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GLM ANALYSIS OF MEDIUM BLUEFIN TUNA RELATIVE ABUNDANCE IN THE WESTERN NORTH ATLANTIC BASED ON ROD AND REEL CPUE

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SUMMARY

A general linear modeling approach was used to develop an index of abundance of medium bluefin tuna based on the catch per unit of effort (CPUE) in the U.S. North Atlantic coast rod and reel fishery. Operating primarily on the continental shelf, the fishery extends from North Carolina to Maine, but medium bluefin primarily are caught off New Jersey, New York, and southern New England during the summer and early fall. CPUE in this fishery varies principally as a function of year, area, time of year, fishing method (i.e., chum or troll), and whether the effort is a tournament activity. An annual index of abundance was produced for the years 1987 through 1992, extending a previous GLM analysis of medium bluefin CPUE through two more years.

RESUME

Une méthode de modèle linéaire généralisé a été utilisée pour élaborer un indice d'abondance du thon rouge de taille moyenne à partir de la prise par unité d'effort (CPUE) dans la pêcherie à la canne/moulinet des Etats-Unis sur le littoral nord-atlantique. Cette pêcherie, qui travaille essentiellement sur la plateforme continentale, s'étend de la Caroline du Nord au Maine, mais le thon rouge de taille moyenne est surtout capturé au large du New Jersey, de New York et de la partie sud de la Nouvelle-Angleterre pendant l'été et en début d'automne. La CPUE de cette pêcherie varie surtout en fonction de l'année, de la zone, de la saison, de la méthode de pêche (c'est-à-dire appât vivant ou ligne traînante), et si l'effort procède de championnats. Un indice de l'abondance annuelle a été calculé pour les années 1987 à 1992, ce qui prolonge de deux années de plus une analyse antérieure par GLM de la CPUE du thon rouge de taille moyenne.

RESUMEN

Se usó el modelo lineal generalizado (GLM) para obtener un índice de abundancia de túnidos de talla media, en base a la captura por unidad esfuerzo (CPUE) en la pesquería de caña-liña de la costa estadounidense del Atlántico norte. La pesquería, que opera principalmente en la plataforma continental, se extiende desde Carolina del Norte hasta Maine, pero el atún rojo de talla media se captura sobre todo frente a las costas de Nueva Jersey, Nueva York y sur de Nueva Inglaterra, durante el verano y principios de otoño. En esta pesquería, la CPUE varía principalmente en función del año, zona, época del año, método de pesca (es decir, "chum" o arrastre) y también si el esfuerzo se despliega en torneos. Se obtuvo un índice anual de abundancia para los años 1987 a finales de 1992, ampliándose dos años más un análisis previo con GLM de la CPUE de atún rojo de talla media.

INTRODUCTION

A general linear modeling approach can be used to standardize catch rates in fisheries. Annual variation in standardized catch rates is assumed to reflect annual variation in the abundance of the stock. Indices of annual abundance have been calculated from the catch per unit effort (CPUE) of small and large bluefin in the rod and reel fishery in the Western North Atlantic off the northern U.S. coast. Three size groups, as distinguished by market category, are caught in the fishery, but the medium market category was not recorded consistently until 1987. Because several age classes intervene between the small and large market categories, as they are currently defined, an index of annual abundance for medium bluefin is needed to adequately evaluate the status of Western Atlantic bluefin. In an exploratory study, Eklund and Browder (1992) prepared the first index of annual abundance for the medium size class of tuna, based on four years of data from the U.S. rod and reel and haldine fishery. In this report, I extend the estimation of abundance indices for medium bluefin tuna two more years using the same general method.

