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Evaluation of the Norway lobster (*Nephrops norvegicus*, L.) resource off the "Serola" bank off Barcelona (western Mediterranean)*

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SUMMARY: The paper describes VPA results for *Nephrops norvegicus* off the Serola Bank (Western Mediterranean) and the yield per recruit of the same exploitable stock using different input parameters of growth and mortality. Also density estimates by swept-area are presented and compared with evaluations by geostatistic methods previously realized on this bank. Results show that in the Norway lobster population off Catalonia there are no signs of high over-exploitation and that the catchability varies considerably between months, decreasing when females are berried during autumn and winter. Values of mean biomass and number, recruits and optimal Y/R, are give for each set of parameters used and for males and females separately.

Key words: N.norvegicus, Mediterranean, fishery, VPA, evaluation, Y/R, population dynamics.

RESUMEN: EVALUACIÓN DEL RECURSO CIGALA (*Nephrops norvegicus*, L.) en el caladero de "Serola" frente a Barcelona (Mediterráneo Noroccidental). — El presente trabajo presenta un VPA como método de evaluación del recurso de *Nephrops norvegicus* en el caladero denominado Serola, frente a Barcelona y también la relación producción por recluta de la misma población utilizando distintos parámetros de crecimiento y mortalidad. Se presenta también una estimación de densidad por el método del área barrida y se compara con datos de estimación por métodos geoestadísticos realizados previamente en la misma zona. Los resultados indican que la población de cigala delante de Barcelona, no presenta síntomas de alta sobreexplotación y que la capturabilidad varía mucho en función de la época del año, decreciendo notablemente en otoño e invierno, período en el cual las hembras están ovadas. Separadamente por sexos se dan valores de biomasa media y número de individuos, reclutas y biomasa óptima de producción por recluta, en función de los distintos parámetros usados.

Palabras clave: N. norvegicus, Mediterráneo, pesquería, VPA, evaluación, Y/R, dinámica de poblaciones.

INTRODUCTION

The *Nephrops* fishery on the "Serola" bank is a traditional fishery developed over several decades between depths of 150 and 300 fathoms off Barcelona (Fig. 1). The biology (growth, moult cycle, reproduction, morphometry, fecundity) of this species in the area have been studied by SARDÀ *et al.* (1981), ABELLÓ and SARDÀ (1982) and SARDÀ (1983, 85, 91). Nevertheless, no previous evaluation or assessment of this stock has been made. Only SARDÀ and FERNÁNDEZ (1981) and SARDÀ and ABELLÓ (1984) present some data about the distribution and abundance of this species in the area. Now, further investigation with a VPA method, applied to this species in other areas (ERIKSON, 1979, 82; ANON., 1991; has been used to evaluate the *Nephrops* stock and to compare it with estimates from the swept area method for a density index. Curves of yield per recruit are also presented and discussed separately by sexes using different growth and mortality parameters.

MATERIAL AND METHODS

Sampling was carried out using a commercial trawler of 750 HP every two months during 1991 on the "Serola" ground (Fig.1).

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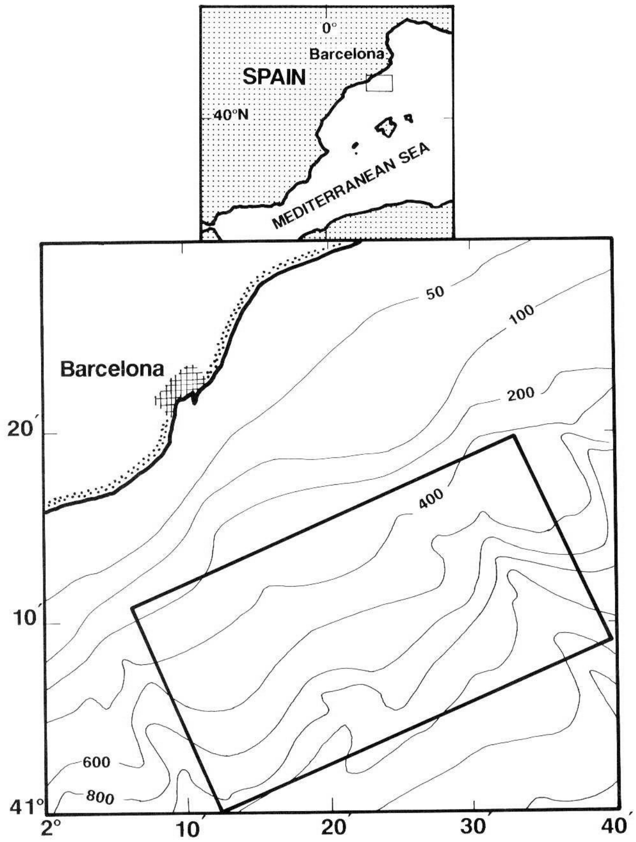

FIG. 1. — Location of the study area. Depth in m.

