Annual Indices and Trends of Abundance for Gag (*Mycteroperca microlepis*) on the Shallow Continental Shelf in the Northeastern Gulf of Mexico

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Annual Indices and Trends of Abundance for Gag (*Mycteroperca microlepis*) on the Shallow Continental Shelf in the Northeastern Gulf of Mexico

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Fisheries-independent annual indices and trends of gag abundance for 2001 through 2008 were developed by an approach that controls effects of intrinsic habitat quality at sampling sites. For this, the theory and implications for fisheries population modeling derive from MacCall (1990), while the applicability to gag was established by Lindberg et al. (2006). Replicate fixed sampling sites of standardized habitat units (SHUs) were sampled once each summer (June-September) by the same skilled science divers using a standardized underwater visual census (UVC). The study system along the 13m depth contour offshore from Levy and Dixie Counties, Florida (Figure 1a), and the UVC protocol, were the same as described by Lindberg et al. (2006). Except here, the SHUs built in 1991-1993 were well past their colonization period and subject to public fishing since 1996 (Larsen 2005). The UVC counted gag in 10 cm size classes ranging from <20 cm TL to >89cm TL. In addition, the recorded data included SHU type (size and spacing, see Figure 1b) and location, date, time, horizontal visibility, water temperature and counts of other grouper species present (e.g. red grouper and Goliath). Given experiments reported by Lindberg et al. (2006), SHUs in this study system are known to be replicates of contrasting intrinsic habitat quality. More specifically, 16-cube SHUs were more preferred by gag than 4-cube SHUs, although spacing among SHUs (i.e. 25m, 75m or 225m) interacted with SHU size (e.g. Lindberg et al. 2006, figure 5, page 739). Nevertheless, all SHU configurations in this system were comparable to higher quality natural hard-bottom habitat of the region (Lindberg 2008), as judged with respect to gag habitat selection established by Lindberg et al. (2006).

Annual gag count data from all 132 SHUs in this study system comprised the full dataset, with no outliers, removals or exclusions. Each SHU was sampled once per year. For analyses of abundance, gag counts were summed across size classes for total counts per SHU per sampling interval. Because the UVC protocol was standardized throughout this study the total counts were the same as CPUE values. In addition to year, other factors in the experimental design and analyses included individual SHU identification, two SHU sizes ("SHUsize", 4-cube and 16-cube), two SHU spacings ("SHUspacing", close = 25m and 75m, wide = 225m), and 22 arrays (i.e. a location where 6 same-sized SHUs were arranged in a hexagonal array of a given spacing; Figure 1b).

Total gag counts were modeled as a mixed model (PROC GLIMMIX in SAS® v9.2) with SHU size, spacing and year as main effects, and with array and SHU identification within array as random effects to account for repeated observations at fixed sites over years.. Gag count data were log(x+1) transformed and the errors modeled as normally distributed. Residual analyses indicated this transformation was appropriate. Other candidate models were considered but discarded. Neither a Poisson regression model nor a negative binomial model was adequate due to distributional assumptions (over dispersion issues) and problems fitting random effects (convergence issues), respectively.

Two similar models were considered. One included year as a class variable, allowing each year to have an independent effect on responses. The other included year as a continuous variable, which assumed gag counts were either stable, decreasing or increasing, at a constant rate on the logarithmic scale, over the eight-year period. The models were otherwise identical. Additionally, each model contained the interaction effect of year and habitat. The models contained the random effects required by the experimental design. A similar model was also run that included only year as a fixed factor to examine overall changes in abundance without respect to habitat factors.

SHUspacing was clearly not significant (e.g., F=0.00, p=0.9646 in a model with year as a continuous variable). Consequently, models reported here excluded SHUspacing as a factor, and included the interaction term year*SHUsize as the test of the prediction from theory that relatively lower quality habitat would show a faster decline (or, conversely, relatively higher quality habitat would show a faster increase).

With year as a class variable, the year*SHUsize interaction was marginal (F=1.96, p=.0676) while the effects of year (F=5.71, p<.0001) and SHUsize (F=13.3, p=.0014) were each clearly significant (Table1). Figure 2 shows the least squares estimated log gag counts by year for the reefs of relatively higher and lower intrinsic habitat quality (i.e. 16-cube and 4-cube reefs, respectively). Statistical results including diagnostics for this model are given in Appendix I.

With year as a continuous variable (i.e. gag abundance assumed to be linearly related to year), overall gag abundances decreased at a faster rate on the SHUs of relatively lower habitat quality compared to those of relatively higher quality. This is evidenced by a significant year*SHUsize interaction term (F=5.10, p =.0241, Table 2) and the different slopes of the model predicted curves (Figure 3). Statistical results including diagnostics for this model are given in Appendix II.

With year as the only fixed factor, gag abundance regardless of habitat quality had a significant negative slope between 2001 and 2008 (β = -.0969, SE = .00866; t = -11.19, p<.0001). Statistical results including diagnostics for this model are given in Appendix III.

While analyses of gag size distributions over time, as affected by habitat factors, may be possible with the full dataset, we do not report them here. Instead, we provide proportionate size-frequency distributions in Figure 5 for all gag counted each year on all 4-cube and 16-cube SHUs spaced at 225m. The SHUs at this wider spacing can be considered independent, and this representation of a reduced dataset avoids any unexamined effects of SHU spacing on size distributions.

Literature Cited

Larsen, S.J. 2005. Influence of high-resolution spatial information on resource exploitation: an example from angler impacts on artificial reefs. Master's Thesis, University of Florida, Gainesville, FL. 45 pp.

Lindberg, W.J., T.K. Frazer, K.M. Portier, F. Vose, J. Loftin, D.J. Murie, D.M. Mason, B. Nagy, M.K. Hart. 2006. Density-dependent habitat selection and performance by a large mobile reef fish. *Ecological Applications* 16:731-746.

Lindberg, W.J. 2008. Habitat selection and the performance of gag grouper across a range of hard bottom habitat in the northeastern Gulf of Mexico. Final Project Report NOAA Grant Number NA04NMF4330075. National Marine Fisheries Service. 35pp.

MacCall, A.D. 1990. *Dynamic geography of marine fish populations*. Books in recruitment fishery oceanography. Washington Sea Grant Program, University of Washington Press, Seattle, Washington. 153 pp.

