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Estimation of Abundance of Shrimp (*Pandalus borealis*) from Stratified Random Surveys - Problems of Variation in Distribution and Availability

by

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Abstract

A time/depth stratification design was used for shrimp in the Cartwright Channel during the July 1983 research cruise. Results showed that shrimp were generally more abundant in depths between 400 and 500 m and between 0800 and 1600 hrs (NST). Because of variation in the data, the temporal and spatial differences were difficult to demonstrate statistically (analysis of variance).

To obtain reliable estimates of biomass, a large sample size is necessary, especially for areas where abundance and variation in catches are high. It may be more expedient to sample the shallow, less productive strata at night, allowing more time during daylight hours to sample the strata where shrimp concentrations are high.

Résumé

Au cours de la campagne par navire de recherche de juillet 1983, on a utilisé un modèle de stratification temps/profondeur pour les crevettes du chenal Cartwright. Les résultats démontrent que ces dernières sont en général plus abondantes aux profondeurs comprises entre 400 et 500 m et aux heures de 0800 à 1600 (HN de T.-N.). Les différences temporelles et spatiales ont été difficiles à démontrer statistiquement (analyse de la variance), à cause de la variation des données.

Pour obtenir des estimations fiables de la biomasse, il faut un échantillon important, surtout dans les régions où les prises sont très variables. Il serait peut-être plus commode d'échantillonner les couches peu profondes et moins riches la nuit, ce qui donnerait plus de temps aux heures de clarté pour échantillonner les couches où les concentrations de crevettes sont élevées.

Introduction

Indices of shrimp abundance from research surveys off Labrador often are limited as indicators of stock status due to extreme variation associated with mean values. Initially, systematic line surveys were employed but, after more accurate descriptions of bottom topography became available, the stratified random design was adopted. Even with intensive sampling in recent years, mean estimates of biomass have been characterized by extremely wide confidence intervals.

In 1983, the Invertebrates and Marine Plants Subcommittee of CAFSAC proposed that the method of estimating biomass should be improved in order to reduce variability. Consequently, during the 1983 shrimp survey off Labrador, time was allotted to address this problem. An area in the Cartwright Channel (Div. 2J) was chosen to provide data on the changes in shrimp distribution in time and space. This was done in addition to the 'routine' stratified random survey.

The data are analyzed and presented here to demonstrate the difficulties in constructing a survey design which will provide representative estimates or even indices of stock size. These difficulties fall into two general categories: 1) statistical - defining an appropriate algorithm amenable to accepted statistical analyses and 2) practical - deploying a research vessel, crew and scientific staff to the study area for a limited amount of time to collect enough information to satisfy the requirements of 1) above.

Materials and Methods

Depths greater than 300 m in the Cartwright Channel (Fig. 1) were surveyed to observe differences in shrimp distribution. Three depth strata were considered, 301-400 m, 401-500 m, and greater than 500 m. A total of 32 sets were made in these depths, 10, 10 and 12, respectively, as part of the standard stratified random design. These subsequently were broken down within depth strata into three time intervals, 0001-0800 hrs (NST), 0801-1600 hrs, and 1601-2400 hrs. Eight additional random positions were selected for sampling so that each time/depth cell contained at least three observations. Details for the 40 sets are given in Table 1.

Depths greater than 300 m were chosen because shrimp are more abundant at these depths. The three strata are combinations of the original 50 m interval design. Three time intervals were chosen because diel variation in availability of shrimp previously has been demonstrated (e.g. Allen 1959; Barr 1970, Carlsson et al. 1978 and Parsons and Sandeman 1981). Generally, shrimp are more available to bottom trawls in the daytime. Two eight-hour intervals adjacent to the 0800-1600 hr interval were selected to represent periods of reduced availability. Other than this general guideline, the selection of precise intervals was subjective.

Standard, 30-minute survey sets were made at each station using the Sputnik 1600 shrimp trawl lined in the codend with 13 mm mesh. The net was towed in a northerly direction at 3 knots using a 3:1 warp/depth ratio. The catch was sorted by species and each major species was weighed and measured.

Biomass was estimated by areal expansion according to the method of Smith and Somerton (1981). Catch data for time/depth factors were subjected to analyses of variance following the General Linear Models procedure of SAS. These analyses were conducted on the original catch data and ranked data. Time effects in each depth interval were tested by the Kruskal-Wallis single factor analysis of variance by ranks.

Results

Distribution of catches from the 40 time/depth sets over the 24-hour cycle (Fig. 2) shows that, generally, catches are more variable between 1200 and 2200 hrs. Average catches from 2200-1000 hrs were lower and less variable (with the exception of one large set at 0115 hrs). Some of the variation can be explained by differences in abundance between depth strata. Catches obtained between 301 and 400 m were less than 25 kg (Fig. 3, 115.61 kg at 0115 hrs not included) and showed greatest variation between 1200 and 1600 hrs. At 401-500 m, catches were less than 30 kg before 1200 hrs but generally higher and more variable between 1200 and 2400 hrs (Fig. 4). In the deepest stratum, most catches were less than 40 kg throughout the day (Fig. 5). Two peak catches of approximately 100 kg each occurred between 1300 and 1600 hrs followed by a decline to 2400 hrs. Average catches per time/depth cell are given in Fig. 6.

