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An examination of the effect of alternative pooling strata in the estimation of abundance in the Antarctic minke whale.

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ABSTRACT

This paper presents the results of an investigation aimed to assess the effect of different pooling of sighting data on the estimation of abundance in the Antarctic minke whale. Sighting data from the 2nd and 3rd circumpolar IDCR/SOWER surveys were used in this investigation (DESS). Analysis of Variance (ANOVA) was conducted to test for significant difference in perpendicular distance or school size between groups stratified by survey mode, vessel, year or whether stratum is South or Norh. There was significant difference in perpendicular distance and school size between South and North strata, whereas there were no significant differences between survey vessels (except in the 1985/86 and 1986/87 surveys). It was concluded that, except in these two surveys, strata can be pooled longitudinally in each latitudinal stratum rather than stratified by vessels. Abundance estimates for the minke whales in the second and the third circumpolar IDCR/SOWER cruises were re-calculated using the pooling option suggested from the results of ANOVA. Preliminary results suggest that Antarctic minke whale abundance in the 3rd circumpolar are underestimated due, in part, to pool strata inadequately.

INTRODUCTION

At IWC Scientific Committee meeting last year, for various reasons it was suggested that pooling might better be done longitudinally. This issue was addressed in Branch and Butterworth (2001) , where it was noted that pooling strata by vessels had the lowest AIC, and vessels tended to survey in both the north and the south strata. However, it was agreed that this would be worth investigating further, particularly since mean school size is thought to be smaller in the north strata than in the south strata (IWC, 2002).

It is necessary to pool strata in order to estimate perpendicular distance and mean school size if there are not sufficient sightings. In general, pooling two or more groups that have different nature would bias estimates. This raise one question on pooling strata to estimate abundance how we should pool strata in order to estimate abundance more preciously. Branch and Butterworth (2001) pooled strata across vessel in case pooling strata is necessary because pooling across vessels had the lowest Akaike's Information Criteria (AIC) (Akaike, 1973). Burt and Stahl (2000; 2001) pooled all strata to estimate perpendicular distance and mean school size in estimating the minke whale abundance from IWC/SOWER in 1997/98 and 1998/99.

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For three reasons written below, we compared pooling strata longitudinally (i.e. pool strata that classified as North strata and pool strata that classified as South strata, Classification is shown in Table 1) to other pooling aproach using ANOVA. One is that mean school size is expected smaller in north strata than in south strata. This is supported by a fact that immature males have tendency to form smaller school and to distribute in north strata, whereas mature males tend to forms larger schools and to distribute in south strata, suggested by the results of logistic regression analyses applied to JARPA data (Fujise *et al.*, 1999). Second is that sighting ability of two vessels expected to be almost same because *Shonan Maru No.1* (*SM1*) and *Shonanmaru No.2* (*SM2*) have same type of platforms. Third is that it was suggested that weather condition is worse in north strata than in south strata (Murase et at., 2002).

Examinations in this study consist of two parts. One is examination of pooling approach. Second, we estimated the abundance using alternative pooling approach supported by results of ANOVA and compared these estimate to previous estimates.

MATERIALS AND METHODS

Data

We used sighting data for IWC/IDCR-SOWER from 1985/86 to 1998/99 contained in database package DESS (IWC Database-Estimation System Software v 3.1, Strindberg and Burt 2000). In this study, we used perpendicular distance of detections of Antarctic minke within 1.5 n.miles from transect line and we only used school size data in closing mode and whose estimate was confirmed in order to consistent with data set used for abundance estimation using 'standard methodology' (Branch and Butterworth, 2001; Burt and Hughes, 2002).

Factor

We examined factor which expected to affect average of perpendicular distances and school size. We examined factors; year, mode, vessel, period and NS. Definition of each factor is following;

year: seasons sighting was made (1985/86-1998/99)
mode: Survey mode. (closing mode or passing mode)
vessel: Vessels used. (*SM1*, *SM2* and *K27*[2])
period: We divide survey period in each year into the first half of a survey and the second half of a survey. The first half is defined as a period in which vessels surveys western part of the survey area in each year except 1987/88, 1989/90 and 1996/97. The second half is defined as a period in which vessels surveys eastern part of the survey area in each year except 1987/88, 1989/90 and 1996/97. In these years, the first half is defined as a period in which vessels surveys eastern part of the survey area in each year. The second half as defined similarly.
NS: N is north strata and S is south strata. Classification of N and S is listed in Table 1.