Von Bertalanffy growth parameters were estimated separately by sex using the size frequency analysis of the total samples using the ELEFAN I computer program (GAYANILO *et al.*, 1988) and applying the method of BHATTACHARYA (1967). Length measurements were carried out over 1-mm size intervals (*CL*: from the end of the orbit of eye to the end of the cephalothorax dorsally). These estimate were also compared with the results obtained previously using direct laboratory methods (SARDÀ, 1985), which have been taken as a basis for comparison for establishing size and age groups in the framework of the programs applied.

Indirect empirical methods (TAYLOR, 1960; RIKHTER and EFANOV, 1976; PAULY, 1980) were employed to produce estimates of natural mortality, and further estimates were obtained by applying the mortality curve calculated from the size structure (RICKER, 1975). Based on the results of the different methods and comparison with the results reported by other authors, the PAULY equation (1980) has been selected as the most representative equation for *Nephrops norvegicus*:

$$\log M = -0.0066 - 0.2791 \log L_\infty + 0.6543 \log K + 0.4634 \log T$$

where L_∞ and K, are parameters of the von Bertalanffy equation, L_∞ is the size in cm and K, is the growth rate; T is the mean temperature on the Norway lobster grounds in the Western Mediterranean, estimated at 13°C (HOPKINS, 1985).

The population dynamics of Norway lobster was studied by means of LCA (Length Cohort Analysis), a VPA (Virtual Population Analysis) based method developed by JONES (1981). As input data it uses length rather than age distributions, and requires the steady-state assumption, allowing the analysis to be carries out without long historical data series. In this analysis the catch equation was employed instead of Pope's one used by JONES (1981). Using the vector of fishing mortalities by length obtained by this procedure, yield per recruit at different effort levels were calculated. Some sensitivity analysis to different values of input parameters, particularly growth and natural mortality, were also done. The analyses were carried out with the VIT programme (LLEONART and SALAT, 1992).

The input parameters were:

- Von Bertalanffy growth parameters (SARDÀ, 1985 and data from the present work)
- Natural mortality (ANON., 1991; and data from this work)
- Length at 50% maturity (SARDÀ, 1991)
- Length-weight relationship (SARDÀ *et al.*, 1981)
- Monthly size frequencies during 1991
- Total landings of 1991 (data from fishermen's associations)

Two sets of growth parameter estimates were used: a) the values calculated by SARDÀ (1985) based on moult growth and the intermoult period in animals kept in captivity in laboratory aquaria and b) the values calculated by applying the method of Bhattacharya to annual frequency values from the samples collected in this experiment.

The basic input parameter values used in the analyses were calculated in accordance with the preceding considerations, yielding:

a) Data from SARDÀ (1985):

Males:	L_∞, 85.0	Females:	L_∞, 68.3 (LC mm)
	K, 0.07		K, 0.10 (years^{-1})
	to, −2.50		*to*, −1.58 (years)

b) Method of Bhattacharya:

Males:	L_∞, 82.0	Females:	L_∞, 70.0 (LC mm)
	K, 0.10		K, 0.10 (years^{-1})
	to, −0.69		*to*, −2.07 (years)

Natural mortality (PAULY, 1980):
Males: $M = 0.398$ Females: $M = 0.416$ (years^{-1})

Natural mortality (ANON., 1991):

Males: $M = 0.2$ Females: $M = 0.2$ (years^{-1})

Length at 50% maturity (SARDÀ, 1991)
Males: $CL = 28$ mm Females: $CL = 32$ mm

Length-weight relationship (SARDÀ *et al.*, 1981)
Males: $a = 0.002754$ Females: $a = 0.002400$ (gr)
$b = 3.12$ $b = 3.26$

The values of landings used in the analysis for the study period were those furnished by the fishermen's associations, increased by 25%, which was the estimate of the proportion of catches not officially accounted for in the harbour. Between September 1990 and September 1991 landings of Norway lobsters at Barcelona harbour were 15000 kg (♂: 8000 kg; ♀: 7000 kg).