Type III Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
year	7	100.5	5.71	<.0001
habitat	1	21.67	13.30	0.0014
year*habitat	7	100.5	1.96	0.0676

Table 1: Tests of fixed effects for mixed model in which year was modeled as a class variable

Type III Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
year	1	1170	108.12	<.0001
habitat	1	1170	5.03	0.0252
year*habitat	1	1170	5.10	0.0241

Table 2: Tests of fixed effects for mixed model in which year was modeled as a continuous variable

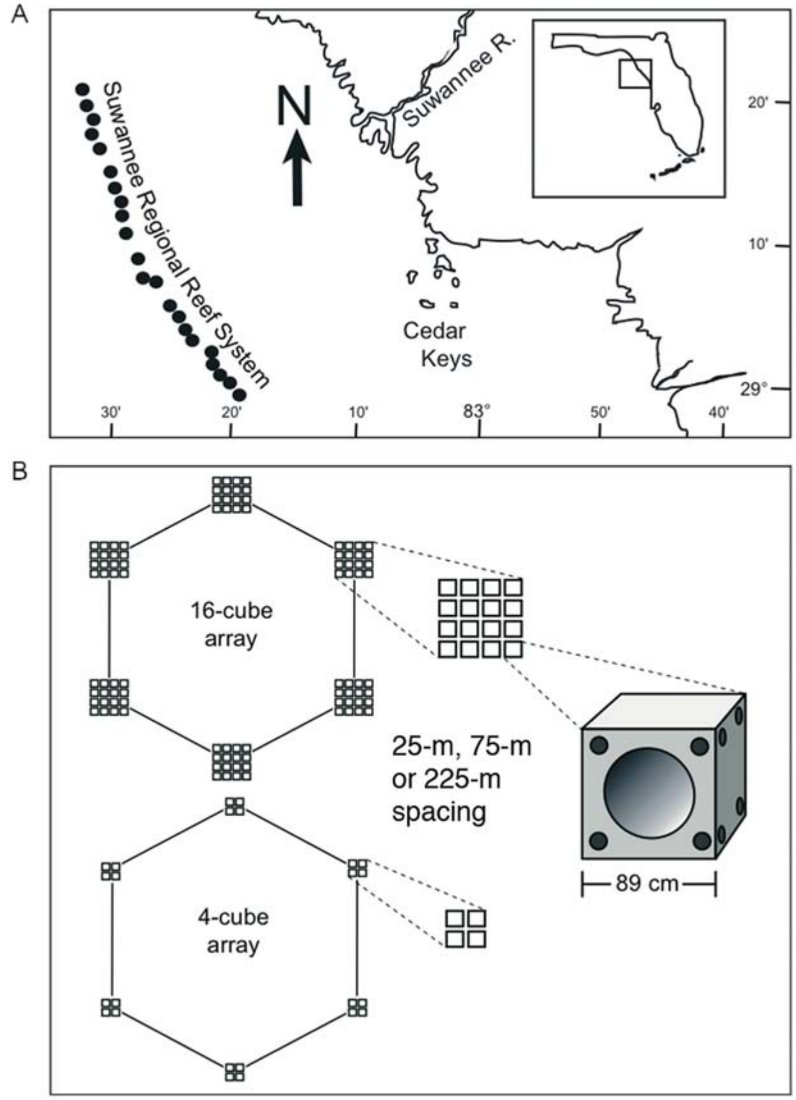


Figure 1: (a) Map of the study area showing locations of 22 standardized reef arrays comprising the Suwannee Regional Reef System; (b) hexagonal arrays of SHUs at each location have equal-sized SHUs of either four or 16 prefabricated concrete cubes, and 25-m, 75-m, or 225-m spacing. (Copied from Lindberg et al. 2006)