ANOVA

As for average perpendicular distance, we examined five factors; year, survey mode (closing mode or passing mode), vessel (*SM1*, *SM2* or *Kyo Maru No.27* (*K27*)), period (first half or second half of the survey) and NS (north strata or south strata). First, ANOVA was applied to data sets of perpendicular

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[2] *K27* was involved in IWC/IDCR surveys in 1979/80,1980/81 and 1983/84-1986/87. From 1987/88, two vessels (*SM1* and *SM2*) have been involved in the surveys (Matsuoka *et al.*, 2001)

distance for each year. Following model was applied to data sets in each year;

$$(\text{PerpDist})_{j,k,l,m} = \mu + (\text{mode})_j + (\text{vessel})_k + (\text{period})_l + (\text{NS})_m + \varepsilon \qquad (1)$$

where $(\text{PerpDist})_{j,k,l,m}$ is average of perpendicular distance for factor (i, j, k, m), μ is average for all data and ε is error. As mentioned in the RESULTS, results of ANOVA were not always consistent with each other years. Therfore, we applied following model to data sets in the 2nd /3rd circumpolar. It was applied to part of the data, if necessary. The model was written by

$$(\text{PerpDist})_{j,k,l,m} = \mu + (\text{year})_i + (\text{mode})_j + (\text{vessel})_k + (\text{period})_l + (\text{NS})_m + \varepsilon \qquad (2).$$

As for mean school size, we examined four factors; year, vessel, period and NS. ANOVA was applied for this examination. First, we applied ANOVA to data of school size in each year. Statistical model was described by fomula folloing;

$$(\text{SchoolSize})_{k,l,m} = \mu + (\text{vessel})_k + (\text{period})_l + (\text{NS})_m + \varepsilon \qquad (3).$$

where $(\text{SchoolSize})_{k,l,m}$ is average of school size for factor (k, l, m). μ and ε are same as in formula (1). Similar to the case of perpendicular distance, we applied data sets in the 2nd/ 3rd circumpolar. Model was described by

$$(\text{SchoolSize})_{i,k,l,m} = \mu + (\text{year})_i + (\text{vessel})_k + (\text{period})_l + (\text{NS})_m + \varepsilon \qquad (4).$$

Interactions of the factors were not considered in this study.

Abundance estimate

In order to examine effects on abundance estimate of alternative pooling supported by the results of ANOVA, we compared previous estimate (Branch and Butterworth, 2001; Burt and Stahl, 2001). We did not pool strata in Prydz bay and south strata, though we classified strata in Prydz bay (i.e. BN and BS in 1988/89 and Prydz in 1994/95) as south strata, because there was sufficient number of sightings to estimate esw and mean school size in each stratum and it is not necessary to pool them with other south strata. Methods of abundance estimation were described in Branch and Butterworth (2001).

First, we estimated abundance both in closing mode and in passing mode and then we calculated inverse-variance weighted average of the abundance in pseudo-passing mode (i. e. abundance estimate in closing mode divided by correction factor R) and that in passing mode. Secondary, we compare these values to previous estimates. In order to make abundance estimate in this study comparable to previous estimates, we assume correction factor R=0.826 (CV=0.089) (Branch and Butterworth, 2001) for the surveys except 1998/99. For 1998/99 surveys, it is assumed R=0.751 (CV=0.152) (Haw, 1991). R reflects the ratio of minke whale school density estimates in closing mode compared to passing mode.

RESULTS

Perpendicular distance

Table 2 shows p-values for each factor with respect to perpendicular distance for each season from 1985/86 to 1998/99. The p-values less than 0.05 indicate that there was significant difference among the groups. There was tendency to the factor 'NS' affected average of perpendicular distance more than the factor 'vessel' did, but results of ANOVA were not always consistent among years. Table 3 shows results of ANOVA for the second circumpolar and the third circumpolar. There was significant difference among the year and between south strata and north strata. There was significant difference among vessels in the second circumpolar. Significant differences among vessels were observed in 1985/86 and 1986/87 surveys because three vessels (*SM1*, *SM2* and *K27*) conducted sighting survey, while two vessels (*SM1* and *SM2*) conducted sighting survey in the 2nd and the 3rd circumpolar except 1985/86 and 1986/87. Therefore, ANOVA were applied to data set in the 2nd circumpolar excluding 1985/86 and 1986/87. From the results of table 3, significant difference between North strata and South strata was observed whereas that among vessels was not observed. It can be concluded that strata should be pooled longitudinally rather than pooled by vessels to estimate an esw for IWC/IDCR-SOWER survey data after 1986/87.

School size

Table 4 shows p-values for each factor with respect to school size for each season from 1985/86 to 1998/99. The p-values less than 0.05 shows there was significant difference among the groups. Results of ANOVA were not always consistent among years. Table 4 shows results of ANOVA for the second circumpolar and the third circumpolar. There is significant difference among the vessels in the 3rd circumpolar. But, by excluding the data in 1991/92 survey whose coverage is insufficient in north strata, there observed significant difference between south strata and north strata. Reason for excluding 1991/92 data was discussed later. There was no significant difference among the vessels and between south strata and north strata in the 2nd circumpolar. But there is tendency that p-value for the factor NS is lower than that for the factor of vessels.

Adequate pooling approach

From these results, it was suggested that strata should be pooled longitudinally except 1985/86 and 1986/87 surveys. For these two surveys, strata should not be pooled longitudinally or not stratified by vessels. With respect to 1985/86survey, abundance should be estimated for each stratum separately. There were enough sightings in each stratum to estimate perpendicular distance for each stratum separately. As for 1986/87, because there were not enough sightings in each stratum, strata must be pooled. On one hand, significant difference among three vessels in perpendicular distance was observed, while significant difference between south strata and north strata was not observed. Therefore, we pooled across vessels for 1986/87 surveys.