Estimates of biomass from the original depth stratification and from the time/depth stratification are given in Table 2. The 24-hour sampling produced an estimate of 694 tons with upper and lower confidence intervals (95%) of 916 and 472 tons, respectively. The 0001-0800 hr interval resulted in a much lower mean estimate of 394 tons. Variance was extremely high in the most shallow depth stratum due to the inclusion of the exceptionally large set mentioned previously. This resulted in a wide confidence range, 1179 and -391 tons. During the period around midday (0801-1600 hrs), catch rates were higher in the two deeper strata. The mean biomass estimate was 713 tons with confidence limits of 1158 and 267 tons. The estimate for the afternoon to midnight period (1601-2400 hrs) dropped to 590 tons with confidence intervals of 803 and 377 tons, but the estimate for the 401-500 m stratum (399 tons) was higher than in the other two periods.

Actual catch data and corresponding ranks for analyses of variance are given in Table 3. Using catch data, values of F were not significant ($\alpha = 0.05$) for either time or depth factors but the interaction of factors was significant (Table 4). Because assumptions of normality and homoscedasticity likely were violated using the actual catch data, it was decided to rank all data from lowest to highest to provide a more 'robust' analysis, eliminating the effects from making such assumptions (Conover, 1980). Values of F suggest no significant time effects, significant depth effects and no interaction effects ($\alpha = 0.05$). The Kruskal-Wallis tests (Table 5) indicated no significant time effects in either the 301-500 m or >500 m strata but time effects were significant for the 401-500 m stratum.

Discussion

Both the raw catch data and biomass estimates suggest that differences in abundance (or availability) existed due to time effects and depth effects. Generally, shrimp were more abundant in the research trawl between 0800 and 1600 hrs. and at depths ranging from 401 to 500 m. This observation is consistent with findings for shrimp stocks in many other areas in that most demonstrate some distributional changes with time and depth. Because of the variation inherent in the data from the Cartwright Channel, it is difficult to demonstrate these differences by conventional statistical methods. Parametric tests are inconclusive, likely because the underlying assumptions of the methods are violated. Two factor ranking procedures demonstrated some depth differences but time differences only could be found in the 401-500 m stratum using single factor analysis of variance by ranks. Based on the variable nature of the data, the non-parametric tests must be considered more appropriate. The unfortunate element in using statistical analyses is that when one is determined to find differences (or similarities), one generally will. A more objective observation might suggest that, if a few anomalously high data points are not considered, then the analysis (statistical or interpretive) would most certainly show differences due to both time and depth.

Another problem in analysing the data involves the initial selection of time intervals. The assumption that the 0801-1600 hr interval adequately represented the period of maximum availability was not entirely accurate. Data from the study showed that an eight hour period from 1200-2000 hrs might have been a better choice. However, rather than grapple with the problems of post-stratified design, at this point, it was decided to analyse the data as originally intended. This may account for the failure to demonstrate time differences for the more shallow and deepest strata.

The estimates of biomass are enlightening in that the mean value obtained from the 32 sets of the original depth stratification (694 t) is very similar to that of the 0801-1600 hr time interval (713 t). Confidence limits are within 32% of the former but within 62% of the latter. The more precise estimate is likely due, in part, to a greater sample size (32 vs 15).

Conclusion

The following conclusions were made considering both the practical and statistical difficulties outlined earlier. Because of the large variance associated with catches of shrimp from any defined stratum in the Cartwright Channel, it is desirable to obtain as large a sample size as possible to reduce that variance. This was evident when comparing the original estimate to that from the period of 'optimum availability'. Abundance usually is less in shallow water and variance at these depths, although significant in itself, will not greatly affect the confidence in the 'total' estimate. Therefore, these depths, or any depths where shrimp are comparatively scarce, should be sampled at night, perhaps between 2200-0600 hrs (depending on area and time of year). Other depths, where more biomass is found and catches are more variable, should be sampled during the daytime. Although it is general practice to distribute random fishing positions according to the area of the individual strata, it would be more beneficial in the case of shrimp (and likely other species as well), to sample more intensively in strata where most variation is encountered, particularly where abundance is relatively high.

This approach would require some flexibility in the survey design in that if conditions were radically different from those antipicated, some reassignment of random stations would be necessary. Indeed, the approach would require much closer supervision than that required in the more 'routine' surveys.

Other alternatives have been proposed in past meetings which can be considered here. Daytime sampling, only, has been proposed but is not considered appropriate for three reasons. Firstly, 'daytime' is difficult to define and, as shown here, time of high abundance can extend well into the 'night'. Secondly, sample size would be greatly reduced, likely resulting in even less reliable estimates and, thirdly, it would be a waste of valuable vessel time.

Increasing the length of tow to one hour might reduce variance somewhat, but it is not likely worth the trade-off in reduced sample size. Extending the length of tow would reduce the total number of samples taken by 35-40%.