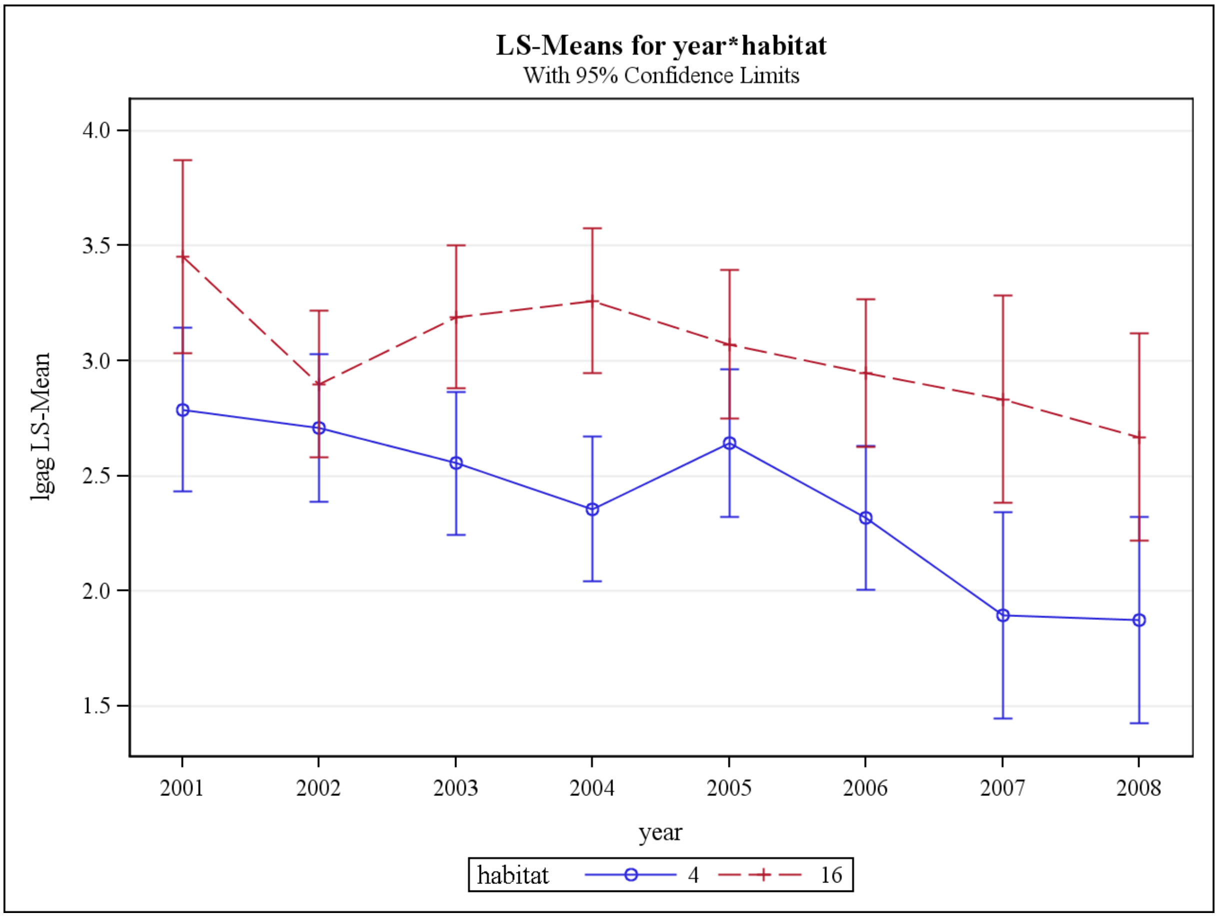


Figure 2: Log LS-Means of gag counts from the model in which year was a class variable, with the effect of intrinsic habitat quality contrasted, i.e. 4-cube (blue circles) and 16-cube (red +) reefs being relatively lower and higher quality, respectively. Error bars indicate 95% confidence intervals.

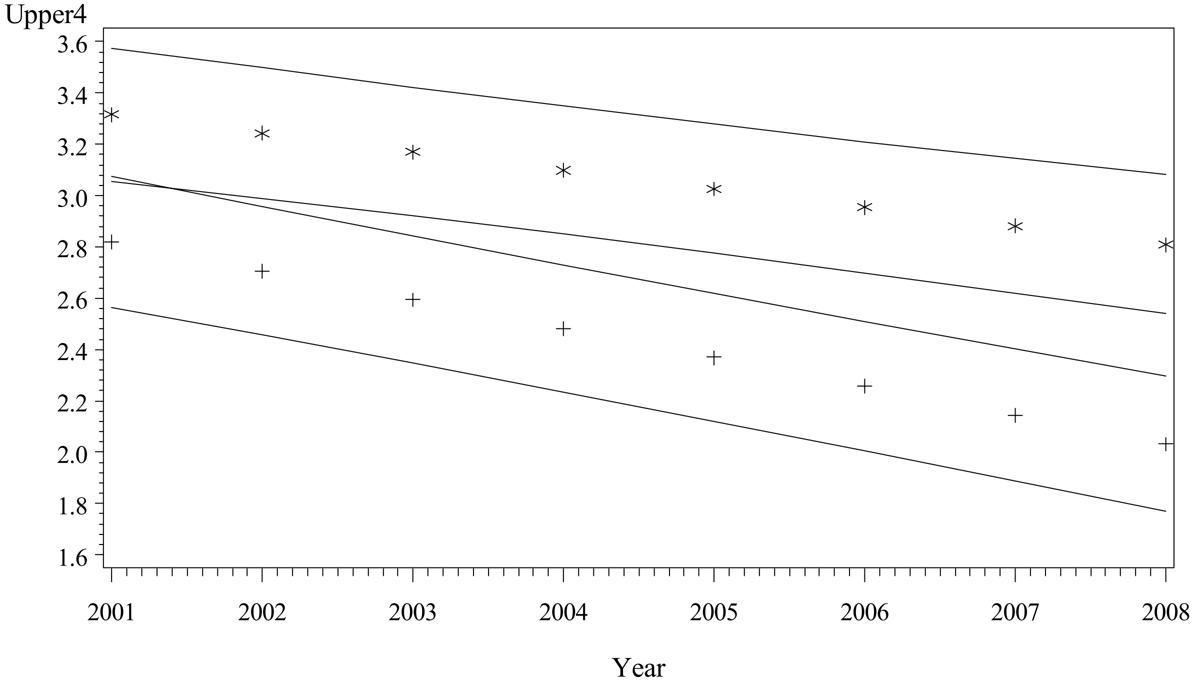
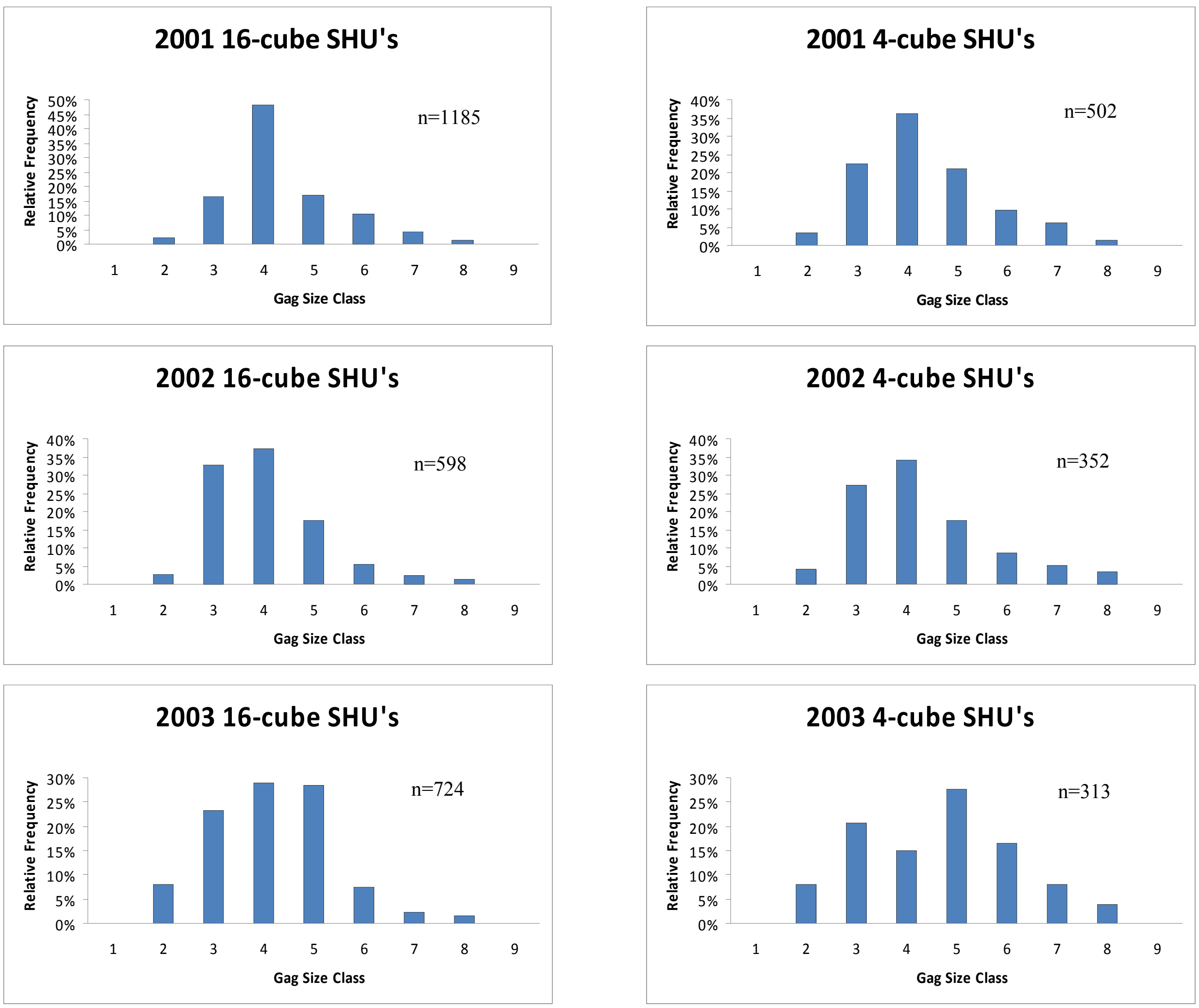
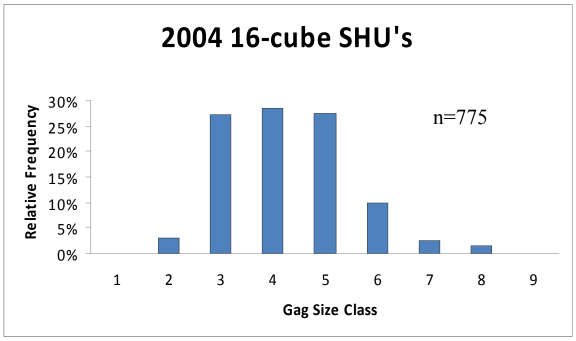
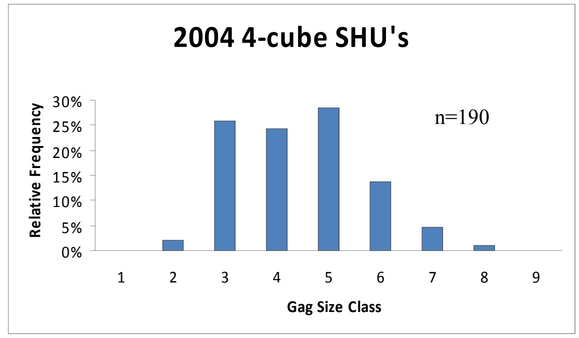