Abundance estimation

Table6 shows abundance estimate from 1985/86 to 1998/99 estimated in this study. Fig. 1 shows perpendicular distance and detection function. These figures illustrate distributions of perpendicular and esw are different between south strata and north strata. Table 7 shows comparison of abundance estimate using different pooling approach. We didn't compare abundance estimate from 1985/86 and 1986/87 because we adopted same pooling approach as Branch and Butterworth (2001). Increase of abundance estimate is ranged from –9.2% to 46.6% of previous estimate due to alternative pooling approach. It was suggested that selection of pooling approach regarded as one of factors that might affect abundance estimate.

DISCUSSION

Reason for excluding school size data in 1991/92

In this year, only south of 66S was surveyed in longitudinal band between 165E and 170W. EN was located south of 66S and north of 71S. This means EN should be treated as south strata. But we treated this stratum as north strata in this study because if EN were treated as south strata, there would not be sufficient number of sightings to estimate esw in north strata. By treating EN as north strata, mean school size in north strata would be more than that in south strata. For this reason, the school size data in 1991/92 was exceptional. Therefore, 1991/92 data were excluded from data set in the 3rd circumpolar.

Restriction on pooling approach due to small number of sightings in each stratum.

We consider the case where results of ANOVA suggest that strata should not be pooled and some of strata don't have sufficient number of sightings to estimate esw and mean school size. In this case, strata must be pooled, even though results of ANOVA suggest that strata should not be pooled. This kind of problem also occurs when we select pooling approach by AIC (Branch and Butterworth, 2001).

Factors that have contributed to the change in IWC/IDCR-SOWER abundance estimates

Abundance estimate in this study does not consider factors that have contributed to the change in IWC/IDCR-SOWER abundance estimates other than real change in abundance (Appendix 8 of IWC, 2002); coverage of Management Area, location of ice edge, timing of survey, proportion of animals in south of ice edge, school size distribution, proportion of sightings classified as "like-minke" probability of observing animals on the track line and bias of closing mode estimates compared to passing mode. Some of these factors have been examined (Shimada et al., 2002a; 2002b; Okamura et al, 2002). Abundance estimate that these factors were not taken into account should be revised by taking them into account in future.

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Table 1. Classification of north strata and south strata adopted in this study.

year	north strata	south strata
1985/86	WN,WM, EN, EM	WS, ES
1986/87	WN. EN, EM	WS1, WS2, WS3, WBAY, EBAY, ES1, ES2
1987/88	WN, EN	WS, ES
1988/89	WN, EN	WS, ES, BN, BS
1989/90	WN, EN	WS, ESBAY
1990/91	WN, EN	WS, ES
1991/92	WN, EN	WS, ES
1992/93	WN, EN	WS, ES
1993/94	WN, EN	WS, ES
1994/95	WN, EN	WS, ES, PRYDZ
1995/96	WN, EN	WS, ES
1996/97	WN, EN	WS, ES
1997/98	WN, EN1, EN2	WS, ES1, ES2
1998/99	WN, EN	WS, ES

Table 2. Results of ANOVA for perpendicular distance for each year. Numbers are p-value. p-value less than 0.05 (significant level) indicates there is significant difference among the factor.

a) 2nd circumpolar

	8586	8687	8788	8889	8990	9091
mode	0.135	0.044	0.529	0.001	0.012	0.826
vessel	$p < 0.001$	$p < 0.001$	0.966	0.008	0.007	0.007
period	0.285	0.001	0.244	0.617	0.012	0.579
NS	$p < 0.001$	0.961	0.857	0.002	0.423	0.660

b) 3rd circumpolar

	9192	9293	9394	9495	9596	9697	9798	9899
mode	0.072	0.465	0.064	0.267	0.417	0.390	0.174	0.253
vessel	0.067	0.398	0.107	0.930	0.710	0.011	0.922	0.791
period	0.621	0.777	0.133	$p < 0.001$	0.448	0.798	0.741	0.039
NS	0.025	0.580	0.004	0.298	0.557	0.250	0.655	0.007

Table 3. Results of ANOVA for perpendicular distance in the 2nd and the 3rd circumpolars. Numbers are p-value. p-value less than 0.05 (significant level) indicates there is significant difference among the factor.

	CPIII	CPII	CPII(*)	CPII+III	CPII+III(*)
year	$p < 0.001$	0.20647	0.726	$p < 0.001$	$p < 0.001$
mode	0.644	$p < 0.001$	$p < 0.001$	$p < 0.001$	0.005
vessel	0.068	0.004	0.532	0.001	0.075
period	0.066	$p < 0.001$	0.003	0.013	0.500
NS	0.027	0.001	0.032	$p < 0.001$	0.001

*: excluding data in 1985/86 and 1986/87 surveys (see in text).

