Stock Assessment of Pacific Sardine for 1999 with Management Recommendations for 2000
Executive Summary

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The following summarizes Pacific sardine stock assessment results and harvest recommendations for the Pacific Fishery Management Council's (PFMC) management season beginning January 1, 2000. Stock assessment results will be discussed at the Coastal Pelagic Species Management Team (CPSMT) meeting on December 9, and will be presented to the Coastal Pelagic Species Advisory Subpanel (CPSAS) on December 14. A complete sardine Stock Assessment and Fishery Evaluation (SAFE) document will be prepared prior to the March 2000 Council meeting.

Pacific sardine landings for the directed fisheries off California and Baja California reached the highest in recent history during the 1999 calendar year with a combined total of 115,051 metric tons (mt) harvested (Table 1, Figure 1). California landings for 1999, limited by a State of California management quota, were projected to be approximately 60,315 mt, 47% higher than 1998. The Ensenada, Mexico fishery experienced a 14% increase from the previous year, with final harvest projected to be 54,735 mt. The Ensenada fishery was not limited by a management quota.

For calendar year 1999, the Director of California Department of Fish and Game allocated a sardine quota of 120,474 mt to California's sardine fishery. This quota was based on a July 1, 1998, 'inside area' biomass estimate of 1,073,091 mt (Hill et al., 1999). As of October 31, 1999, the California fishery had landed 47,993 mt, with 72,481 mt of the quota remaining for November and December 1999. Off southern California, market squid availability was high during semester 1, 1999. This availability remains high, and the late-fall squid fishery has resumed. The wetfish fleet, which harvests sardine, continues to concentrate effort on market squid, a more profitable species.

Pacific sardine biomass (age 1+ as of July 1, 1999) was estimated using an integrated stock assessment model called CANSAR-TAM (Catch-at-age ANalysis for SARdine - Two Area Model; Hill et al. 1999), which is based on the original CANSAR model described by Deriso et al. (1996). CANSAR-TAM was developed to account for the expansion of the Pacific sardine stock northward beyond the California bight to include waters off the whole northwest Pacific coast. CANSAR and CANSAR-TAM are age-structured analyses using fishery-dependent and fishery-independent data to obtain annual estimates of sardine abundance, year-class strength, and age-specific fishing mortality for 1983 through the first semester of 1999. Non-linear least-squares criteria are used to find the best fit between model estimates and input data. Biomass estimates were adjusted by the model to better match the fishery-independent (survey) indices of relative abundance, including: aerial spotter sightings (Lo et al., 1992), CalCOFI egg and larval data, spawning area, and spawning biomass estimated using the daily egg production method (DEPM; Lo et al., 1996). The assessment model is based on a semi-annual time increment (Jan-Jun, semester 1, and July-Dec, semester 2) and now includes seventeen years of data. CANSAR-TAM recalculates biomass for all years in the time series. Bootstrap procedures were used to estimate 95% confidence limits and CV's for biomass and recruitment point estimates.

The CalCOFI, spawning area, and DEPM spawning biomass surveys indicate a steady increase in sardine relative abundance over the entire time series, with all three reaching their highest levels in 1999. (Table 2, Figures 3, 4, 6). The CalCOFI proportion positive index had undergone considerable saturation in recent years due to the higher frequency of positive stations as the sardine stock expanded throughout and beyond the Southern California Bight. This problem was addressed in the current assessment by expanding the offshore range of CalCOFI stations included in the index. In addition, the survey was fit with an exponent (β=0.3547) to accommodate the assumption that the index was a non-linear function of sardine egg production.

Unlike the other fishery-independent surveys, the aerial spotter index has displayed a dramatic downward trend since 1995, with 1999 relative abundance values as low as those projected for 1989 (Table 2, Figure 5). Reasons for this downward trend are uncertain, but may be related to the spotter index covering a relatively small portion of the total sardine distribution. Spotter pilot effort tends to be nearshore, southerly, and within the range of the wetfish fleet. Sardine sightings are primarily concentrated in nearshore areas where the majority of spotter and fishing effort occurs. Based on our knowledge of sardine egg distribution in 1996 through 1999, it is highly likely that the area of the stock extends well beyond the area of the spotter survey. We accommodated spotter index saturation in our model by assuming a nonlinear function to sardine biomass, applying an exponent of β=0.4585.