Three runs were carried out combining the main parameters, and the results have been set out in Table I for comparison. Sets of size-frequency distributions used are in Appendix I.

Swept-area estimates

The swept-area method covered a total of 140 square miles on the Serola Bank, Norway lobster fishing grounds off Barcelona at depths between 150 and 800 m (Fig. 1). Specifications of trawl gear are in CONAN *et al.* (1992), and SARDÀ *et al.* (1993), haul location and captures are in Appendix II.

The swept-area method for each haul was estimated generally for the purpose of corroborating the geostatistical estimates, using the equation:

$a = D * h * x2$, being $D = v * t$ (SPARRE *et al.*, 1989)

where v is the towing speed in knots, h is the mouth opening of the net (14 m), t is the effective towing time (h), and $x2 \pm 0.5$ (PAULY, 1980) is a factor of catch efficiency.

A total of 59 hauls were made in the study area on the first survey and 62 on the second survey, with an effective swept area of 0.225 square miles per survey. The total surface area of the "Serola" ground was estimated as 144 miles squared.

Geostatistical estimate

The geostatistical estimate is based in the "kriging" method which is explained by CLARK (1979) and was applied in *Nephrops*, as the data base of this work, by CONAN *et al.* (1992). In a theoretical approximation, it consists in analysing and modelling the covariance between sampling units as a function of distance between their locations, and in calculating optimal weights to be attributed to each sampling unit for calculating a predicted average characteristic of a given location to be assessed. Results from CONAN *et al.* (1992) was used with comparing proposes in this paper.

RESULTS

LCA

In Table I global LCA results for males and females, using three sets of natural mortality and growth parameters, are presented. The main features are that males appear to have more biomass and number of individuals than females, and that these results seem not to be very sensitive to the set of parameters used.

From the biomass balance (under the "steady-state" assumption) a rate of annual turnover between 50 and 70% would be expected.

The mean biomass of the stock exploited in equilibrium at the present level would represent between 17 and 35% of the estimated virgin biomass for mortalities of 0.2 and 0.4 respectively.

The Y/R (yield per recruit) analyses show the Norway lobster seems to be exploited near the optimum for natural mortalities near 0.4 for both sexes (Fig. 2c and Fig. 3d). For natural mortalities of 0.2, the stock is overexploited, but since the curves obtained are flat shaped (Fig. 2e,a and Fig. 3f,b), the present Y/R being approximately, 17% under the maximum value for *b, e* and *f* curves (Figs. 2 and 3). The variations in growth parameters for males shows a more sensitive Y/R curve than for females (differences between *a* and other curves). In general it can be considered that overexploitation is light. That means that although effort is high, the exploitation pattern in the part of the fishing mortality vector corresponding to younger ages (selectivity) is not bad regarding resource conservation. Nonetheless, in our judgement, these selectivity results are not attributable to the gear but to the species' burrowing behaviour, since individuals smaller than 20 mm *CL* are practically non-existent in the catches (SARDÀ *et al.*, 1993), even at times of, the year during the recruitment period. However the fishery is probably far from the MSY (maximum sustainable yield).

The VPA for the Norway lobster (*Nephrops norvegicus*) was highly sensitive to the mortality values used (Table I), less so to the growth parameters. The value of 0.2 is considered to be the more accurate

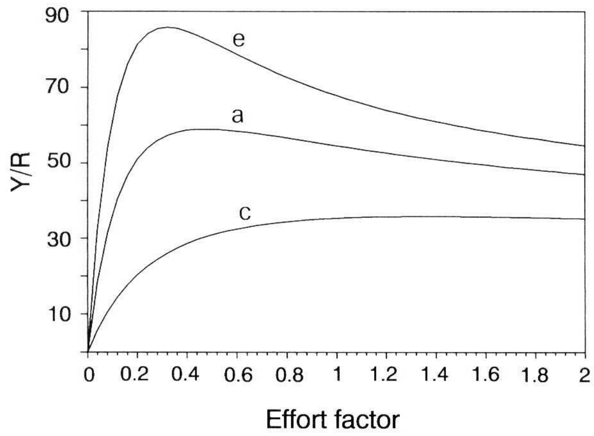

FIG. 2. — Y/R for males. a, c, e, reference curves, explanation in table I.