Table 4. Results of ANOVA for school size for each year. Numbers are p-value. p-value lees than 0.05 (significant level) indicates there is significant difference among the factor.

a) 2nd circumpolar

	8586	8687	8788	8889	8990	9091
vessel	0.125	0.580	0.643	0.564	0.082	0.699
period	0.544	0.356	0.244	0.211	0.011	0.620
NS	0.063	0.164	0.811	0.894	0.873	0.496

b) 3rd circumpolar

	9192	9293	9394	9495	9596	9697	9798	9899
vessel	0.002	0.844	0.323	0.139	0.067	0.699	0.702	0.551
period	0.006	0.930	0.047	0.405	0.255	0.481	0.384	0.066
NS	0.413	0.315	0.425	0.171	0.264	0.023	0.005	0.142

Table 5. Results of ANOVA for school size in the 2nd and the 3rd circumpolars. Numbers are p-value. p-value less than 0.05 (significant level) indicates there is significant difference among the factor.

	CPIII	CPIII(**)	CPII	CPII+III
year	0.026	0.042	0.048	0.020
vessel	0.016	0.363	0.743	0.889
period	0.022	0.264	0.253	0.370
NS	0.266	0.004	0.270	0.234

**: excluding data in 1991/92 surveys (see in text).

Table 6 Revised Antarctic minke whake abundance in the south of 60°S by pooling option suggested by the results of ANOVA in this study.