METHODS

Recreational fishing data for the coastal states from Virginia to Massachusetts are routinely obtained by phone and dock survey by the individual states, universities, or the National Marine Fisheries Service (NMFS). They are then compiled by the National Marine Fisheries Service. They provide a sample of catch and associated effort. Four primary targets have been consistently recorded: (1) marlin/tuna, (2) shark, (3) large bluefin, and (4) small bluefin. The category "marlin/tuna" refers to a general offshore fishery for both marlins and tunas. Unfortunately, medium bluefin was not recorded as a target until 1991; therefore, it was necessary to include records for other target categories as well as medium in this analysis and to include target as a variable in the models. Shark was excluded because an exploratory analysis by Eklund and Browder (1992) determined that few medium tuna were caught by effort directed at sharks. Because medium bluefin was listed as a target in only one year, a variable called "new target" was declared for this analysis, and records were classified as either (1) marlin/tuna or (2) bluefin. All target categories for bluefin (small, medium and large) were classified in the bluefin new target category.

Other descriptors of fishing effort also are recorded; for instance, gear, fishing method, and type of bait. The primary gear are rod and reel and handline. Chumming and trolling are the two principal fishing methods. Dead bait is the principal type of bait. Effort sometimes is part of a tournament, and tournament participation is recorded. Hours of fishing and number of lines fished also are recorded.

CPUE was defined in this analysis as number caught per 1000 line hours (number of lines x hours of fishing). The dependent variable was the natural log of CPUE + 1 (the 1 was added because zero fish were caught on some trips and it is impossible to take the log of zero). The independent variables I examined for their effect were: area, target, boat type (charter or private), interview type (phone or dock), and bimonth. The months from June through October were grouped as follows into units called "bimonths": June-July, August, and September-October. Based on Eklund and Browder (1992), I included the areas from New Jersey north in the analysis, excluding Virginia, Maryland, and Delaware. The areas are defined as in previous GLMs of this fishery: New Jersey-New York (NYNJ), southern New England (SONE), and the Gulf of Maine (GOMA).

The data set used in the analysis was created from the original records by randomly grouping the catch and the effort into one or more units of 15 trips within each analysis stratum (i.e., each combination of all main effects used in the model). Original records that did not fit into a unit of 15 records were discarded. Grouping in some manner is routinely used to reduce the high individual variance found in hook and line CPUE data (Browder and Prince 1990, Cramer et al. 1992). Eklund and Browder (1991) found little difference in the pattern of annual variation in CPUE from grouped or non-grouped data.

Models were prepared for the entire defined study region and for each of the subregions. Separate models were prepared for each subregion because of the high proportion of variation that could be explained by a year-area interaction term (Eklund and Browder 1992).

In a departure from the previous study, I used only models in which all main effects were either statistically significant at ($p<0.1$) or were components of significant interaction terms. Only interaction terms that seemed relevant were tested in model building. Models with year interactions were examined but were not used for obtaining annual abundance indices.

YEAR least square means obtained from each model were the basis of the abundance indices. LSmeans were backtransformed so that the indices could be expressed in terms of the original input data, number of fish caught per 1000 line hours of fishing. A bias correction (Bradu and Mundlak 1970) was applied.

RESULTS AND DISCUSSION

Over the six years of the analysis, more fishing effort was expended in southern New England than in the other two areas, and this is where the most medium bluefin were caught. The distribution of original trip data among areas is as follows: GOMA, 1819; SONE, 4417; and NYNJ, 2518. The distribution of medium bluefin catches recorded from 1987-1992 is as follows: GOMA, 105; SONE, 377; and NYNJ, 183. Least square difference (LSD) tests applied to GLM results suggested that catch rates did not differ significantly ($p<0.05$) among areas. Catch rates were significantly higher in September-October than in any other period in the full region and in the SONE area. They were significantly higher in September-October than in August in the NYNJ area.

The models prepared in this analysis are described in Table 1. Regression coefficients for the #1 models are given in Appendix A. The models are referred to as "FULL", "GOMA", "SONE", or "NYNJ", depending on the area they cover. The best models in each category were designated the number "1" models. The number "2" models are corresponding models with YEAR-interaction terms.

In Table 1, the variables included in the model are indicated by their contributed model sum of squares. An empty space under a particular variable name on a given row indicates the variable was not included in that particular model. The next-to-last column of Table 1 gives the percentage of total variance in ln(CPUE+1) explained by the model (r^2). The last column of Table 1 gives the percentage of explained sum of squares (ExSS) contributed by YEAR-interaction terms.