Relative influence of survey data on biomass estimates from CANSAR-TAM can be controlled by specifying weighting factors (λ_r) for each data type. For the 1999 assessment, surveys were differentially weighted based on the relative amount of area 'sampled' by each index. GIS methods were used to estimate total area covered by each of the four indices, with the assumption that DEPM and spawning area indices covered 100% of the total survey area (i.e., λ_r=1.0). Based on this method, the CalCOFI index was down weighted to λ_r=0.7 and the spotter index was down weighted to λ_r=0.15.

Based on CANSAR-TAM, we estimate the July 1,1999 total age 1+ biomass to have been 1,581,346 mt (Table 3, Figure 8). This estimate includes a bias correction based on 2,000 bootstrap runs. This estimate provides an approximation of coast-wide population biomass. Sardine biomass has increased dramatically from 1983 to 1999 (Table 3, Figure 8). Age composition data and model outputs provide preliminary indication of a strong 1998 year class (Table 3), which dominated catch off southern California during semester 2, 1998. The 1998 year class contributed to the increase in total population biomass between 1998 and 1999.

Proposed Harvest Guideline for 2000:

To calculate the proposed harvest guideline for 2000, we used the MSY control rule defined in Amendment 8 of the Coastal Pelagic Species-Fishery Management Plan (Option J; Table 4.2.5-1 in the CPS FMP, PFMC 1998). This formula should theoretically perform well at preventing overfishing and maintaining relatively high and consistent catch levels over the long term. The Amendment 8 harvest formula for sardine is:

$$\mathbf{H_{t+1} = (BIOMASS_t\text{-}CUTOFF) \times FRACTION \times DISTRIBUTION}$$

where H_{t+1} is the total U.S. coast wide harvest guideline, CUTOFF is the lowest level of estimated biomass at which harvest is allowed, FRACTION is an environmentally-dependent fraction of biomass above CUTOFF that can be taken by fisheries, and STOCK DISTRIBUTION is the fraction of total $BIOMASS_t$ in U.S. waters. $BIOMASS_t$ is the estimated biomass of fish age 1+ for the whole stock at the beginning of season t. Resultant values for the 2000 fishery are as follows:

TOTAL BIOMASS	CUTOFF	FRACTION (F_{msy})	U.S. DISTRIBUTION	HARVEST GUIDELINE
1,581,346	150,000	15%	87%	186,791 mt

FRACTION in the MSY control rule for Pacific sardine is a proxy for F_{msy} (i.e., the fishing mortality rate for deterministic equilibrium MSY). FRACTION depends on recent ocean temperatures because F_{msy} and productivity of the sardine stock is higher under ocean conditions associated with warm water temperatures. An estimate of the relationship between F_{msy} for sardine and ocean temperatures (T) is:

$$F_{msy} = 0.248649805\ T^2 - 8.190043975\ T + 67.4558326$$

where T is the average three season sea surface temperature at Scripps Pier, California during the three

preceding seasons. Under Option J (PFMC 1998), F_{msy} varies between 5% and 15%. F_{msy} will be equal to 15% under current oceanic conditions (T_{1999} = 18.04 degrees C; Figure 7).

Literature Cited:

Deriso, R. B., J. T. Barnes, L. D. Jacobson, and P. J. Arenas. 1996. Catch-at-age analysis for Pacific sardine (*Sardinops sagax*), 1983-1995. Calif. Coop. Oceanic Fish. Invest. Rep. 37:175-187.

Hill, K. T., L. D. Jacobson, N. C. H. Lo, M. Yaremko, and M. Dege. 1999. Stock assessment of Pacific sardine (*Sardinops sagax*) for 1998 with management recommendations for 1999. Calif. Dep. Fish Game, Marine Region Admin Rep. 99-4. 94 p.

Lo, N. C. H., L. D. Jacobson and J. L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49:2515-2526.

Lo, N. C. H., Y. A. Green Ruiz, Merecedes J. Cervantes, H. G. Moser, R. J. Lynn. 1996. Egg production and spawning biomass of Pacific sardine *(Sardinops sagax)* in 1994, determined by the daily egg production method. CalCOFI 37:160-174.

PFMC 1998. Amendment 8 (to the northern anchovy fishery management plan) incorporating a name change to: the coastal pelagic species fishery management plan. Pacific Fishery Management Council, Portland, OR.