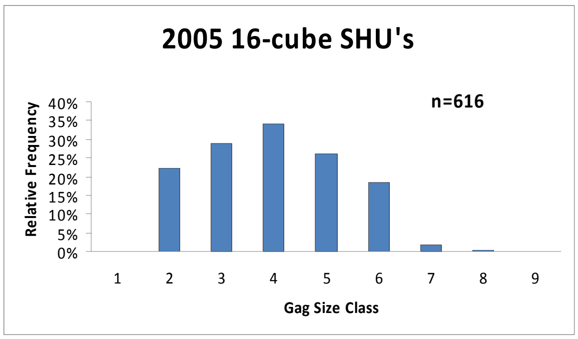
Figure 3: Log LS-Means of gag counts from the model in which year was a continuous variable, with the effect of intrinsic habitat quality contrasted, i.e. 4-cube (+ symbols) and 16-cube reefs (* symbols) being relatively lower and higher quality, respectively. Lines indicate joined 95% confidence intervals around the means.

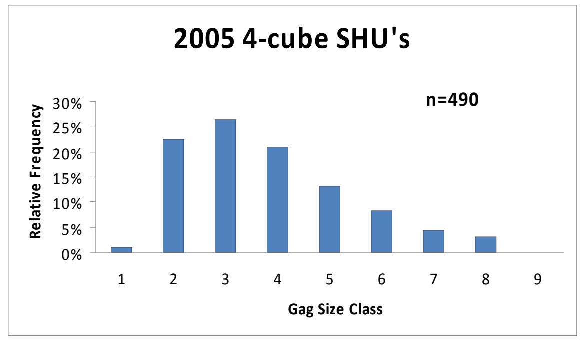
Figure 4: Relative size-frequency distributions from annual censuses of gag on patch reefs of contrasting habitat quality (i.e. widely spaced 16-cube and 4-cube standardized habitat units, 24 of each type per year). Size classes are: **1**= <20 cm TL, 2=20-29 cm TL, **3**=30-39 cm TL, **4**=40-49 cm TL, **5**=50-59 cm TL, **6**=60-69 cm TL, **7**=70-79 cm TL, and **8**=80-89 cm TL, **9**= >90 cm TL.

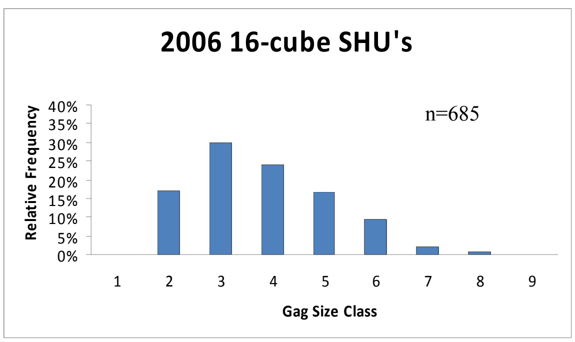


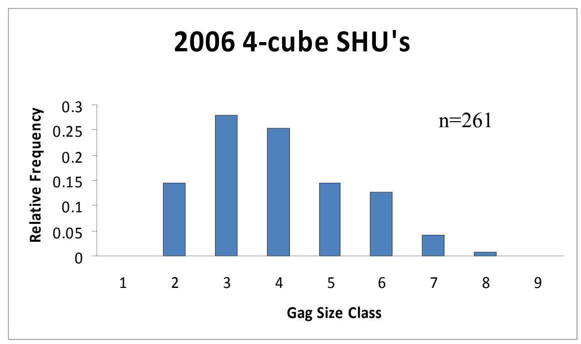

2004 16-cube SHU's
Relative Frequency
0%
5%
10%
15%
20%
25%
30%
n=775
1 2 3 4 5 6 7 8 9
Gag Size Class