Boat type and interview type were not significant explaining variables in any of the models. Fishing method (chum or troll) and whether the effort was tournament or nontournament were significant explaining variables in all models. Target and bimonth were significant variables in most models. Interactions of area with bimonth, area with fishing method, and tournament or nontournament with fishing method were significant variables in some models. Interactions of year with area and year with bimonth, when included, were always significant.

The best model for the entire region (FULL 1) explained 22.85% of the variation in ln(CPUE+1). Inclusion of the interaction terms YEAR-AREA and YEAR-BIMONTH (FULL 2) increased the explained percentage of variation to 37.2%. The two YEAR-interaction terms contributed 33.42% of the ExSS. More than half was contributed by the YEAR-AREA term.

The strong contribution of YEAR-interaction terms to model ExSS suggests that the pattern of variation in lnCPUE+1 across the variables BIMONTH and AREA changes from one year to the next. This lack of consistency could confound results of models that do not include the YEAR effect. The areas were modeled separately to reduce this problem, even though least square difference (LSD) tests of the output of FULL 1 indicated that ln(CPUE+1) did not differ significantly among AREAs.

Models obtained for each area also are described in Table 1.

Models without YEAR interactions explained from 32.87% to 42.31% of total variation in ln(CPUE+1). Models that include the interaction of YEAR with BIMONTH explained from 42.19% to 49.71% of the variation in ln(CPUE+1). The interaction of YEAR with BIMONTH contributed from 7.75% to 31.53% of ExSS. The NYNJ model (NYNJ 1) not only had the highest r^2 but also the lowest percentage ExSS contributed by the interaction of BIMONTH with YEAR.

Annual abundance indices calculated by the models without YEAR-interaction terms are shown with their 95% confidence limits in Figure 1. The four models provide somewhat different pictures of change in abundance across years. In the Gulf of Maine, maximum catch rates occurred in 1988, with only slighly lower rates in 1989. Maximum abundance was reached in 1989 in New York-New Jersey, with much lower rates in all other years. Maximum catch rates occurred in 1990 in southern New England. According to the full model, maximum catch rates in the region as a whole occurred in 1989. All four models seem to agree that the lowest catch rates during the period of record occurred in 1992. In all four cases, the backtransformed LSmean for 1992 was an unrealistic negative value. (The model is not prevented from producing a negative backtransformed LSMean since 1 must be subtracted from the backtransformed value.)

In response to ICCAT recommendations, new U.S. management measures were implemented for the 1992 fishery season. Among these measures was a no-sale provision for fish smaller than 70 inches (178 cm) straight fork length. The degree to which 1992 catch rates were influenced by this management measure are not known. A comparison of the targets listed in 1991 and 1992 may, however, provide some perspective on this question. Recording a medium market category was initiated in the survey in 1991, and there were 29 trip records in the medium target category in 1991 (26 in SONE and 3 in NYNJ) but none in 1992. This suggests that less effort may have been directed at medium bluefin in 1992 than in 1991.

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Cramer, J., C. A. Brown, and J. A. Lucy. 1992. Standardized catch rates of small bluefin tuna in the Virginia (U.S.) rod and reel fishery. ICCAT Working Document SCRS/91/02.

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Table 1. Variables included the "best" models (1) and models with the same models with year*area and/or year*bimonth interactions (<1). The included variables are indicated with the value of the their sum of squares (type III SS in SAS). Also given are the percent of variance explained by each model (R^2) and the percentage of the model sum of squares accounted for by the sums of squares of the year interaction terms.

Model	Year	Area	Bimonth	Tourn	New Target	Fish method	Area* bimonth	Area* fishmet	Tourn* fishmet	Year* area	Year* bimonth	% Var. expln.	%ExSS in yr inter-actions
FULL 1	37.38	13.99	3.83	13.84	6.82	1.27	22.60	21.58				22.85	
FULL 2	35.63	5.83	0.93	9.83	7.86	0.10	16.95	16.07		55.37	25.01	37.20	33.42
GOMA 1	14.68			1.76	3.05	7.69						36.77	
GOMA 2	4.44		2.15	2.49	2.58	5.96					14.39	42.41	31.53
SONE 1	38.69		26.70	11.22	4.50	1.85			5.90			32.87	
SONE 2	34.11		11.76	7.82	6.90	0.71			4.10		30.21	42.19	21.05
NYNJ 1	48.71		4.54	2.10		2.64						42.31	
NYNJ 2	42.76		1.46	3.60		3.04					6.20	49.71	7.75

Table 2. LSMeans and their standard errors for #1 models.