Pacific Sardine Fishery:

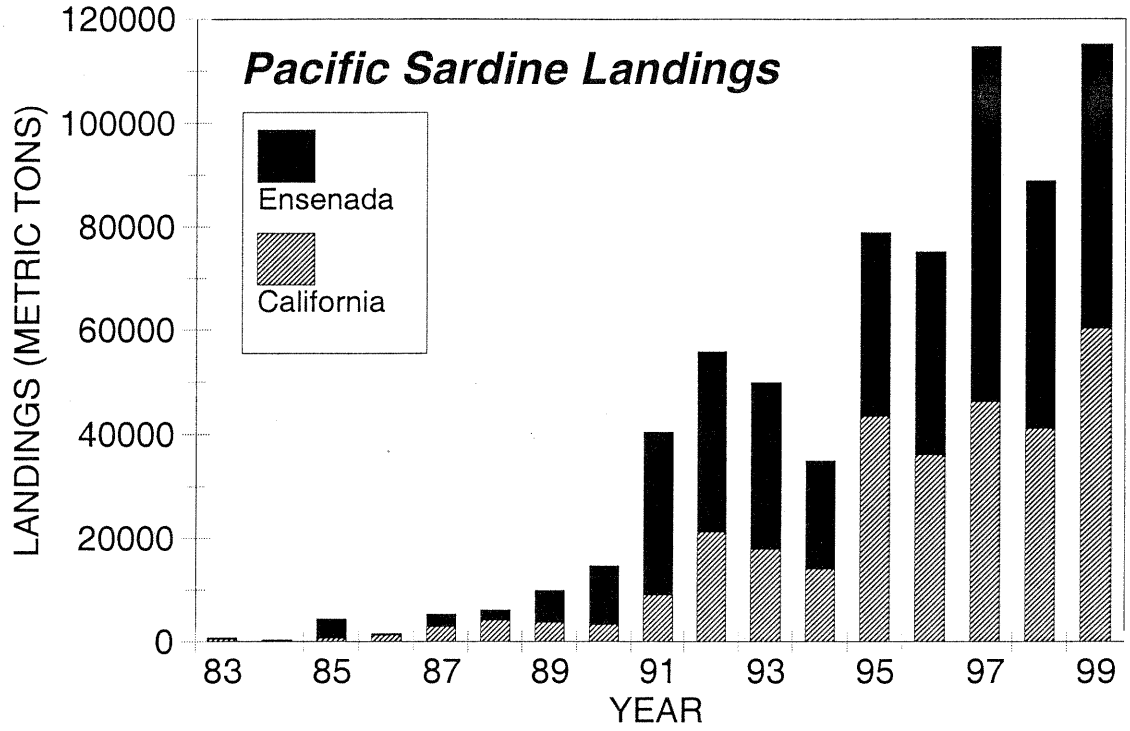

Figure 1. Annual Pacific sardine landings in California and Ensenada.

Table 1. Pacific sardine landings (metric tons) in California and Baja California, 1983-1999.

	CALIFORNIA			ENSENADA			
YEAR	semester 1	semester 2	CA TOTAL	semester 1	semester 2	MX TOTAL	CA-MX TOTAL
83	245	244	489	150	124	274	762
84	188	187	375	0	0	0	375
85	330	335	665	3,174	548	3,722	4,388
86	804	483	1,287	99	143	243	1,529
87	1,625	1,296	2,921	975	1,457	2,432	5,352
88	2,516	1,611	4,128	620	1,415	2,035	6,163
89	2,161	1,561	3,722	461	5,761	6,222	9,945
90	2,272	1,033	3,305	5,900	5,475	11,375	14,681
91	5,680	3,354	9,034	9,271	22,121	31,392	40,426
92	8,021	13,216	21,238	3,327	31,242	34,568	55,806
93	12,953	4,889	17,842	18,649	13,396	32,045	49,887
94	9,040	5,010	14,050	5,712	15,165	20,877	34,927
95	29,565	13,925	43,490	18,225	17,169	35,394	78,884
96	17,896	18,161	36,057	15,666	23,399	39,065	75,121
97	11,865	34,331	46,196	13,499	54,941	68,439	114,636
98	21,841	19,215	41,055	20,239	27,573	47,812	88,868
99	31,745	28,570	60,315	34,760	19,975	54,735	115,051

Pacific Sardine Survey Indices:

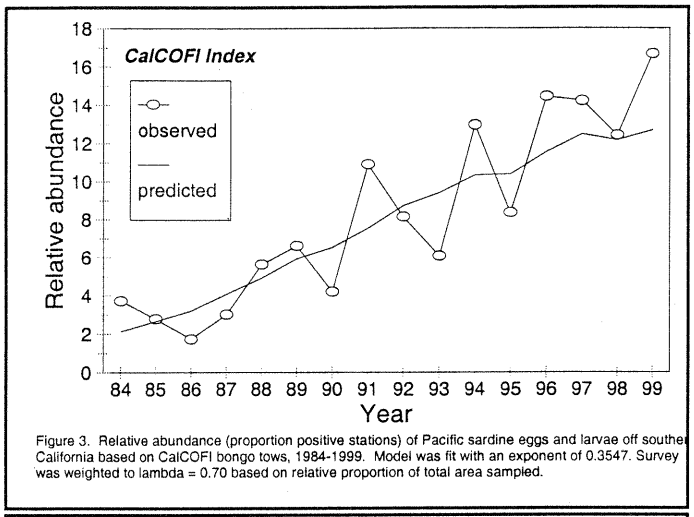

Figure 3. Relative abundance (proportion positive stations) of Pacific sardine eggs and larvae off southern California based on CalCOFI bongo tows, 1984-1999. Model was fit with an exponent of 0.3547. Survey was weighted to lambda = 0.70 based on relative proportion of total area sampled.

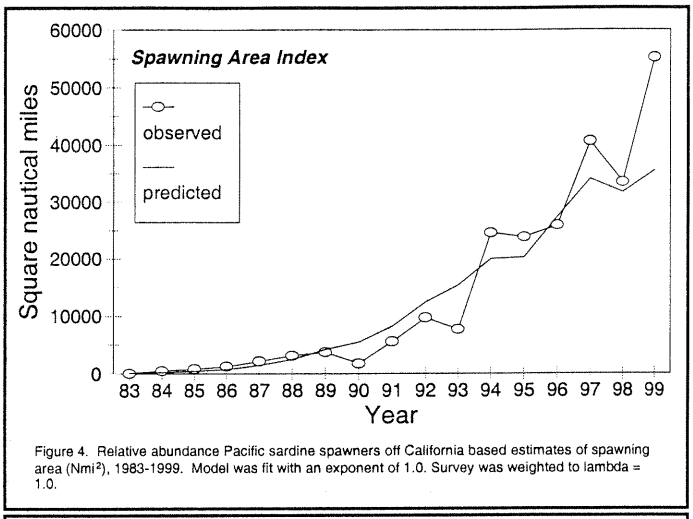

Figure 4. Relative abundance Pacific sardine spawners off California based estimates of spawning area (Nmi^2), 1983-1999. Model was fit with an exponent of 1.0. Survey was weighted to lambda = 1.0.

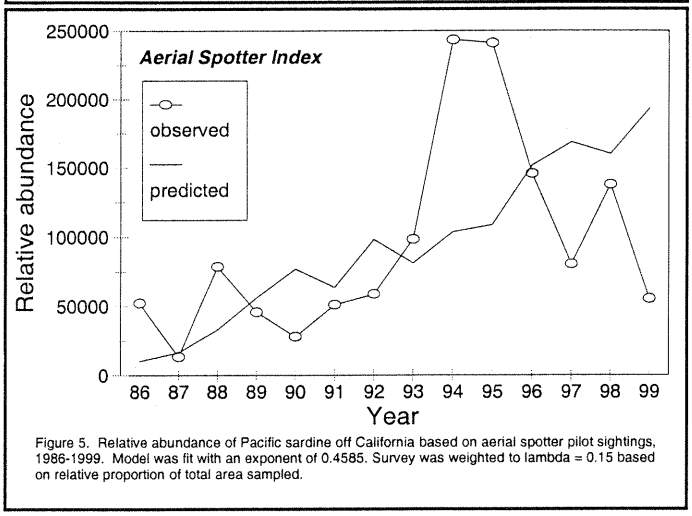

Figure 5. Relative abundance of Pacific sardine off California based on aerial spotter pilot sightings, 1986-1999. Model was fit with an exponent of 0.4585. Survey was weighted to lambda = 0.15 based on relative proportion of total area sampled.