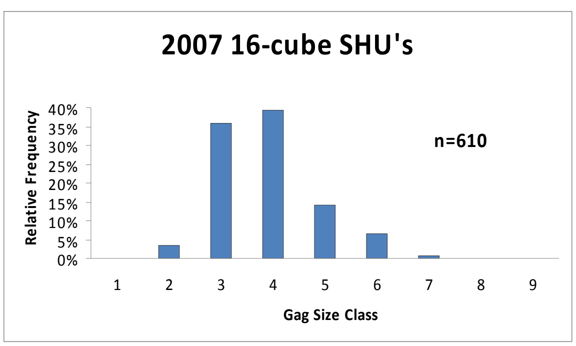

2004 4-cube SHU's
Relative Frequency
0%
5%
10%
15%
20%
25%
30%
n=190
1 2 3 4 5 6 7 8 9
Gag Size Class

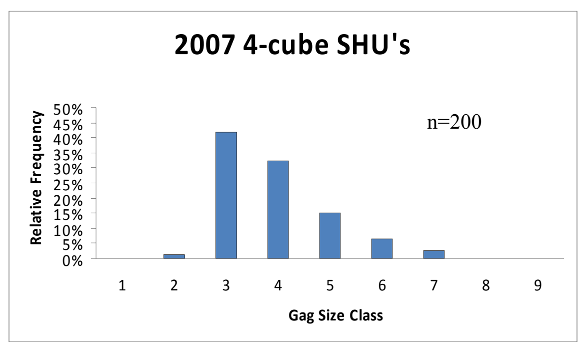

2005 16-cube SHU's
Relative Frequency
0%
5%
10%
15%
20%
25%
30%
35%
40%
n=616
1 2 3 4 5 6 7 8 9
Gag Size Class

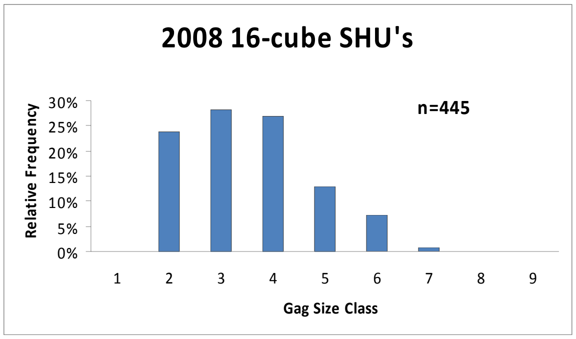

2005 4-cube SHU's
Relative Frequency
0%
5%
10%
15%
20%
25%
30%
n=490
1 2 3 4 5 6 7 8 9
Gag Size Class

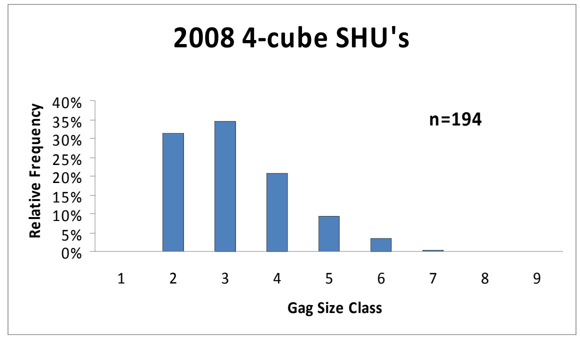

2006 16-cube SHU's
Relative Frequency
0%
5%
10%
15%
20%
25%
30%
35%
40%
n=685
1 2 3 4 5 6 7 8 9
Gag Size Class


2006 4-cube SHU's
Relative Frequency
0
0.05
0.1
0.15
0.2
0.25
0.3
n=261
1 2 3 4 5 6 7 8 9
Gag Size Class


2007 16-cube SHU's
Relative Frequency
0%
5%
10%
15%
20%
25%
30%
35%
40%
n=610
1 2 3 4 5 6 7 8 9
Gag Size Class


2007 4-cube SHU's
Relative Frequency
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
n=200
1 2 3 4 5 6 7 8 9
Gag Size Class


2008 16-cube SHU's
n=445
Relative Frequency
30%
25%
20%
15%
10%
5%
0%
1
2
3
4
5
6
7
8
9
Gag Size Class


2008 4-cube SHU's
n=194
Relative Frequency
40%
35%
30%
25%
20%
15%
10%
5%
0%
1
2
3
4
5
6
7
8
9
Gag Size Class

Appendices – Analyses conducted in PROC GLIMMIX of SAS® v9.2

Included are descriptions of class levels, the optimization process, appropriate plots of the residuals, and least squares (LS) estimates.

Appendix I. Information, diagnostics, and results of the mixed model including year as a class variable

Table 1. Description of class levels in the model

Class Level Information		
Class	**Levels**	**Values**
year	8	2001 2002 2003 2004 2005 2006 2007 2008
array	22	0 1 2 3 4 5 6 7 8 9 10 11 13 14 15 16 17 19 20 21 22 23
habitat	2	4 16
reefid	132	0N 0NE 0NW 0S 0SE 0SW 10N 10NE 10NW 10S 10SE 10SW 11N 11NE 11NW 11S 11SE 11SW 13N 13NE 13NW 13S 13SE 13SW 14N 14NE 14NW 14S 14SE 14SW 15N 15NE 15NW 15S 15SE 15SW 16N 16NE 16NW 16S 16SE 16SW 17N 17NE 17NW 17S 17SE 17SW 19N 19NE 19NW 19S 19SE 19SW 1N 1NE 1NW 1S 1SE 1SW 20N 20NE 20NW 20S 20SE 20SW 21N 21NE 21NW 21S 21SE 21SW 22N 22NE 22NW 22S 22SE 22SW 23N 23NE 23NW 23S 23SE 23SW 2N 2NE 2NW 2S 2SE 2SW 3N 3NE 3NW 3S 3SE 3SW 4N 4NE 4NW 4S 4SE 4SW 5N 5NE 5NW 5S 5SE 5SW 6N 6NE 6NW 6S 6SE 6SW 7N 7NE 7NW 7S 7SE 7SW 8N 8NE 8NW 8S 8SE 8SW 9N 9NE 9NW 9S 9SE 9SW