	FULL 1		GOMA 1		SONE 1		NYNJ 1	
Year	LSMEAN	STDERR	LSMEAN	STDERR	LSMEAN	STDERR	LSMEAN	STDERR
1987	0.22509	0.07666	-0.06153	0.18698	0.30228	0.10000	0.18683	0.11751
1988	0.15245	0.09419	0.61827	0.19079	0.14238	0.11892	0.12062	0.21134
1989	0.74052	0.08160	0.58950	0.20274	0.50503	0.11852	1.34353	0.11614
1990	0.49093	0.07078	-0.19189	0.15173	1.06162	.0.10125	0.14529	0.10727
1991	0.24581	0.07349	0.07426	0.16870	0.44784	.0.11038	0.09497	0.10690
1992	-0.10214	0.13914	-0.36612	0.25555	-0.08947	.0.26232	-0.12241	0.19263

Table 3. Bias-corrected backtransformed means and standard errors for #1 models.

	FULL 1		GOMA 1		SONE 1		NYNJ 1	
Year	BACKTR LSMEAN	BACKTR STDERR	BACKTR LSMEAN	BACKTR STDERR	BACKTR LSMEAN	BACKTR STDERR	BACKTR LSMEAN	BACKTR STDERR
1987	0.25049	0.07967	-0.04309	0.20561	0.35972	0.10518	0.21378	0.12469
1988	0.16986	0.09877	0.88980	0.21021	0.16119	0.12628	0.15368	0.23533
1989	1.10403	0.08503	0.84053	0.22475	0.66872	0.12583	2.85847	0.12316
1990	0.63794	0.07334	-0.16505	0.16384	1.90590	00.10655	0.16305	0.11324
1991	0.28212	0.07626	0.09252	0.18376	0.57450	00.11671	0.10593	0.11283
1992	-0.08831	0.14929	-0.28356	0.29117	-0.05358	.0.29995	-0.09865	0.21244