The use of conversion factors is another way to improve the method by adjusting catches to time of 'optimum' availability. At present no reliable conversion factors exist and preliminary investigations suggest that diel patterns are, themselves, so variable that using conversion factors may create more harm than good.

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Table 1. Set details for fishing stations used in time/depth stratification, Cartwright Channel, 1983.

Set No.	Month	Day	Time NST	Depth (m)	Latitude	Longitude	Catch (kg)
2	7	8	1223	444	5422.6	5557.5	57.34
3	7	8	1348	486	5424.6	5557.5	97.52
4	7	8	1530	496	5424.2	5556.7	57.15
5	7	8	1742	327	5420.4	5552.3	4.41
11	7	9	542	339	5421.7	5551.8	2.72
12	7	9	708	319	5424.9	5551.5	6.09
13	7	9	839	427	5426.5	5556.2	28.68
15	7	9	1530	379	5423.3	5554.4	13.89
16	7	9	1717	472	5427.4	5556.9	111.01
17	7	9	1913	535	5426.7	5602.0	32.06
18	7	9	2104	529	5428.1	5604.4	23.78
19	7	9	2316	524	5428.7	5610.3	3.96
20	7	10	132	496	5429.6	5606.0	6.10
21	7	10	310	492	5431.6	5607.9	12.25
22	7	10	454	487	5432.7	5611.5	11.79
24	7	10	810	564	5438.4	5615.3	15.16
25	7	10	957	581	5438.1	5619.1	7.48
26	7	10	1155	519	5436.8	5622.4	13.59
27	7	10	1323	570	5440.8	5620.7	99.90
28	7	10	1520	569	5442.4	5616.5	100.12
29	7	10	1720	528	5440.5	5613.4	37.89
30	7	10	1924	482	5441.1	5607.0	81.02
31	7	10	2126	432	5439.7	5600.7	76.61
32	7	10	2325	457	5438.0	5603.9	28.66
33	7	11	115	365	5439.9	5557.1	115.61
39	7	11	1355	304	5438.6	5552.8	7.89
40	7	11	1527	373	5435.1	5558.2	4.42
41	7	11	1702	428	5436.3	5558.2	61.69
42	7	11	1834	370	5435.0	5556.9	4.54
50	7	12	1218	324	5428.4	5551.2	16.11
51	7	12	1427	383	5430.5	5556.6	24.64
52	7	12	1557	412	5429.8	5557.0	32.21
53	7	12	1736	322	5432.5	5552.8	0.34
54	7	12	1950	489	5430.7	5607.4	22.05
55	7	12	2135	510	5429.9	5609.0	17.13
56	7	12	2331	576	5437.5	5617.1	12.89
57	7	13	218	474	5429.5	5601.9	15.58
58	7	13	345	432	5434.5	5600.7	8.16
59	7	13	457	424	5438.1	5559.2	20.87
60	7	13	659	527	5437.8	5610.8	50.68

Table 2. Biomass estimates for shrimp, Cartwright Channel, 1983.

Time	Depth	No. Sets	Area sq.n mi	Av. wt/ set (kg)	Variance	Biomass (t)	95% C.I.	
							Upper	Lower
24-hour sampling	301-400	10	171.40	20.03	1175.41	92		
	401-500	10	114.50	63.19	819.92	351		
	>500	12	131.00	30.34	1163.58	250		
	Total	32	416.90			694	916	472
0001-0800	301-400	3	171.40	41.47	4125.02	191		
	401-500	3	114.50	14.87	40.76	83		
	>500	4	131.00	20.20	420.61	120		
	Total	10	416.90			394	1179	-391
0801-1600	301-400	5	171.40	13.39	61.22	62		
	401-500	5	114.50	54.58	757.32	303		
	>500	5	131.00	47.25	2327.92	348		
	Total	15	416.90			713	1158	267
1601-2400	301-400	3	171.40	3.10	5.72	14		
	401-500	5	114.50	71.80	902.21	399		
	>500	7	131.00	21.39	131.09	177		
	Total	15	416.90			590	803	377

Table 3. Data used in two-factor analyses of variance for time/depth stratification design in the Cartwright Channel, 1983. (Ranks in brackets.)

Depth	Time 0001-0800		Time 0801-1600		Time 1601-2400	
301-400	2.72	(2)	13.89	(16)	4.41	(4)
	6.09	(7)	7.89	(10)	4.54	(6)
	115.61	(40)	4.42	(5)	0.34	(1)
			16.11	(19)		
			24.64	(24)		
401-500	15.58	(18)	57.34	(32)	111.01	(39)
	8.16	(11)	97.52	(36)	81.02	(35)
	20.87	(21)	57.15	(31)	76.61	(34)
			28.68	(26)	28.66	(25)
			32.21	(28)	61.69	(33)
>500	6.10	(8)	15.16	(17)	32.06	(27)
	12.25	(13)	7.48	(9)	23.78	(23)
	11.79	(12)	13.59	(15)	3.96	(3)
	50.68	(30)	99.90	(37)	37.89	(29)
			100.12	(38)	22.05	(22)
					17.13	(20)
					12.89	(14)

Table 4. Results of analyses of variance for time/depth stratification design in the Cartwright Channel, 1983.

