.975 + 0.491 population
High availability: harvest = 446.91 + 0.491 population

AIC	logLik
141.5113	-65.75564

Coefficients:

	Value	Std. Error	*t*-value	*P*-value
Slope Pop	0.49081	0.016158	30.376120	0.0000
Inter Low	-81.82445	23.850279	-3.430754	0.0056
Inter Med	140.97545	13.989387	10.077314	0.0000
Inter High	305.93522	20.460161	14.952728	0.0000

Residual standard error: 1.632186
Degrees of freedom: 15 total; 11 residual

Population has varied little in WAH-area villages through time. The effect of increasing village population size will increase WAH harvest. Since population sizes have not changed appreciably, WAH local harvest is expected not to change much either.

The random permutation of availability groupings shows harvest changes depending on accessibility of caribou. This is most striking in GMU 22 where, for the worst-case scenario, harvest could be less than a quarter of what it is now. This could be a situation where the herd shrinks and/or winters out of GMU 22. In the situation where the herd becomes highly available to all villages, harvest will double.

Random permutation of availability groupings for GMUs 23 and 26A produces less notable changes in village harvest. This exercise indicates local village harvest is not as dependent on herd availability.

The existing village sampling has been subjective. A scheme is needed to select villages for harvest surveys to ensure we obtain information from each element in our model space. This directs a village should be sampled from within each of the 3 availability states in a GMU for a total of 9 villages surveyed per year. Villages surveyed should be randomly chosen from within each availability grouping in the GMU. Funding is improbable for a complete yearly selection of 9 villages. A reduced village sample selection effort should be examined for its effects on harvest estimates.

WAH herd size is not incorporated into this model but may affect harvest. A larger herd may allow increased opportunity for harvest for all villages. It may also visit areas not usually frequented by the WAH allowing for harvest near or outside its periphery range. Addition of a herd size component to the models deserves investigation.

References

Dau, J. 2003. Units 21D, 22A, 22B, 23, 24, 26A caribou management report. – *In*: Healy, C. (ed.). *Caribou management report of survey and inventory activities 1 July 2000–30 June 2002*. Alaska Department of Fish and Game. Project 3.0. Juneau, Alaska, USA, pp. 181–221.

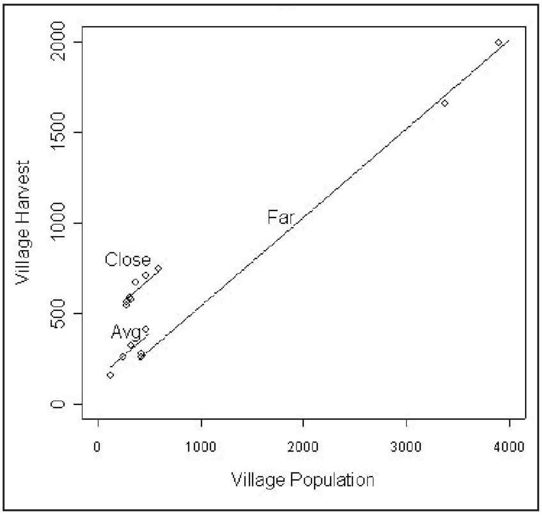

Fig. 6. GMU 26A regression model.

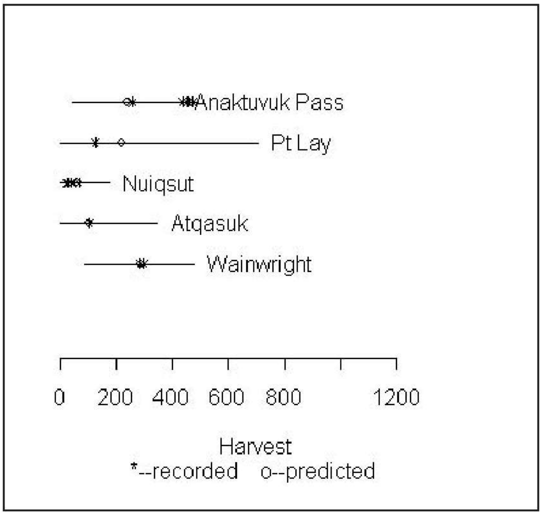

Fig. 7. GMU 26A WAH harvest and CI by village.

Pinheiro, J. & Bates, D. 2000. *Mixed-effects models in S and S-PLUS*. Springer-Verlag, New York.

Rencher, A. C. 2000. *Linear models in statistics.* John Wiley and Sons, Inc., New York, USA.

Waller, L. A. & Gotway, C. A. 2004. *Applied spatial statistics for public health data*. John Wiley and Sons, Inc. New York, USA.