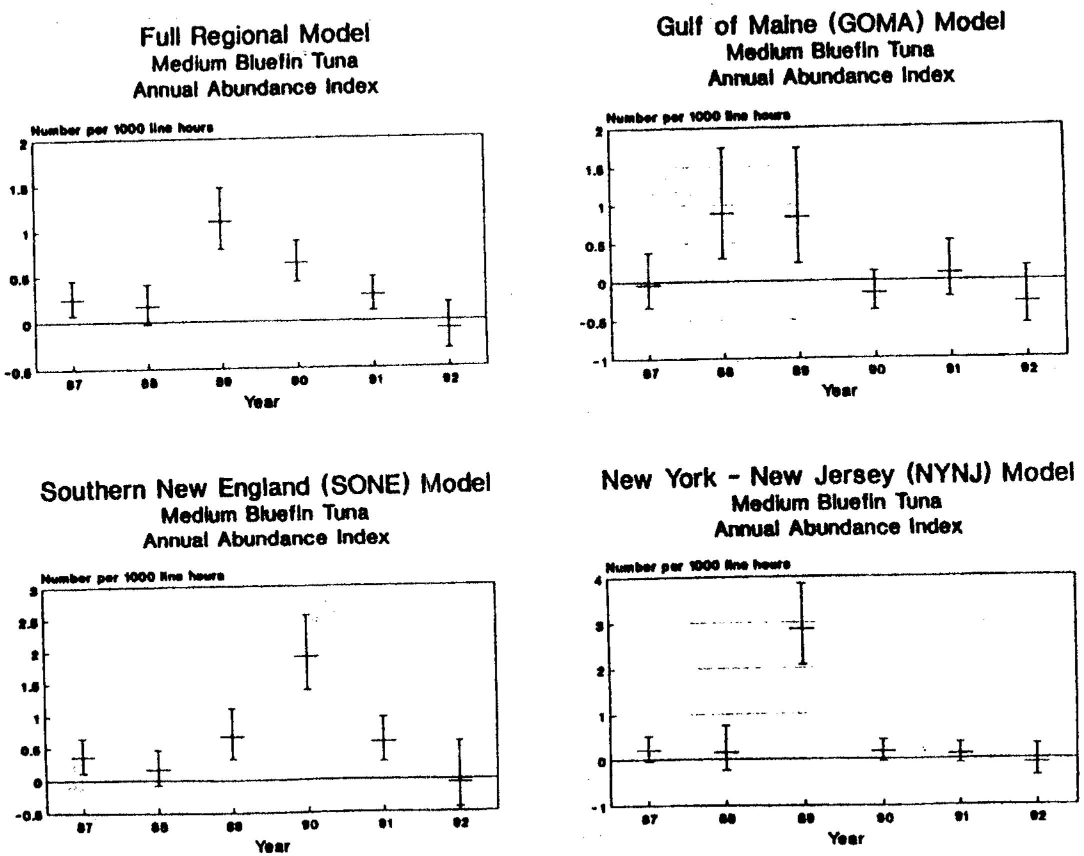

Figure 1. Indices of annual abundance from the full regional model and a model for each

APPENDIX A
Regression Coefficients from the Models without YEAR interactions

Model FULL 1

Medium Bluefin Tuna
MODEL WITH BINON, NUTARGET, TOURN, FISHMETH, WITH AREA INTERACTIONS
DATA PREPARED FROM 15-RECORD COMBINATIONS
15:54 Friday, September 10, 1993

General Linear Models Procedure

Dependent Variable: LNCKSUM1

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.2615132077 B	1.42	0.1547	0.18357164
YEAR	87	0.3227329273 B	2.07	0.0386	0.15577667
	88	0.2545836888 B	1.55	0.1224	0.16462881
	89	0.8426616365 B	5.38	0.0001	0.15657535
	90	0.5930719280 B	3.91	0.0001	0.15167826
	91	0.3479499618 B	2.29	0.0224	0.15206620
	92	0.0000000000 B	.	.	.
AREA	GOMA	-.5113288555 B	-2.68	0.0075	0.19082570
	NYNJ	-.5791793259 B	-3.61	0.0003	0.16064246
	SONE	0.0000000000 B	.	.	.
BINONTH	1	-.7168370872 B	-6.09	0.0001	0.11774326
	2	-.6505049060 B	-5.83	0.0001	0.11165766
	3	0.0000000000 B	.	.	.
TOURN	NON TOURN	0.3736352594 B	4.50	0.0001	0.08303279
	TOURNAMENT	0.0000000000 B	.	.	.
NUTARGET	1	-.2273219015 B	-3.16	0.0016	0.07195028
	2	0.0000000000 B	.	.	.
FISHMETH	CHUM	0.4598877339 B	4.78	0.0001	0.09613045
	TROLL	0.0000000000 B	.	.	.
AREA*BINONTH	GOMA 1	0.8191552929 B	3.70	0.0002	0.22112175
	GOMA 2	0.9524187971 B	4.56	0.0001	0.20888961
	GOMA 3	0.0000000000 B	.	.	.
	NYNJ 1	0.7914759790 B	4.25	0.0001	0.18636446
	NYNJ 2	0.4488754050 B	2.50	0.0127	0.17962407
	NYNJ 3	0.0000000000 B	.	.	.
	SONE 1	0.0000000000 B	.	.	.
	SONE 2	0.0000000000 B	.	.	.
	SONE 3	0.0000000000 B	.	.	.
AREA*FISHMETH	GOMA CHUM	-.9619269643 B	-5.51	0.0001	0.17460825
	GOMA TROLL	0.0000000000 B	.	.	.
	NYNJ CHUM	-.1308362808 B	-0.85	0.3947	0.15362124
	NYNJ TROLL	0.0000000000 B	.	.	.
	SONE CHUM	0.0000000000 B	.	.	.
	SONE TROLL	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