Source	DF	SS	MS	F	Pr>F	r^2	C.V.
A. Catch Data							
Model	8	18260.40	2282.55	2.66	0.0238	0.41	87.16
Error	31	26585.93	857.61		$\sqrt{MSE}$		$\bar{y}$
Corrected total	39	44846.33			29.28		33.60
Source							
Time	2	998.74		0.58	0.5646		
Depth	2	4539.94		2.65	0.0868		
Time x Depth	4	9912.15		2.89	0.0383		
B. Ranks							
Model	8	2556.22	319.53	3.57	0.0048	0.48	46.14
Error	31	2773.78	89.48		$\sqrt{MSE}$		$\bar{y}$
Corrected total	39	5330.00			9.46		20.50
Source							
Time	2	276.50		1.55	0.2293		
Depth	2	1304.17		7.29	0.0025		
Time x Depth	4	713.82		1.99	0.1199		

Table 5. Results of Kruskal-Wallis single factor of analyses of variance by ranks for time effects at different depths.

Depth (m)	Source	DF	SS	MS	F	Pr>F	r^2	C.V.
301-500	Model	2	40.13	20.07	2.30	0.1627	0.36	49.25
	Error	8	69.87	8.73		$\sqrt{MSE}$		$\bar{y}$
	Corrected total	10	110.00			2.96		6.00
401-500	Model	2	105.60	52.80	6.91	0.0130	0.58	39.49
	Error	10	76.40	7.64		$\sqrt{MSE}$		$\bar{y}$
	Corrected total	12	182.00			2.76		7.00
>500	Model	2	29.59	14.80	0.62	0.5533	0.09	57.49
	Error	13	310.41	23.88		$\sqrt{MSE}$		$\bar{y}$
	Corrected total	15	340.00			4.89		8.50