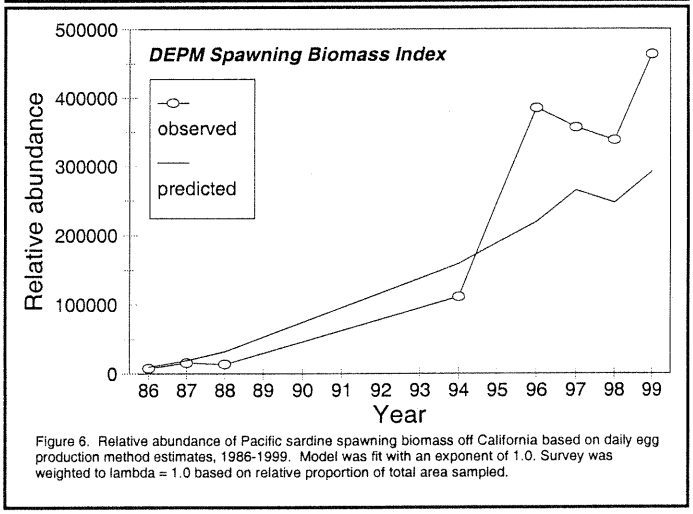

Figure 6. Relative abundance of Pacific sardine spawning biomass off California based on daily egg production method estimates, 1986-1999. Model was fit with an exponent of 1.0. Survey was weighted to lambda = 1.0 based on relative proportion of total area sampled.

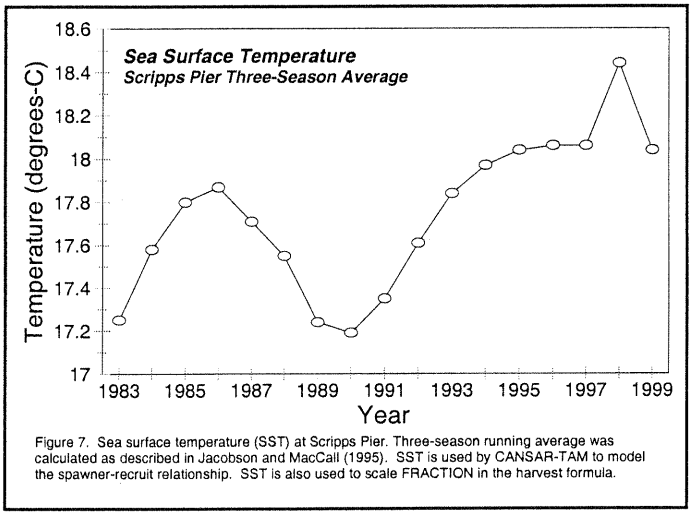

Figure 7. Sea surface temperature (SST) at Scripps Pier. Three-season running average was calculated as described in Jacobson and MacCall (1995). SST is used by CANSAR-TAM to model the spawner-recruit relationship. SST is also used to scale FRACTION in the harvest formula.

Table 2. Pacific sardine survey indices, 1983-1999.

Year	CalCOFI	DEPM	Spawning Area	Spotter	SST
1983	--	--	40	--	17.25
1984	3.727	--	480	--	17.58
1985	2.771	--	760	--	17.8
1986	1.729	7,659	1,260	52,426	17.87
1987	3.008	15,705	2,120	13,490	17.71
1988	5.639	13,526	3,120	78,674	17.55
1989	6.615	--	3,720	45,857	17.24
1990	4.202	--	1,760	28,072	17.19
1991	10.895	--	5,550	51,225	17.35
1992	8.140	--	9,697	58,984	17.61
1993	6.084	--	7,685	98,270	17.84
1994	12.963	111,493	24,539	243,585	17.97
1995	8.367	--	23,816	241,220	18.04
1996	14.453	384,694	25,889	145,772	18.06
1997	14.229	356,300	40,592	80,270	18.06
1998	12.424	337,596	33,447	137,711	18.44
1999	16.667	463,213	55,173	55,437	18.04