a) 2[nd] circumpolar

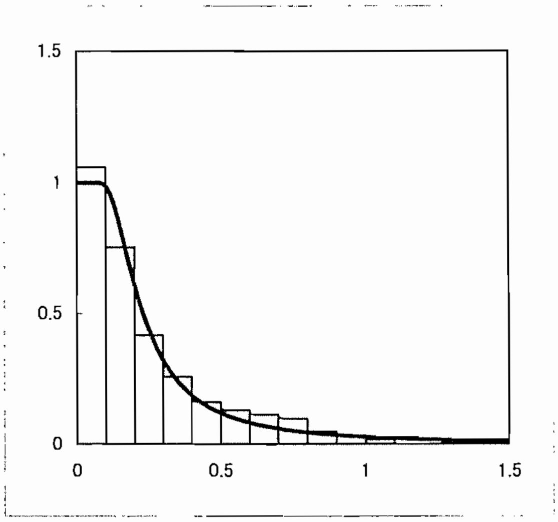
YEAR	AREA	STRATUM	MODE	A	n	L	n/L	CV	E(s)	CV	Ws	CV	P	CV
8586	V	EN	closing	279611	38.0	865.3	0.044	0.414	3.20	0.222	0.362	0.260	54,314	0.537
		WN		139065	19.0	566.7	0.034	0.516	1.93	0.184	0.304	0.297	14,787	0.624
		EM		165912	96.3	735.0	0.131	0.255	2.69	0.143	0.605	0.152	48,238	0.330
		WM		166349	27.5	354.0	0.078	0.498	1.91	0.196	0.458	0.355	27,007	0.642
		ES		107717	137.6	763.4	0.180	0.189	3.08	0.098	0.537	0.107	67,562	0.266
		WS		104814	44.7	767.6	0.058	0.248	3.55	0.216	0.625	0.140	17,267	0.358
8586	V	EN	IO	279611	69.4	884.4	0.079	0.325	3.20	0.222	0.702	0.157	49,939	0.424
		WN		139065	44.0	386.8	0.114	0.379	1.93	0.184	0.310	0.230	49,273	0.480
		EM		165912	155.6	1063.5	0.146	0.347	2.69	0.143	0.742	0.096	43,937	0.388
		WM		166349	42.6	492.0	0.087	0.593	1.91	0.196	0.355	0.273	38,583	0.682
		ES		107717	178.5	739.2	0.241	0.276	3.08	0.098	0.426	0.109	101,590	0.317
		WS		104814	109.1	662.0	0.165	0.147	3.55	0.216	0.812	0.214	37,886	0.338
8687	II	ES1	closing	23142	7.0	179.0	0.039	0.548	2.82	0.113	0.369	0.173	3,453	0.585
		WS1		10270	11.0	81.8	0.134	0.275					5,268	0.344
		WS2(K27)		21143	4.0	193.8	0.021	0.267					2,180	0.239
		WS3(K27)		79605	62.0	783.8	0.079	0.343					22,869	0.550
		EN		124057	62.1	538.2	0.115	0.339	2.23	0.122	0.551	0.293	54,864	0.400
		EBAY		15242	13.0	106.4	0.122	0.382					3,758	0.497
		ES2		44975	42.6	565.8	0.075	0.301					6,834	0.438
		WBAY		11505	18.6	92.2	0.202	0.742					4,693	0.806
		WN		95361	3.0	315.6	0.010	0.444					1,829	0.546
		EM		69908	34.6	474.4	0.073	0.309	1.92	0.109	0.526	0.144	9,073	0.356
		WS2(SM2)		21143	4.0	193.8	0.021	0.267					465	1.016
		WS3(SM2)		79605	62.0	783.8	0.079	0.343					12,706	0.452
8687	II	ES1	IO	23142	25.0	348.6	0.072	0.526	2.82	0.113	0.367	0.177	6,368	0.567
		WS1		10270	10.0	103.7	0.096	0.384					3,801	0.438
		WS2(K27)		21143	5.8	280.5	0.021	0.611					2,521	1.107
		WS3(K27)		79605	87.2	920.2	0.095	0.234					27,527	0.327
		EN		124057	47.6	427.7	0.111	0.448	2.23	0.122	0.663	0.188	52,920	0.495
		EBAY		15242	35.9	125.8	0.286	0.367					7,275	0.430
		ES2		44975	100.7	722.0	0.139	0.245					10,501	0.333
		WBAY		11505	28.4	74.2	0.382	0.188					7,368	0.645
		WN		95361	0.0	201.0	0.000	0.000					0	0.000
		EM		69908	72.7	447.0	0.163	0.265	1.92	0.109	0.571	0.194	18,612	0.346
		WS2(SM2)		21143	5.8	280.5	0.021	0.611					457	0.411
		WS3(SM2)		79605	87.2	920.2	0.095	0.234					13,010	0.453
8788	III	ES	closing	87677	8.0	454.9	0.018	1.038	3.93	0.281	0.404	0.259	7,496	1.106
		WS		74351	59.8	623.5	0.096	0.429					34,648	0.574
		WN		148821	10.4	450.4	0.023	0.948	5.67	0.272	0.170	1.456	57,590	1.758
		EN		168881	3.0	540.7	0.006	0.416					15,656	1.538
8788	III	ES	IO	87677	30.6	660.1	0.046	0.513	3.93	0.281	0.560	0.119	14,275	0.597
		WS		74351	143.1	617.9	0.232	0.141					60,401	0.336
		WN		148821	25.6	365.1	0.070	0.355	5.67	0.272	0.461	0.434	64,025	0.623
		EN		168881	9.0	546.1	0.016	0.394					17,112	0.646
8889	IV	EN	closing	181166	498.8	7.0	0.014	0.333	4.19	0.225	0.234	0.537	22,608	0.671
		WN		156617	701.9	13	0.019	0.761					25,793	0.958
		ES		52441	310.3	26.9	0.087	0.339	3.60	0.240	0.727	0.237	11,227	0.478
		WS		58693	273.8	22.9	0.096	0.324					13,996	0.467
		BN		17486	231	7.0	0.030	0.719	2.93	0.171	0.318	0.319	2,448	0.805
		BS		6520	87.4	14.0	0.160	0.267					4,823	0.450
8889	IV	EN	IO	181166	617.5	17.0	0.028	0.247	4.19	0.225	0.279	0.638	37,385	0.720
		WN		156617	730	1.0	0.001	1.115					1,608	1.304
		ES		52441	244	43.5	0.178	0.263	3.60	0.240	0.970	0.131	17,341	0.379
		WS		58693	245.7	23.0	0.094	0.320					10,181	0.421
		BN		17486	396.8	23.8	0.060	0.252	2.93	0.171	0.832	0.185	1,847	0.356
		BS		6520	144.5	48.5	0.335	0.763					3,853	0.804
8990	I	WN	closing	168761	26.6	560.4	0.048	0.292	1.88	0.128	0.364	0.239	20,726	0.399
		EN		153029	36.4	679.7	0.054	0.264					21,199	0.378
		WS		45128	64.0	602.2	0.106	0.201	2.25	0.076	0.564	0.125	9,578	0.249
		ESBAY		62594	23.7	587.9	0.040	0.324					5,035	0.355
8990	I	WN	IO	168761	31.4	606.7	0.052	0.324	1.88	0.128	0.534	0.184	15,351	0.394
		EN		153029	45.0	750.2	0.060	0.257					16,153	0.341
		WS		45128	185.1	830.9	0.223	0.229	2.25	0.076	0.663	0.096	17,071	0.260
		ESBAY		62594	65.3	793.1	0.082	0.468					8,749	0.484
9091	VI	WN	closing	211788	5.0	479.7	0.010	0.232	2.00	0.213	0.415	0.859	5,314	0.915
		EN		191954	6.6	193.0	0.034	0.456					15,843	0.996
		WS		45414	6.0	304.1	0.020	0.419	3.08	0.176	0.527	0.197	2,623	0.495
		ES		108268	40.0	476.6	0.084	0.281					26,602	0.385
9091	VI	WN	IO	211788	12.0	563.7	0.021	0.389	2.00	0.213	0.444	0.239	10,165	0.504
		EN		191954	22.0	473.6	0.046	0.635					20,103	0.712
		WS		45414	36.1	645.9	0.056	0.228	3.08	0.176	0.596	0.222	6,569	0.363
		ES		108268	19.0	476.3	0.040	0.516					11,164	0.589