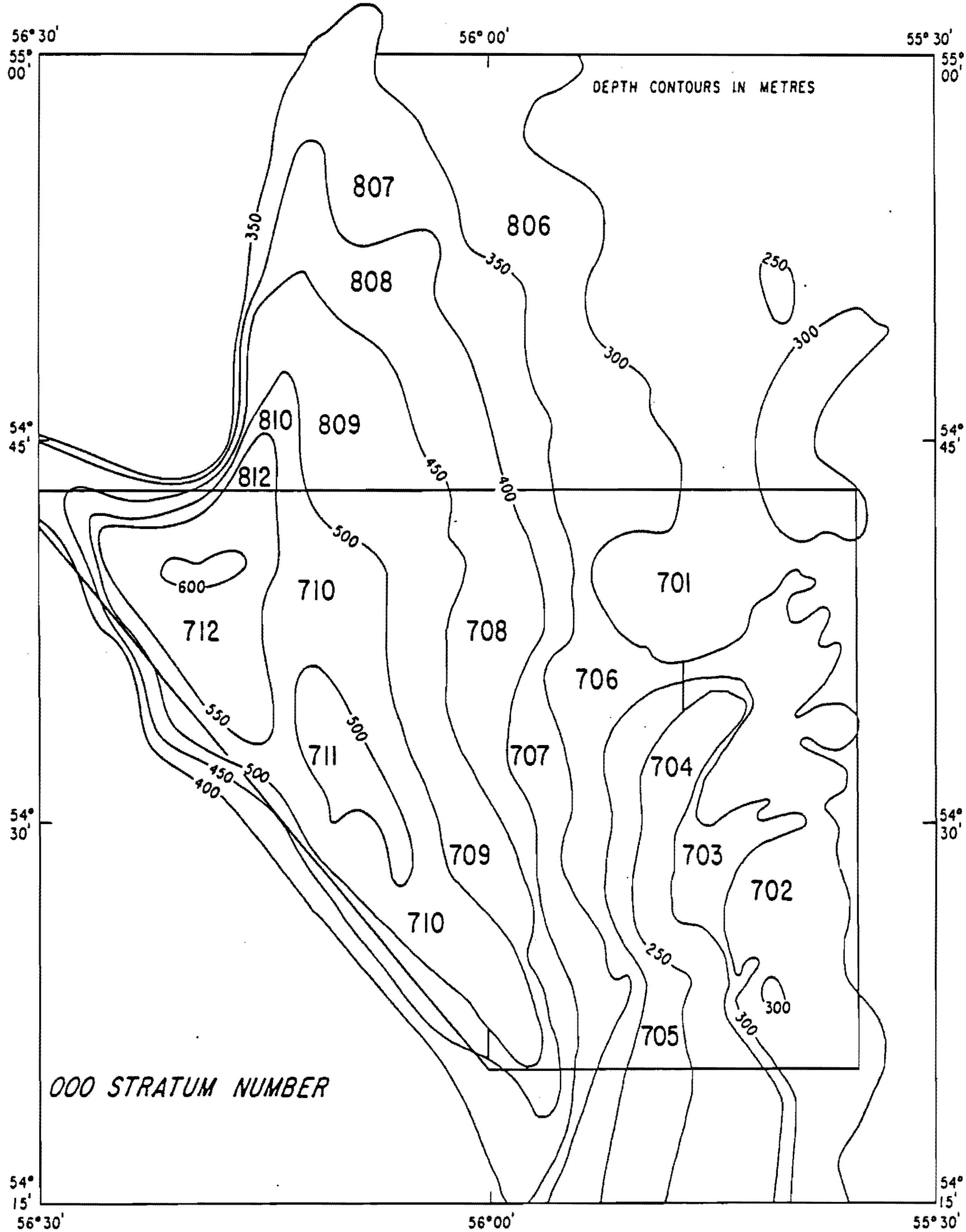

Fig. 1 Stratification of the Cartwright Channel.

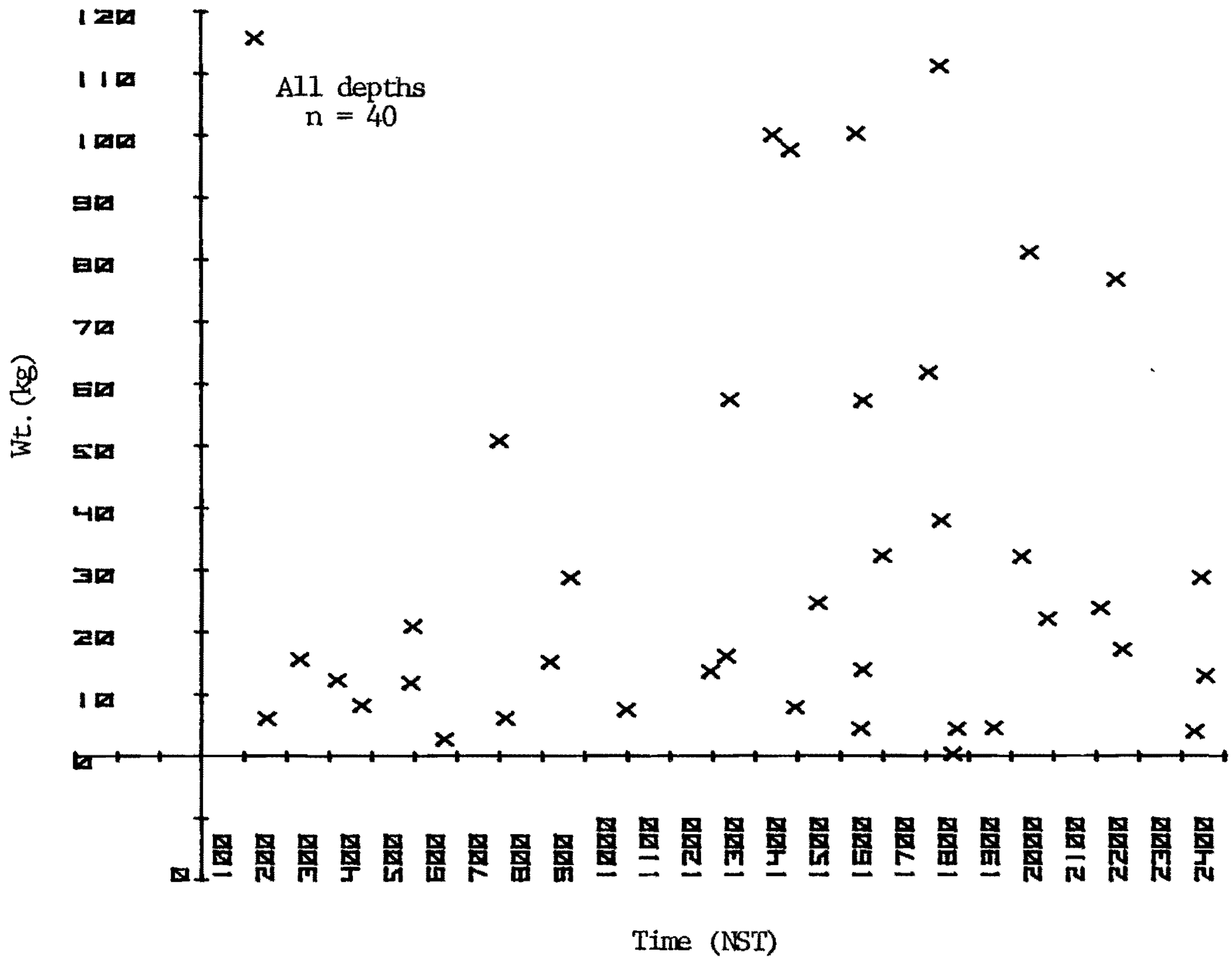

Fig. 2. Distribution of shrimp catches over time, Cartwright Channel, 1983.