Table 2. Optimization information

Optimization Information	
Optimization Technique	Dual Quasi-Newton
Parameters in Optimization	3
Lower Boundaries	3
Upper Boundaries	0
Fixed Effects	Profiled
Residual Variance	Profiled
Starting From	Data

Table 3. Optimization details (Convergence criterion (GCONV=1E-8) satisfied)

Iteration History					
Iteration	**Restarts**	**Evaluations**	**Objective Function**	**Change**	**Max Gradient**
0	**0**	4	2374.9496602	.	53.17716
1	**0**	5	2371.1177168	3.83194338	16.82097
2	**0**	3	2370.901709	0.21600774	21.94998
3	**0**	2	2370.3468053	0.55490374	3.792838
4	**0**	2	2370.2310276	0.11577768	1.557755
5	**0**	2	2370.2157239	0.01530368	0.320781
6	**0**	3	2370.2148094	0.00091456	0.037575
7	**0**	3	2370.2147965	0.00001287	0.002485
8	**0**	3	2370.2147965	0.00000001	0.000057

Figure 1. Plots of Pearson residuals versus predicted values (top left), histogram of residuals with expected normal distribution overlayed (top right), quantile plot of residuals (bottom left), and a box plot of residuals (bottom right).

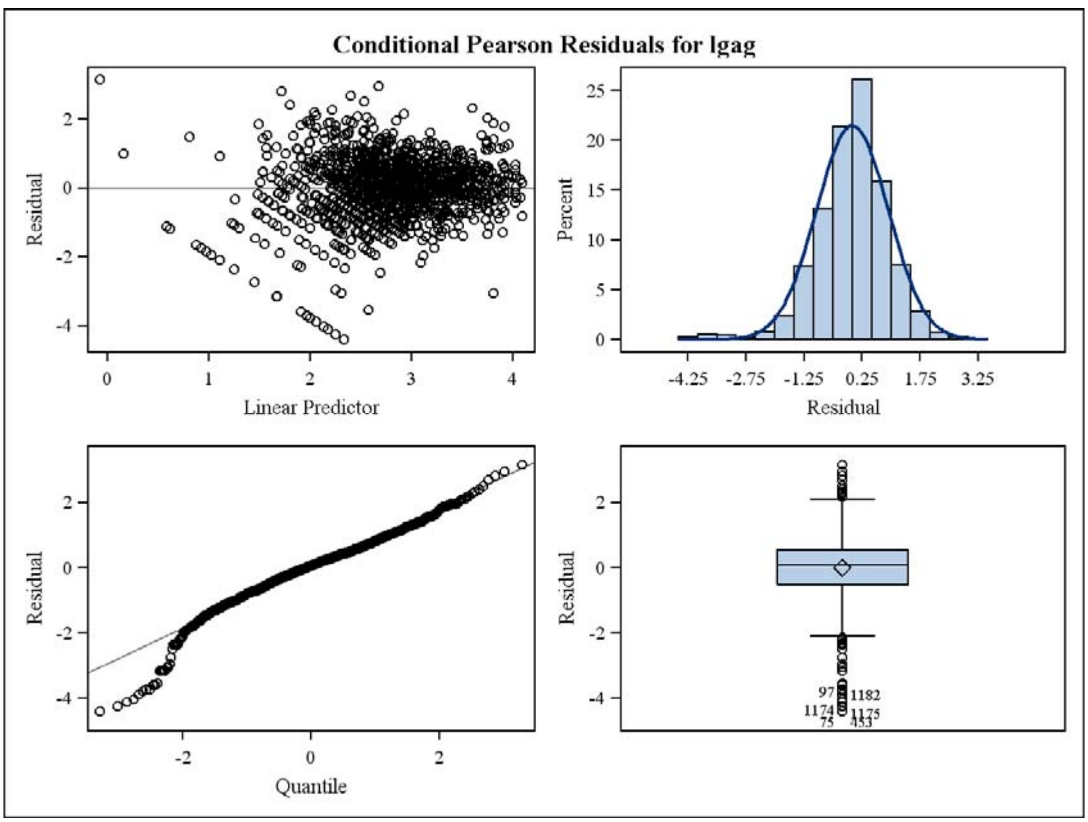


Table 4. LS estimates for year

Year Least Squares Means					
year	Estimate	Standard Error	DF	t Value	Pr > |t|
2001	3.1209	0.1380	73.88	22.61	<.0001
2002	2.8042	0.1131	53.05	24.79	<.0001
2003	2.8728	0.1088	45.33	26.41	<.0001
2004	2.8084	0.1104	47.98	25.45	<.0001
2005	2.8562	0.1136	53.85	25.15	<.0001
2006	2.6327	0.1117	50.43	23.56	<.0001
2007	2.3641	0.1604	112.8	14.74	<.0001
2008	2.2706	0.1604	112.8	14.16	<.0001

Table 5. LS estimates for habitat

Habitat Least Squares Means					
Habitat	Estimate	Standard Error	DF	t Value	Pr > |t|
4	2.3922	0.1249	21.22	19.15	<.0001
16	3.0403	0.1264	22.11	24.05	<.0001

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Table 6. LS estimates for year*habitat

Year*Habitat Least Squares Means						
Year	Habitat	Estimate	Standard Error	DF	t Value	Pr > |t|
2001	4	2.7885	0.1780	61.39	15.66	<.0001
2001	16	3.4534	0.2110	83.58	16.37	<.0001
2002	4	2.7090	0.1603	53.47	16.90	<.0001
2002	16	2.8994	0.1597	52.63	18.16	<.0001
2003	4	2.5545	0.1539	45.35	16.60	<.0001
2003	16	3.1911	0.1538	45.31	20.74	<.0001
2004	4	2.3563	0.1558	47.61	15.13	<.0001
2004	16	3.2606	0.1564	48.35	20.85	<.0001
2005	4	2.6418	0.1603	53.5	16.48	<.0001
2005	16	3.0706	0.1609	54.2	19.09	<.0001
2006	4	2.3186	0.1557	47.47	14.89	<.0001
2006	16	2.9469	0.1603	53.47	18.38	<.0001
2007	4	1.8956	0.2263	112.6	8.37	<.0001
2007	16	2.8326	0.2273	113	12.46	<.0001
2008	4	1.8733	0.2263	112.6	8.28	<.0001
2008	16	2.6679	0.2273	113	11.74	<.0001