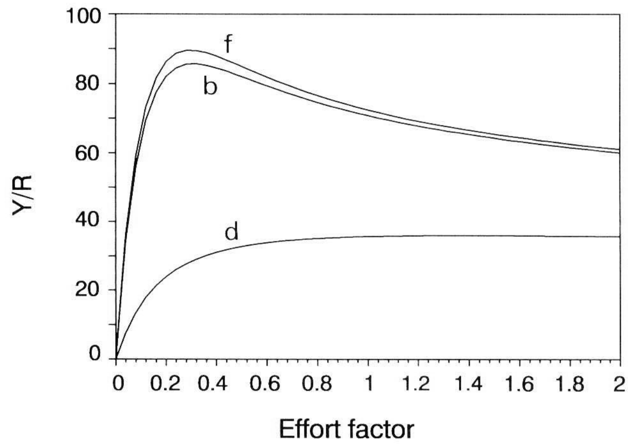

FIG. 3. — Y/R for females. b, d, f, reference curves, explanation in Table I.

natural mortality value for adults, in that it is used by most countries for the North Atlantic and there are no known specific predators on the Norway lobster in the Mediterranean. Higher mortality values yield unrealistic results. Mean biomass values were similar in all the runs performed, though the runs focused on outputs or losses to biomass rather than to inputs. Natural mortality reflected this, and the results were severely affected by changes in natural mortality values.

Given the turnover rate and the mean age of the stock (Table I), probably lower than 3 years, recruitment is quite important to maintain the biomass; the recruitment corresponding to one year would represent, at critical age, around 40% of the stock biomass when $M=0.2$. The densities observed by the swept area method were:

	April	December
No/mile^2	3466	1186
Kg/mile^2	70.6	27.9
No/km^2	1000	343
Kg/km^2	20.4	8.1

TABLE 1.— Output data of VPA and Y/R analysis; *a* to *f*, reference curves in Figs. 2 and 3. *M*, natural mortality; *F mean*, is the mean of fishing mortalities by length weighted according to the effectives of every length class; critical values refer to the length or age at which the cohort biomass reaches its maximum. Y/R, yield per recruit. The optimal factor Y/R is the relative effort corresponding to the maximum of the Y/R vs effort curve.

	Growth parameters from Sardà (1984)		Growth parameters from Bhattacharya (Pauly, 1980)			
	males, a (M = 0.2)	females, b (M = 0.2)	males, c (M = 0.39)	females, d (M = 0.41)	males, e (M = 0.2)	females, f (M = 0.2)
CATCHES (by year)						
Number	67,307	53,366	67,307	53,372	67,307	53,366
Biomass (kg)	8,000	7,000	8,000	7,000	8,000	7,000
Mean length (LC mm)	29.4	27.6	29.4	27.6	29.4	27.6
Mean age (years)	3.6	3.6	3.8	3	3.8	3
POPULATION (annual values)						
Mean annual number	396,394	227,403	399,393	343,214	252,362	216,192
Mean annual biomass (Kg)	24,727	14,797	24,167	20,077	16,280	14,052
Estimated virgin biomass (Kg)	143,872	84,876	76,033	54,205	142,874	82,654
Biomass turnover (%)	52.4	63.7	72.9	76.5	69.1	69.8
Recruits (n°)	146,586	98,847	226,265	196,149	117,779	96,605
Mean length (LC mm)	22.7	21.5	22.4	20.7	23	21.5
Critical length (LC mm)	26	25	26	24	26	25
Mean age (years)	2	2.2	2.6	1.5	2.7	1.6
Critical age (years)	2.7	3	3.1	2.1	3.1	2.3
F mean	0.17	0.235	0.169	0.152	0.267	0.247
Y/R	54.57	70.81	35.35	35.85	67.92	72.46
Optimal factor Y/R	0.42	0.32	1.36	1.36	0.32	0.28

The total estimated biomass in the area (in kg):	9884	3906
Total estimated population in number in the area:	485240	166040

Approximate difference between the two assessments were 40% and the sensitivity analyses show that a 10% increase in effort would not represent excessive pressure on the Norway lobster stock.