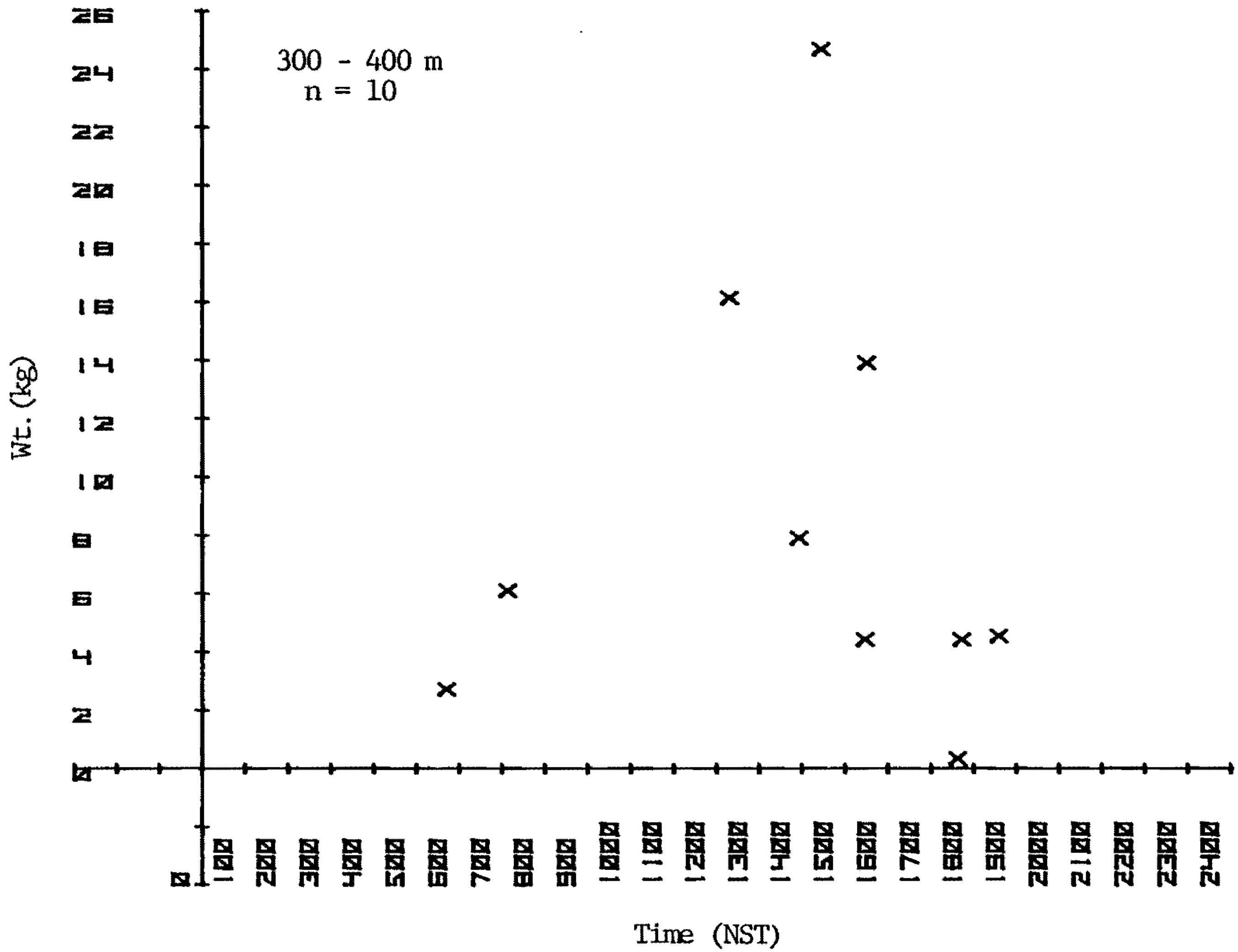

Fig. 3. Distribution of shrimp catches over time in the 300 - 400 m stratum, Cartwright Channel, 1983.