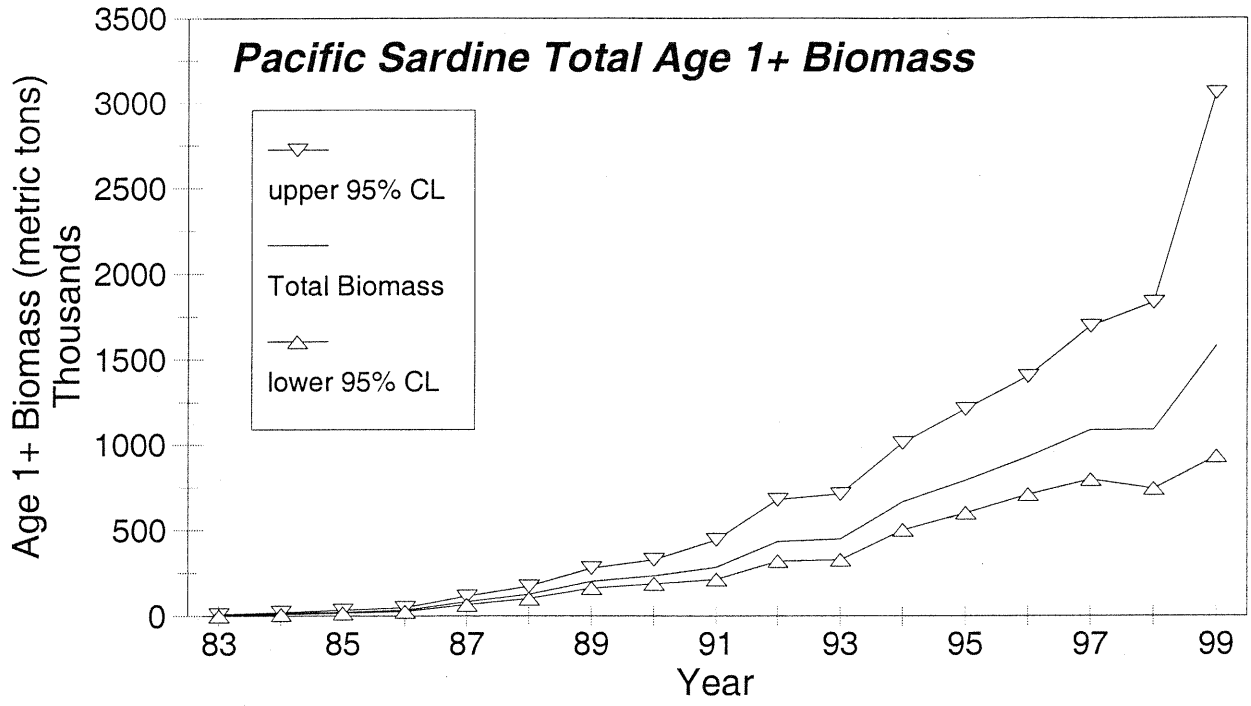

Figure 8. Pacific sardine age 1+ biomass for July 1 of each year, based on CANSAR-TAM.

Pacific Sardine Biomass:

Table 3. Pacific sardine biomass (age 1+, metric tons) and recruitment (age 0) estimated for July 1 of each year estimated by CANSAR-TAM model. Harvest guideline recommendations for 2000 are based on the 'Total' biomass estimate, which theoretically represents the coast-wide stock.

	Age 1+ Biomass (mt)				Age 0 Recruitments ($1x10^3$)		
Year	Inside	**Total**	Lower 95%	Upper 95%	Number	Lower 95%	Upper 95%
83	5,480	**5,480**	3,470	10,396	134,717	89,352	229,798
84	13,597	**13,659**	9,754	22,237	213,707	147,396	347,297
85	21,711	**22,174**	16,809	34,602	216,821	159,990	341,237
86	31,626	**33,130**	26,375	49,177	835,851	618,070	1,238,498
87	77,881	**81,302**	64,847	114,953	851,061	622,096	1,231,753
88	116,013	**125,457**	102,696	171,243	1,518,592	1,115,741	2,312,449
89	181,430	**200,474**	163,224	278,683	1,160,920	842,744	1,840,353
90	198,051	**231,939**	187,548	328,360	4,649,454	3,191,278	7,833,995
91	245,702	**282,620**	213,260	443,835	5,407,115	3,538,532	9,147,414
92	368,123	**434,562**	318,997	678,379	3,891,349	2,535,671	6,797,570
93	345,032	**448,744**	327,303	713,306	8,870,328	6,059,673	14,489,479
94	517,804	**665,697**	501,336	1,013,750	11,433,918	8,076,900	18,422,161
95	583,373	**791,535**	601,469	1,211,808	8,304,507	5,453,404	13,872,792
96	664,949	**931,083**	710,499	1,404,155	10,435,547	6,179,839	18,690,581
97	748,297	**1,087,303**	797,411	1,693,166	10,135,553	5,894,169	18,706,601
98	694,530	**1,090,656**	743,239	1,833,076	23,680,928	13,633,699	48,863,615
99	1,058,807	**1,581,346**	933,155	3,060,895	11,255,893	5,849,691	25,967,093