Biological ratios observed

	April	December
No. of males	419	194
No. of females	490	89
♂/♀	0.8	2.7
% juvenile ♂/total ♂	32.4	20.1
% juvenile ♀/total ♀	38.6	58.4
% mature ♀/total ♀	33.7	0.0
% ovigerous ♀/total ♀	0.0	14.6
% ovigerous ♀/total adult ♀	0.0	72.1

As shown above, the values of the biological ratios were completely different on the two surveys.

The number of females decreased by 17% between the two surveys, because of ovigerous females that were unavailable to the gear.

For comparative purposes, the following table summarizes the results of the geostatistical method (G.M) assessment (CONAN *et al.*, 1992); the values obtained using the swept-area (S.A.) method appear in brackets for comparison.

	April		December	
	G.M.		G.M.	
No/km^2	915	1000	402	343
Kg/km^2	18.2	20.4	12.0	8.1
Total in no.	447984	485240	196819	166040
Total biomass (in Kg)	8910	9884	5875	3906

The higher geostatistical assessments are considered more reliable, because the method works by extrapolating values on the basis of relative densities and the distance between hauls.

Comparison of the methods employed:

	G.M.	S.A.	VPA*
Mean biomass (in Kg)	7392	9884	37500
Standard deviation	97.9	9584	

* Mean estimate of all sets of analysys from Table I.

DISCUSSION

The differences in the results presented herein are attributable solely to the assessment capacity of each of the methods. The swept-area method is a direct density estimation method. It is subject to a certain tendency towards underestimation, since the availability to the gear in an area is never 100%. The geostatistical method is more sophisticated and is more accurate in that it recalculates density based on abundance and distance between samples. These aspects are evident through standard deviations. Higher values are not unexpected when applying this method, which is extremely useful for spatio-temporal mapping. Both methods have to use "zeros" in the calculations, which accounts for the high standard deviation in the S.A. method.

Results from VPA are not strictly comparable with the other two methods, in as much as they furnish a virtual assessment rather than one based on sampling. As a result, this method is considered to provide better predictions and truer estimates, in that it recalculates each cohort based on mortality, growth, and catch data. This method does not estimate the fishable population but rather the virtually existing population, and at the same time it assesses recruitment. The higher values obtained using this method are considered more accurate estimates of the real population present in an area. The fact that *N. norvegicus* is a species that remains buried in its burrows for long periods could contribute to the differences observed.

The Norway lobster population off the coast of Catalonia would appear to be slightly overexploited. Persistence of this state is due primarily to the species own defensive mechanisms against capture, thanks to its burrowing behaviour, limited activity outside the burrow, and complete inaccessibility of juveniles. The small catch of ovigerous females and the important role of recruitment also contribute to maintenance of the condition of the stock. Catchability varies considerably between months. In months when females are berried (September-December), catches fall sharply; nevertheless, there are inter and intra-monthly variations that are difficult to explain.

On the other hand, large differences have been detected between real monthly landings and landings reported by fishermen's associations. Some landings may not be made at the wharfs, and small Norway lobsters (a considerable proportion of the biomass) are not always invoiced, contributing to these differences.

According SARDÀ *et al.* (1993), the mesh size currently in use in trawl gear is 38 mm, which does not permit escape. A moderate increase in mesh size (to 42-45 mm) would not appear to have a significant effect on escapement by individuals. Larger mesh sizes (52-60 mm) considerably increase the escapement size range ("selectivity range") and would not be effective.

Ensuring that the bottom remains in good condition through the use of gear that does not damage it, but leaves the bottom structure intact is essential to the conservation of this resource.

If a closed season is to be implemented on biological grounds, it should take effect at the time of peak gonadal ripeness in females (July-August), since catchability declines of its own accord due to natural causes during the berried period (September-December).

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APPENDIX 1.— Annual size frequency distribution, used in VPA analysis, for both sexes.

MALES		*FEMALES*	
Lc mm	*n.º*	*Lc mm*	*n.º*
10	0	10	0
11	0	11	0
12	0	12	0
13	0	13	0
14	0	14	0
15	1	15	2
16	3	16	7
17	5	17	20
18	43	18	38
19	65	19	86
20	112	20	140
21	130	21	168
22	209	22	310
23	382	23	417
24	366	24	490
25	435	25	620
26	587	26	651
27	588	27	551
28	532	28	626
29	494	29	512
30	460	30	430
31	379	31	308
32	341	32	229
33	295	33	165
34	230	34	130
35	169	35	74
36	113	36	75
37	89	37	61
38	95	38	45
39	72	39	25
40	45	40	19
41	38	41	16
42	41	42	6
43	39	43	4
44	12	44	5
45	5	45	5
46	19	46	2
47	19	47	1
48	14	48	0
49	8	49	0
50	12	50	0
51	8		
52	14		
53	11		
54	2		
55	2		
56	1		
57	3		
58	2		
59	0		
60	0		
61	0		
62	1		
63	0		
64	0		
65	0		
Total	6491	Total	6238

APPENDIX 2.— Data of captures used for swept-area method.