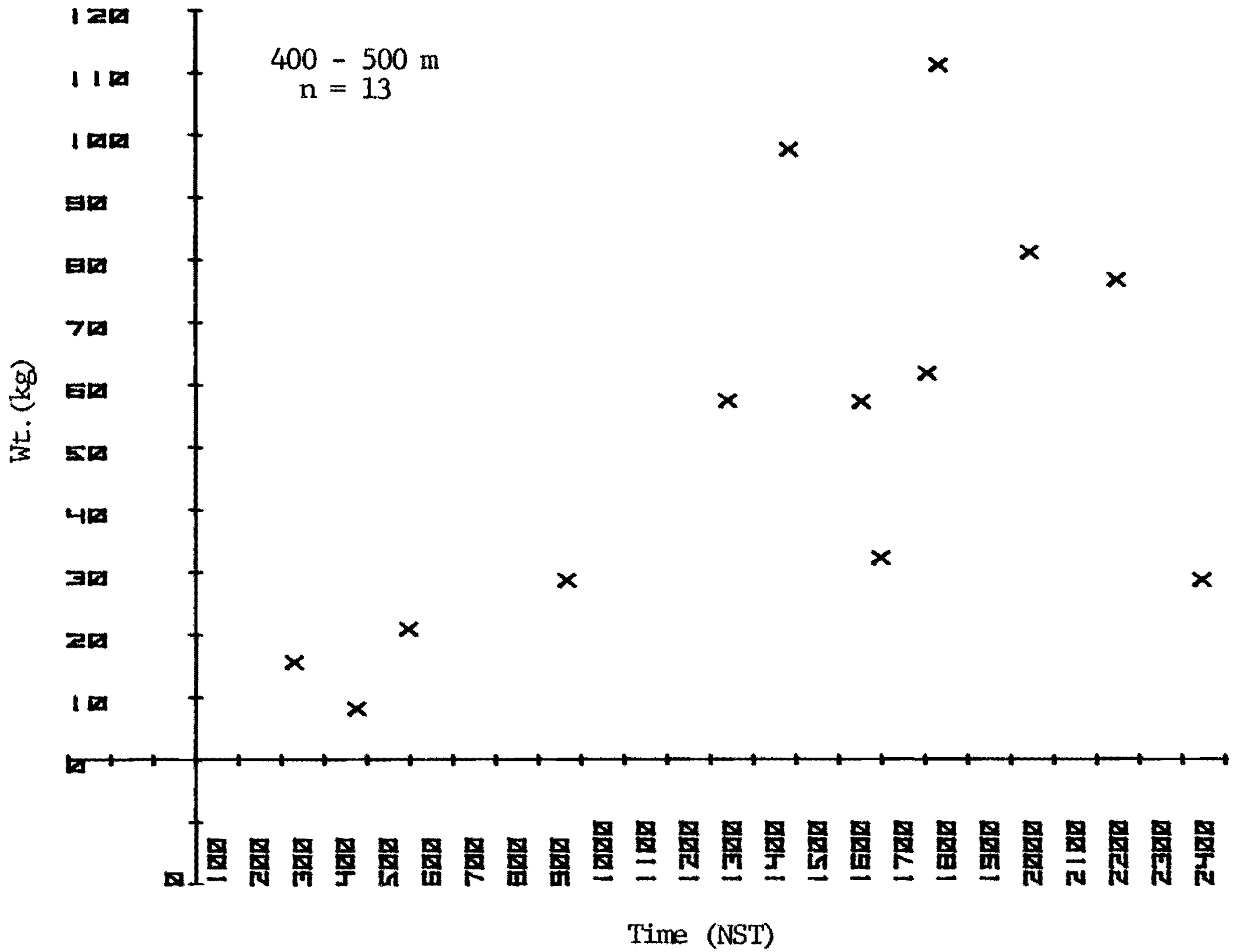

Fig.4. Distribution of shrimp catches over time in the 400 - 500 m stratum, Cartwright Channel, 1983.