Appendix II. Information, diagnostics and results of the model including year as a continuous variable

Table 1. Description of class levels in the model

Class Level Information		
Class	**Levels**	**Values**
array	22	0 1 2 3 4 5 6 7 8 9 10 11 13 14 15 16 17 19 20 21 22 23
habitat	2	4 16
reefid	132	0N 0NE 0NW 0S 0SE 0SW 10N 10NE 10NW 10S 10SE 10SW 11N 11NE 11NW 11S 11SE 11SW 13N 13NE 13NW 13S 13SE 13SW 14N 14NE 14NW 14S 14SE 14SW 15N 15NE 15NW 15S 15SE 15SW 16N 16NE 16NW 16S 16SE 16SW 17N 17NE 17NW 17S 17SE 17SW 19N 19NE 19NW 19S 19SE 19SW 1N 1NE 1NW 1S 1SE 1SW 20N 20NE 20NW 20S 20SE 20SW 21N 21NE 21NW 21S 21SE 21SW 22N 22NE 22NW 22S 22SE 22SW 23N 23NE 23NW 23S 23SE 23SW 2N 2NE 2NW 2S 2SE 2SW 3N 3NE 3NW 3S 3SE 3SW 4N 4NE 4NW 4S 4SE 4SW 5N 5NE 5NW 5S 5SE 5SW 6N 6NE 6NW 6S 6SE 6SW 7N 7NE 7NW 7S 7SE 7SW 8N 8NE 8NW 8S 8SE 8SW 9N 9NE 9NW 9S 9SE 9SW

Table 2. Optimization information

Optimization Information	
Optimization Technique	Dual Quasi-Newton
Parameters in Optimization	2
Lower Boundaries	2
Upper Boundaries	0
Fixed Effects	Profiled
Residual Variance	Profiled
Starting From	Data

Table 3. Optimization details (Convergence criterion (GCONV=1E-8) satisfied)

Iteration History					
Iteration	**Restarts**	**Evaluations**	**Objective Function**	**Change**	**Max Gradient**
0	**0**	4	2539.3318256	.	69.47592
1	**0**	5	2537.0826162	2.24920942	11.50463
2	**0**	4	2536.7186289	0.36398728	2.656044
3	**0**	2	2536.7146208	0.00400813	1.26404
4	**0**	2	2536.7138798	0.00074101	0.052335
5	**0**	2	2536.7138776	0.00000214	0.000568

Figure 1. Plots of Pearson residuals versus predicted values (top left), histogram of residuals with expected normal distribution overlayed (top right), quantile plot of residuals (bottom left), and a box plot of residuals (bottom right).

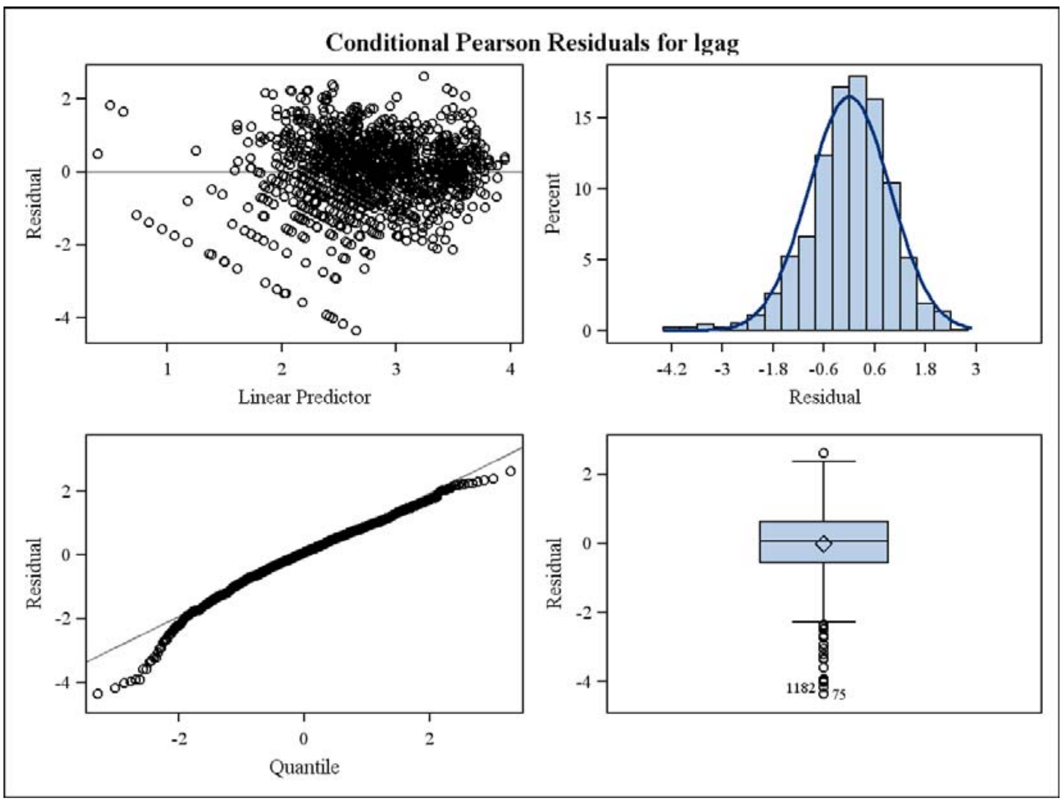

Table 4. LS estimates of habitat means for each year

Habitat Least Squares Means						
Habitat	**Year**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
4	2001	2.8197	0.1224	21.99	23.03	<.0001
16	2001	3.3164	0.1260	24.7	26.32	<.0001
4	2002	2.7072	0.1203	20.53	22.50	<.0001
16	2002	3.2441	0.1224	21.96	26.51	<.0001
4	2003	2.5947	0.1192	19.79	21.76	<.0001
16	2003	3.1717	0.1202	20.48	26.38	<.0001
4	2004	2.4822	0.1191	19.73	20.84	<.0001
16	2004	3.0994	0.1197	20.12	25.89	<.0001
4	2005	2.3697	0.1201	20.35	19.74	<.0001
16	2005	3.0271	0.1208	20.86	25.06	<.0001
4	2006	2.2572	0.1220	21.68	18.51	<.0001
16	2006	2.9547	0.1235	22.76	23.93	<.0001
4	2007	2.1447	0.1248	23.79	17.18	<.0001
16	2007	2.8824	0.1276	25.96	22.59	<.0001
4	2008	2.0322	0.1286	26.77	15.81	<.0001
16	2008	2.8101	0.1331	30.69	21.12	<.0001