b) 3rd circumpolar

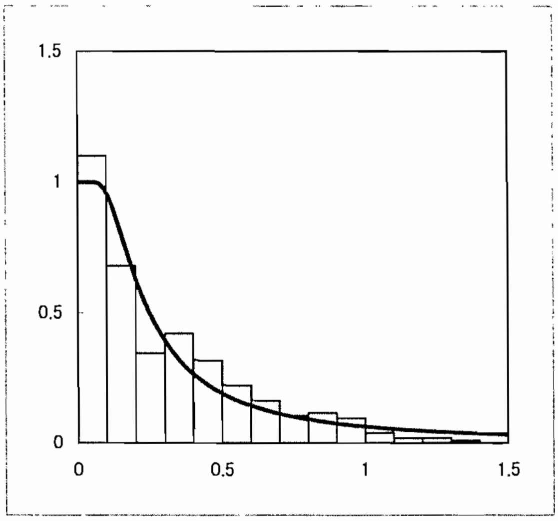
YEAR	AREA	STRATUM	MODE	A	L	n	n/L	CV	E(s)	CV	Ws	CV	P	CV
9192	V	EN	closing	165,429	434.0	76.2	0.176	0.210	2.53	0.096	0.499	0.208	73,638	0.311
		WN		137,734	345.0	3.0	0.009	0.348					3,038	0.417
		ES		82,039	645.7	48.6	0.075	0.030	1.44	0.089	0.448	0.362	9,925	0.481
		WS		58,643	278.1	12.0	0.043	0.346					4,068	0.509
9192	V	EN	IO	165,429	574.8	113.9	0.198	0.230	2.53	0.096	0.649	0.154	63,876	0.293
		WN		137,734	310.3	10.0	0.032	0.691					8,650	0.714
		ES		82,039	687.5	77.0	0.112	0.417	1.44	0.089	0.793	0.096	8,337	0.437
		WS		58,643	456.4	123.3	0.270	0.456					14,380	0.474
9293	III W	EN	closing	150,547	498.2	6.0	0.012	0.391	1.54	0.251	0.163	0.500	8,551	0.576
		WN		210,035	648.9	9.0	0.014	0.235					13,738	0.607
		ES		23,207	380.2	7.7	0.020	0.437	1.57	0.079	0.596	0.187	616	0.482
		WS		61,527	879.4	81.0	0.092	0.193					10,296	0.293
9293	III W	EN	IO	150,547	603.0	12.0	0.020	0.483	1.54	0.251	1.097	0.106	2,101	0.554
		WN		210,035	755.6	32.0	0.042	0.444					6,232	0.521
		ES		23,207	408.8	17.0	0.042	0.340	1.57	0.078	0.545	0.153	1,392	0.381
		WS		61,527	981.2	152.0	0.155	0.211					18,119	0.225
9394	I	EN	closing	293,196	819.4	4.0	0.005	0.981	1.57	0.151	0.431	0.139	2,614	1
		WN		251,735	583.8	17.0	0.029	0.313					13,388	0.375
		ES		72,249	457.2	33.8	0.074	0.241	1.67	0.120	0.533	0.339	8,364	0.433
		WS		50,596	501.7	25.6	0.051	0.276					4,046	0.453
9394	I	EN	IO	293,196	762.5	11.0	0.014	0.642	1.57	0.151	0.322	0.313	10,348	0.73
		WN		251,735	550.2	8.0	0.015	0.267					8,953	0.438
		ES		72,249	598.1	72.2	0.121	0.363	1.67	0.120	0.470	0.117	15,480	0.4
		WS		50,596	566.6	52.0	0.092	0.216					8,235	0.273
9495	III E	EN	closing	146,681	523.8	5.0	0.010	0.396	1.25	0.200	0.147	0.655	5,953	0.791
		WN		148,803	463.8	3.0	0.007	0.850					4,092	1.091
		ES		60,046	439.7	19.8	0.045	0.540	2.47	0.129	0.526	0.284	6,346	0.624
		WS		51,938	414.3	15.6	0.038	0.339					4,597	0.46
		PB		21,096	210.7	18.0	0.085	0.255	1.54	0.140	0.772	0.157	1,796	0.33
9495	III E	EN	IO	146,681	630.7	20.0	0.032	0.514	1.25	0.200	0.58	0.333	5,011	0.644
		WN		148,803	457.9	15.1	0.033	0.412					5,287	0.566
		ES		60,046	459.5	36.9	0.080	0.432	2.21	0.120	0.763	0.111	7,809	0.464
		WS		51,938	496.4	35.0	0.071	0.375					5,922	0.412
		PB		21,096	203.5	40.0	0.197	0.296	1.54	0.140	0.754	0.082	4,232	0.338
9596	VI W	EN	closing	242,073	490.8	27.5	0.056	0.369	2.42	0.127	0.648	0.328	25,307	0.51
		WN		97,945	246.6	6.0	0.024	0.775					4,451	0.851
		ES		72,349	506.7	31.7	0.063	0.290	1.88	0.093	0.676	0.151	6,287	0.34
		WS		34,051	403.3	25.8	0.064	0.299					3,020	0.347
9596	VI W	EN	IO	242,073	554.6	21.0	0.038	0.374	2.42	0.127	0.504	0.332	21,964	0.516
		WN		97,945	281.8	10.8	0.038	0.251					9,001	0.435
		ES		72,349	561.8	40.6	0.072	0.258	1.88	0.093	0.671	0.164	7,301	0.32
		WS		34,051	335.6	10.0	0.030	0.574					1,418	0.605
9697	II E	EN	closing	241,928	588.2	14.0	0.024	0.541	1.65	0.103	0.353	0.350	13,435	0.653
		WN		113,687	262.3	8.0	0.030	0.331					8,089	0.493
		ES		67,072	563.6	26.4	0.047	0.383	1.86	0.108	0.778	0.325	3,764	0.514
		WS		23,028	154.5	6.0	0.039	0.844					1,070	0.911
9697	II E	EN	IO	241,928	672.2	14.0	0.021	0.221	1.65	0.103	0.247	0.864	16,801	0.898
		WN		113,687	201.6	8.0	0.040	0.626					15,045	1.072
		ES		67,072	665.6	30.7	0.046	0.428	1.86	0.108	0.589	0.159	4,890	0.469
		WS		23,028	230.0	25.0	0.109	0.229					3,957	0.299
9798	II W	EN1	closing	84,726	236.0	9.0	0.038	0.600	1.12	0.102	0.581	0.396	3,111	0.726
		EN2		80,013	274.3	18.0	0.066	0.362					5,061	0.742
		WN		52,135	240.1	1.0	0.004	1.050					209	1.126
		ES1		47,036	356.3	23.9	0.067	0.697	2.61	0.113	0.904	0.156	4,542	0.723
		ES2		10,451	83.5	28.9	0.346	0.235					5,215	0.303
		WS		32,620	187.0	2.0	0.011	0.751					503	0.775
9798	II W	EN1	IO	84,726	345.1	6.8	0.020	0.420	1.12	0.102	0.651	0.354	1,438	0.559
		EN2		80,013	258.6	7.0	0.027	0.394					1,863	1.022
		WN		52,135	253.3	6.0	0.024	0.434					1,061	0.569
		ES1		47,036	385.1	37.0	0.096	0.659	2.61	0.113	0.714	0.100	8,247	0.676
		ES2		10,451	142.8	11.6	0.081	1.309					1,550	1.318
		WS		32,620	303.2	2.0	0.007	0.916					393	0.929
9899	IV	EN	closing	169,387	557.4	6.0	0.011	0.282	1.25	0.200	0.490	0.321	2,323	0.472
		WN		105,396	259.4	5.0	0.019	1.213					2,589	1.271
		ES		70,193	608.2	19.4	0.032	0.337	1.27	0.088	0.998	0.196	1,430	0.400
		WS		42,605	377.6	4.0	0.011	0.641					287	0.676
9899	IV	EN	IO	169,387	578.7	18.2	0.031	0.234	1.25	0.200	0.686	0.278	4,856	0.414
		WN		105,396	377.8	17.7	0.047	1.079					4,495	1.132
		ES		70,193	685.9	23.5	0.034	0.204	1.27	0.088	0.730	0.323	2,098	0.392
		WS		42,605	472.3	14.8	0.031	0.387					1,161	0.512