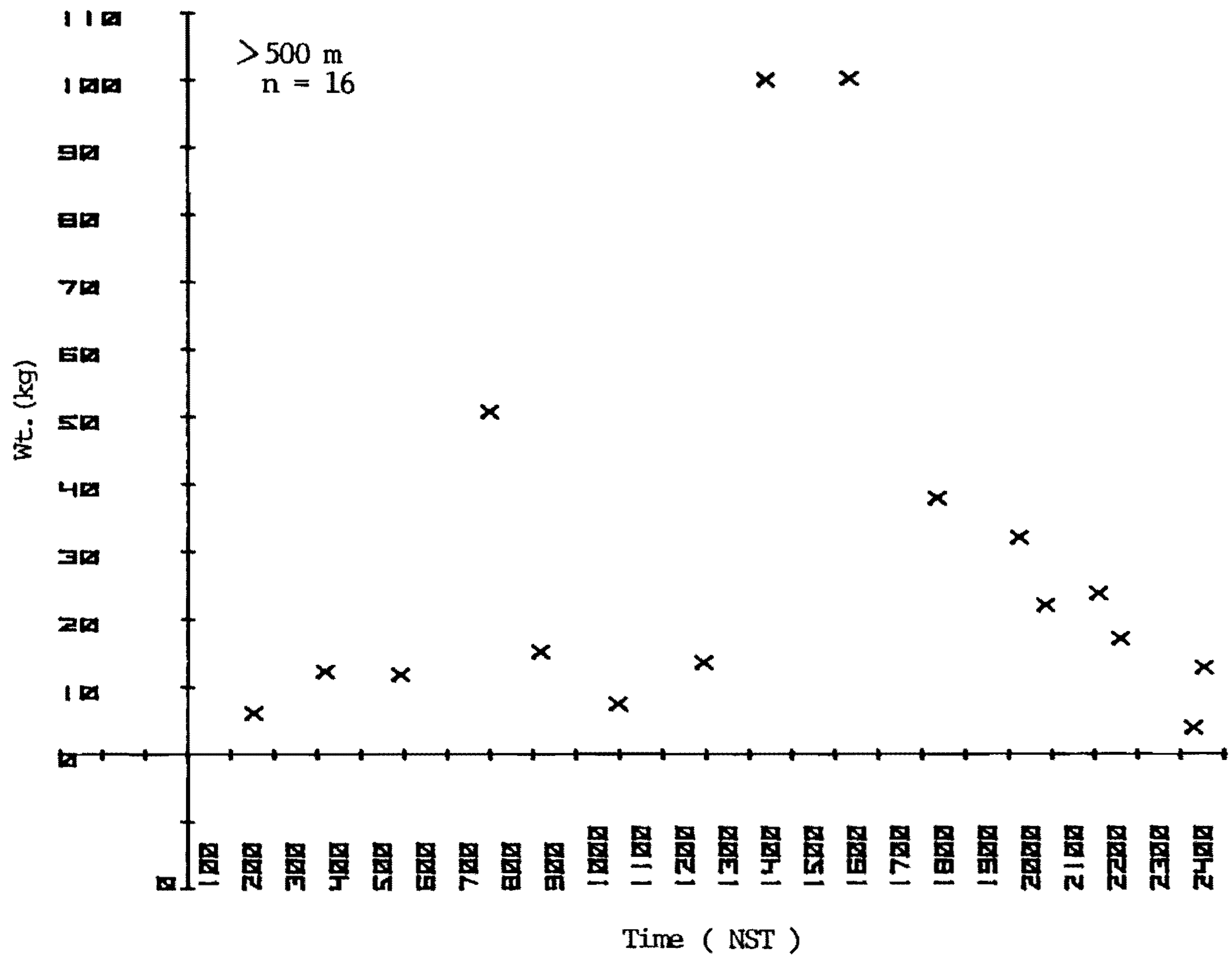

Fig. 5. Distribution of shrimp catches over time in the >500 m stratum, Cartwright Channel, 1983.

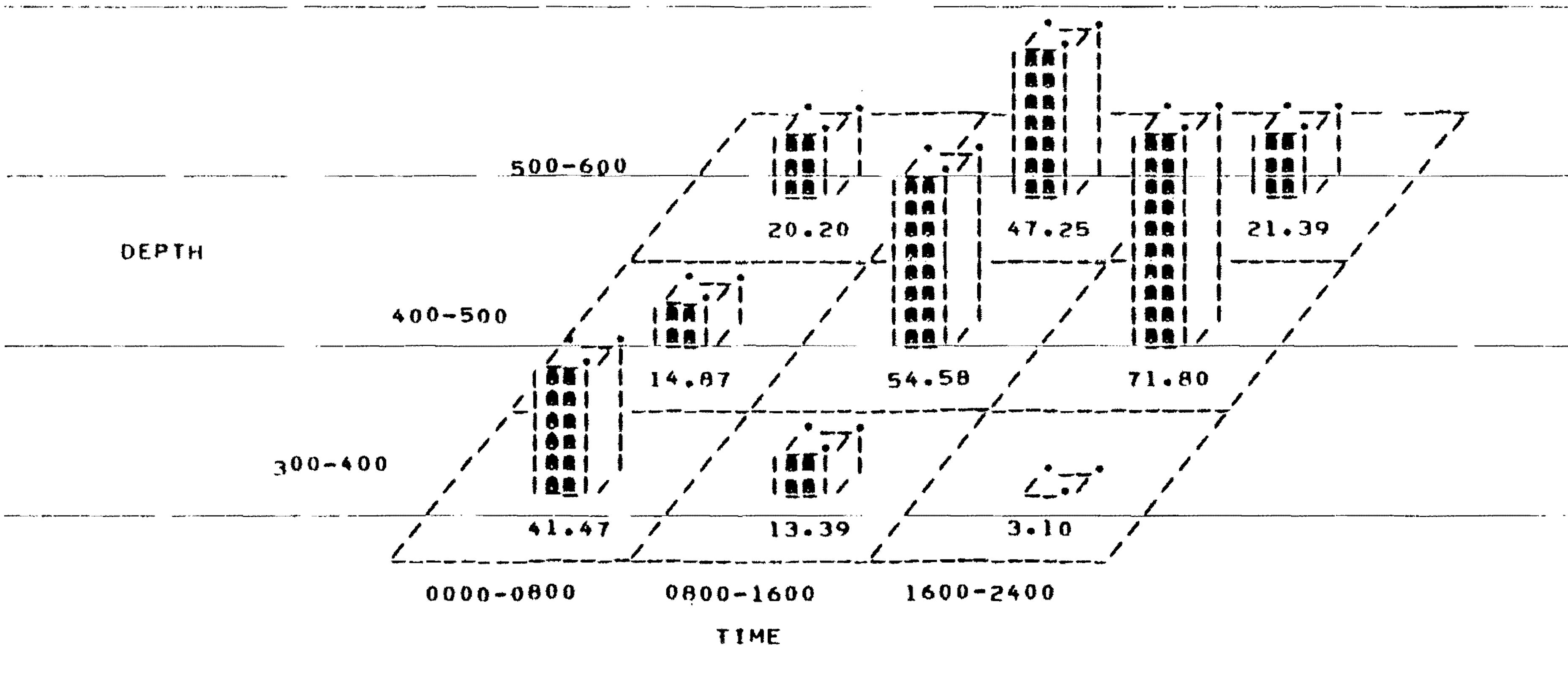

Fig. 6. Average catch (kg) per time (NST)/depth (m) cell, Cartwright Channel, 1983.