Table 5. LS estimates of habitat means calculated over all years

Habitat Least Squares Means					
Habitat	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
4	2.5238	0.1190	19.67	21.20	<.0001
16	3.1262	0.1197	20.12	26.11	<.0001

Appendix III. Information, diagnostics and results of the model testing year effects without habitat effects

Table 1. Description of class levels in the model

Class Level Information		
Class	**Levels**	**Values**
array	22	0 1 2 3 4 5 6 7 8 9 10 11 13 14 15 16 17 19 20 21 22 23
reefid	132	0N 0NE 0NW 0S 0SE 0SW 1N 1NE 1NW 1S 1SE 1SW 2N 2NE 2NW 2S 2SE 2SW 3N 3NE 3NW 3S 3SE 3SW 4N 4NE 4NW 4S 4SE 4SW 5N 5NE 5NW 5S 5SE 5SW 6N 6NE 6NW 6S 6SE 6SW 7N 7NE 7NW 7S 7SE 7SW 8N 8NE 8NW 8S 8SE 8SW 9N 9NE 9NW 9S 9SE 9SW 10N 10NE 10NW 10S 10SE 10SW 11N 11NE 11NW 11S 11SE 11SW 13N 13NE 13NW 13S 13SE 13SW 14N 14NE 14NW 14S 14SE 14SW 15N 15NE 15NW 15S 15SE 15SW 16N 16NE 16NW 16S 16SE 16SW 17N 17NE 17NW 17S 17SE 17SW 19N 19NE 19NW 19S 19SE 19SW 20N 20NE 20NW 20S 20SE 20SW 21N 21NE 21NW 21S 21SE 21SW 22N 22NE 22NW 22S 22SE 22SW 23N 23NE 23NW 23S 23SE 23SW

Table 2. Optimization information

Optimization Information	
Optimization Technique	Dual Quasi-Newton
Parameters in Optimization	2
Lower Boundaries	2
Upper Boundaries	0
Fixed Effects	Profiled
Residual Variance	Profiled
Starting From	Data

Table 3. Optimization details (Convergence criterion (GCONV=1E-8) satisfied)

Iteration History					
Iteration	**Restarts**	**Evaluations**	**Objective Function**	**Change**	**Max Gradient**
0	**0**	4	2547.3081115	.	79.11769
1	**0**	5	2544.3553042	2.95280734	14.35573
2	**0**	3	2544.2872265	0.06807769	3.038952
3	**0**	3	2544.2831985	0.00402799	0.201888
4	**0**	2	2544.2831754	0.00002313	0.019584
5	**0**	2	2544.2831753	0.00000012	6.327E-6

Figure 1. Plots of Pearson residuals versus predicted values (top left), histogram of residuals with expected normal distribution overlayed (top right), quantile plot of residuals (bottom left), and a box plot of residuals (bottom right).

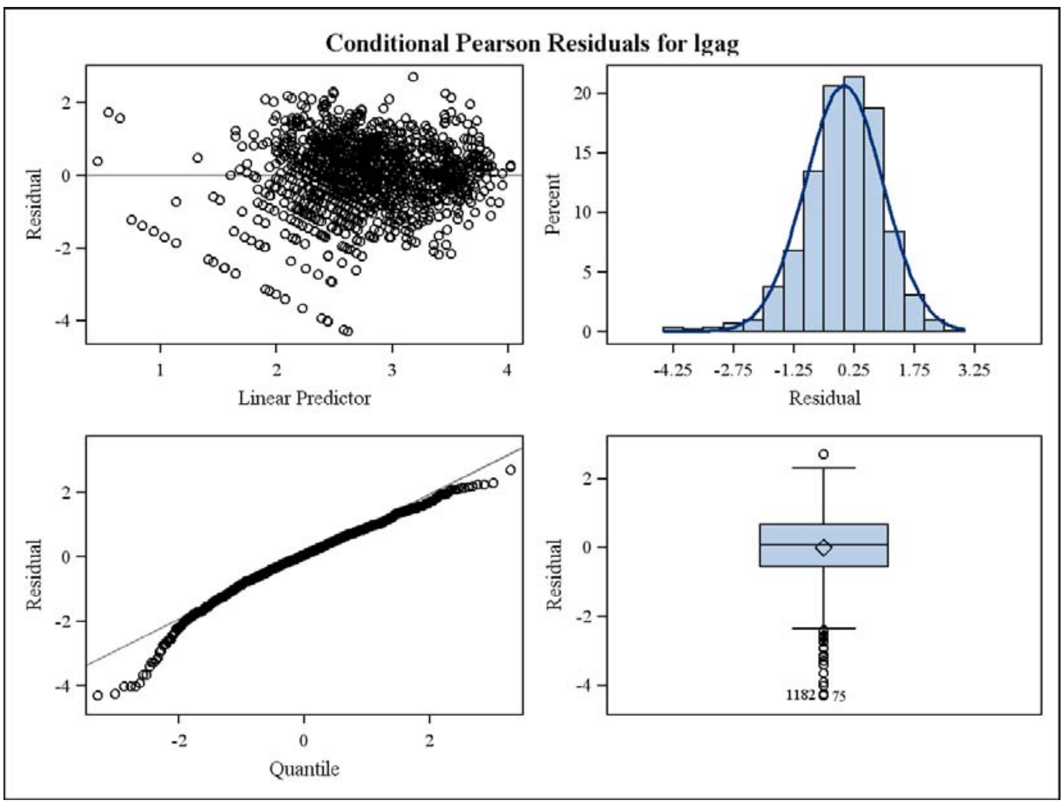

Table 4. Model estimates for intercept and slope parameters

Solutions for Fixed Effects					
Effect	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Intercept	196.96	17.3570	1172	11.35	<.0001
Year	-0.09689	0.008662	1172	-11.19	<.0001