Table 7 Comparison between inverse-variance weighted abundance estimate between previous estimates and those in this study from 1987/88 to 1998/99. References of previous estimates are written in the text.

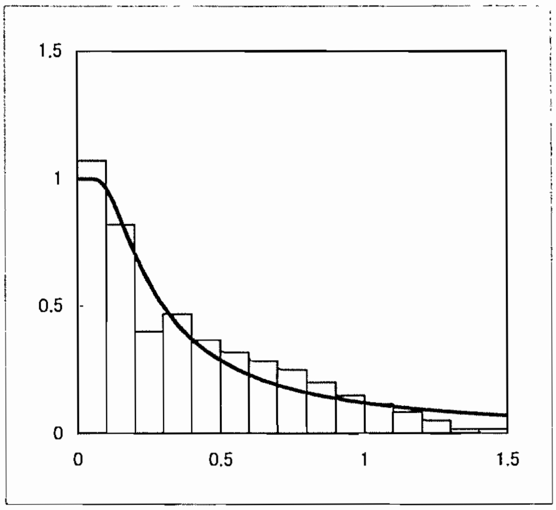
year	revised estimate (A)		previous estimate (B)		(A)-(B)/(B)
	estimate	CV	estimate	CV	(%)
1987/88	153,964	0.331	138,022	0.273	11.6%
1988/89	79,916	0.311	58,170	0.228	37.4%
1989/90	60,452	0.162	63,972	0.170	-5.5%
1990/91	51,848	0.295	56,807	0.283	-8.7%
1991/92	100,159	0.179	98,682	0.177	1.5%
1992/93	29,244	0.191	25,363	0.220	15.3%
1993/94	37,863	0.202	37,479	0.211	1.0%
1994/95	28,715	0.220	31,620	0.198	-9.2%
1995/96	43,517	0.270	37,839	0.207	15.0%
1996/97	36,351	0.386	28,158	0.236	29.1%
1997/98	17,510	0.290	15,434	0.282	13.5%
1998/99	10,470	0.350	7,140	0.345	46.6%