	APRIL				*DECEMBER*			
N	*Haul (Km)*	*Depth (m)*	*N/Km*	*Kg/Km*	*Haul (Km)*	*Depth (m)*	*N/Km*	*Kg/Km*
1	2.27	645	1,511	27.9	1.19	426	62	1.2
2	1.29	646	1,792	28.9	1.24	415	0	0
3	0.91	676	2,213	40.9	0.75	1,054	0	0
4	0.62	648	5,294	102.2	1.06	530	70	1.7
5	0.75	266	0	0	1.14	896	0	0
6	0.92	686	1,052	1	1.51	728	589	7.8
7	0.82	468	90	1.8	1.11	746	533	19.3
8	0.70	583	2,638	56	0.99	609	2,562	50.4
9	1.08	332	0	0	1.44	732	672	10.3
10	1.06	557	981	26.6	1.89	673	433	10.6
11	0.76	484	97	1.4	1.24	792	239	5.9
12	1.01	448	0	0	0.57	830	2,599	94.2
13	0.84	869	440	18.5	1.07	1,030	0	0
14	0.93	494	79	1.7	0.99	1,068	150	0.7
15	1.09	540	204	5.4	1.1	512	68	0.6
16	0.91	596	1,063	17.1	1.02	525	146	5.8
17	0.97	557	460	7.6	0.8	609	464	11.1
18	0.93	368	0	0	1.09	741	68	0.3
19	0.73	744	1,516	32.5	1.11	657	200	8
20	1.12	539	993	21.1	1.57	775	520	21.2
23	1.18	785	63	3.3	1.18	1,001	252	5
24	1.07	466	0	0	1.39	521	54	1.3
25	1.21	609	2,270	52.1	1.4	702	1,535	33.8
26	0.87	753	5,203	102.3	0.99	543	1,199	17.9
27	1.50	662	1,334	16	1.7	814	481	13.9
28	2.36	509	94	1.7	0.95	717	779	29.2
29	0.97	753	3,763	53.7	0.96	1,010	231	4.6
30	1.14	664	259	9.7	0.87	1,290	0	0
31	0.93	702	2,312	43.8	1.02	603	73	1.8
32	0.83	832	978	22.2	1.54	916	0	0
33	1.06	720	140	2.5	0.8	605	1,577	33.8
34	0.97	635	3,604	118.8	0.98	1,120	0	0
35	1.08	654	690	10.3	1.07	713	209	8.7
36	1.08	753	896	15.5	0.91	755	162	1.6
37	1.27	537	176	5.8	1.15	843	62	1.6
38	0.90	576	82	2.4	1.02	635	876	16
39	1.13	693	262	6.5	1.26	459	295	5.8
40	0.79	722	3,827	65.3	1.37	506	271	5.4
41	1.10	663	1,423	35.2	1.34	786	55	0.2
42	0.94	779	1,651	22	1.06	710	70	5.2
43	0.79	777	658	18.8	0.83	549	0	0
44	0.23	1,024	0	0	1.96	658	0	0
45	0.77	939	96	1.4	1.15	444	0	0
46	0.97	997	0	0	1.32	1,134	0	0
47	0.73	878	1,114	23.7	1.11	1,116	0	0
48	1.07	1,015	138	2.4	1.49	1,006	50	3.7
49	0.85	976	262	5.6	1.11	732	67	1.6
50	0.61	803	11,845	217.5	1.20	768	124	1.2
51	0.88	942	419	7.3	0.98	860	152	10.6
52	0.45	1,079	0	0				
53	0.66	403	672	18.6				
54	3.39	1,059	0	0				
55	6.15	1,077	0	0				
56	5.27	1,264	0	0				
57	1.65	829	946	22.5				
58	0.99	938	1,507	26.3				
59	2.49	856	1,195	20				