Model NYNJ 1

Medium Bluefin Tuna
NYNJ MODEL - WITH NO INTERACTIONS
DATA PREPARED FROM 15-RECORD COMBINATIONS
10:57 Monday, September 13, 1993

General Linear Models Procedure

Dependent Variable: LNCRSUM1

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		-0.274383654 B	-1.18	0.2386	0.23211945
YEAR	87	0.309244864 B	1.39	0.1658	0.22231842
	88	0.243035693 B	0.85	0.3975	0.28658387
	89	1.465937515 B	6.66	0.0001	0.22026659
	90	0.267700302 B	1.24	0.2155	0.21541924
	91	0.217385512 B	1.01	0.3136	0.21518767
	92	0.000000000 B	.	.	.
BIMONTH	1	0.000062375 B	0.00	0.9996	0.13027129
	2	-0.333677766 B	-2.63	0.0092	0.12686642
	3	0.000000000 B	.	.	.
TOURN	NON TOURN	0.274803442 B	2.11	0.0359	0.13004321
	TOURNAMENT	0.000000000 B	.	.	.
FISHMETH	CHUM	0.251551794 B	2.37	0.0187	0.10610403
	TROLL	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

Model GOMA 1

Medium Bluefin Tuna
GOMA MODEL - WITHOUT YEAR INTERACTION OR BIMONTH
DATA PREPARED FROM 15-RECORD COMBINATIONS
16:42 Monday, September 13, 1993

Dependent Variable: LNCRSUM1

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		-.5260222976 B	-1.50	0.1359	0.35057127
YEAR	87	0.3045860081 B	1.14	0.2579	0.26804015
	88	0.9843907168 B	3.48	0.0007	0.28288843
	89	0.9556208084 B	3.43	0.0008	0.27862697
	90	0.1742249876 B	0.67	0.5052	0.26074960
	91	0.4403731338 B	1.73	0.0857	0.25427006
	92	0.0000000000 B	.	.	.
NMTARGET	BLUEFIN	0.4752733985 B	2.59	0.0107	0.18353092
	MARLIN/TUNA	0.0000000000 B	.	.	.
TOURN	NON TOURN	0.4113539586 B	1.97	0.0514	0.20921537
	TOURNAMENT	0.0000000000 B	.	.	.
FISHMETH	CHUM	-.5668183154 B	-4.11	0.0001	0.13795576
	TROLL	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

Model SONE 1

Medium Bluefin Tuna
SONE MODEL - WITH ONE INTERACTION BUT NO YEAR INTERACTION
DATA PREPARED FROM 15-RECORD COMBINATIONS
10:57 Monday, September 13, 1993

General Linear Models Procedure

Dependent Variable: LNCRSUM1

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.034369083 B	0.12	0.9063	0.29163450
YEAR	87	0.391753033 B	1.44	0.1506	0.27195846
	88	0.231849448 B	0.83	0.4053	0.27825269
	89	0.594506163 B	2.15	0.0326	0.27715337
	90	1.151093226 B	4.24	0.0001	0.27146154
	91	0.537316792 B	1.96	0.0507	0.27399344
	92	0.000000000 B	.	.	.
BIMONTH	1	-0.615939482 B	-5.32	0.0001	0.11578393
	2	-0.663618958 B	-6.04	0.0001	0.10993489
	3	0.000000000 B	.	.	.
NMTARGET	BLUEFIN	0.260960386 B	2.63	0.0088	0.09908795
	MARLIN/TUNA	0.000000000 B	.	.	.
TOURN	NON TOURN	0.135475432 B	0.97	0.3317	0.13935962
	TOURNAMENT	0.000000000 B	.	.	.
FISHMETH	CHUM	-0.150867273 B	-0.69	0.4921	0.21935429
	TROLL	0.000000000 B	.	.	.
TOURN*FISHMETH	NON TOURN CHUM	0.719569057 B	3.02	0.0028	0.23863271
	NON TOURN TROLL	0.000000000 B	.	.	.
	TOURNAMENT CHUM	0.000000000 B	.	.	.
	TOURNAMENT TROLL	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.