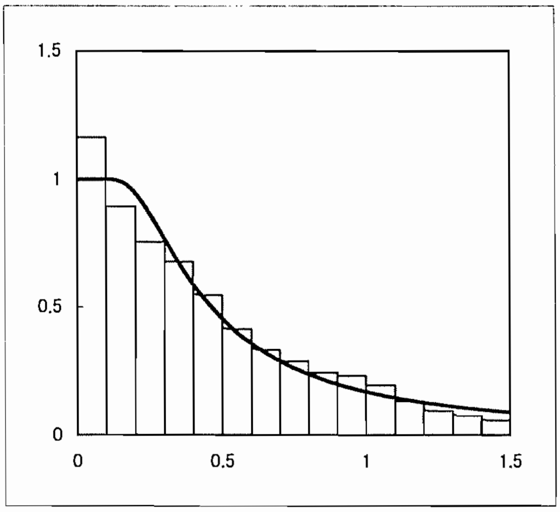
1985/86 in WN closing mode



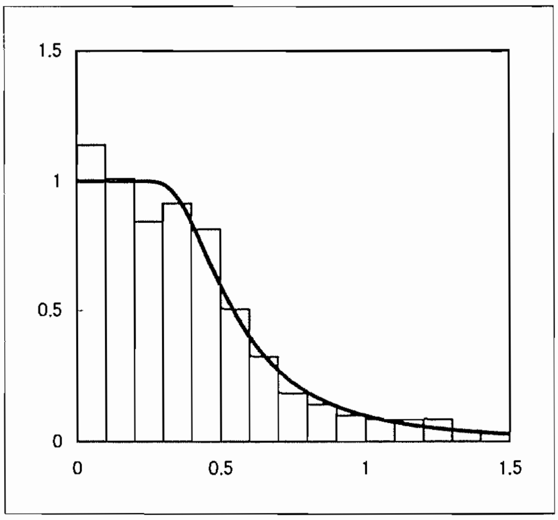
1985/86 EN in closing mode



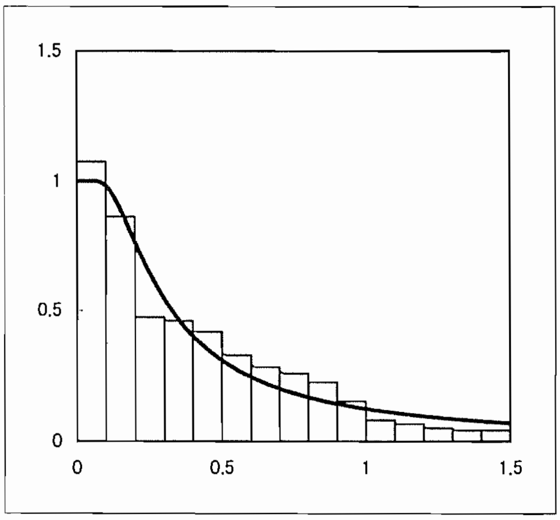
1985/86 WM in closing mode



1985/86 EM in closing mode

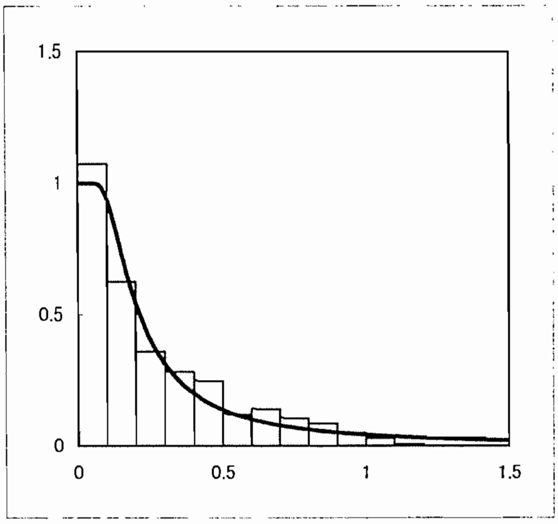


1985/86 WS in closing mode

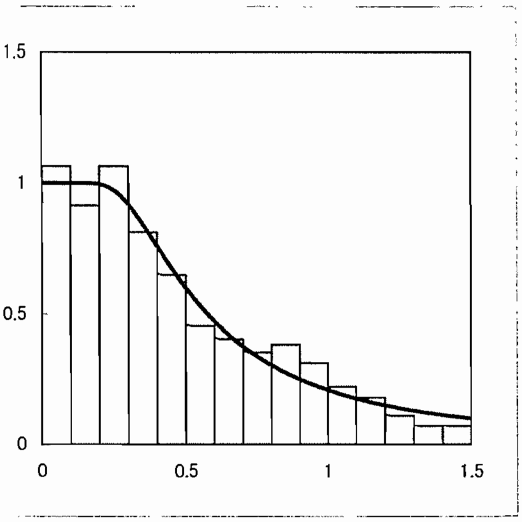


1985/86 ES in closing mode

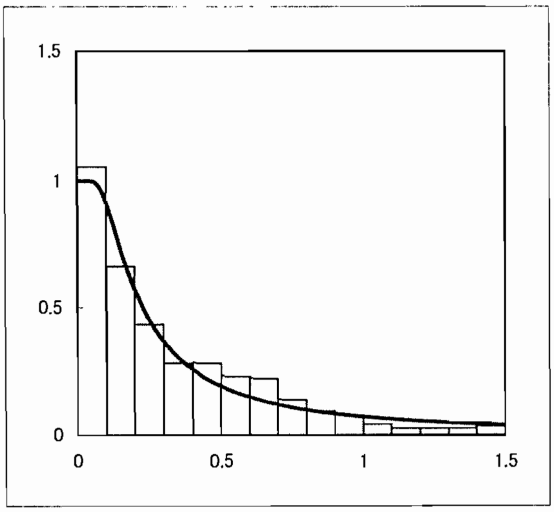
Fig 1. Detection function and distribution of prependicular distance.



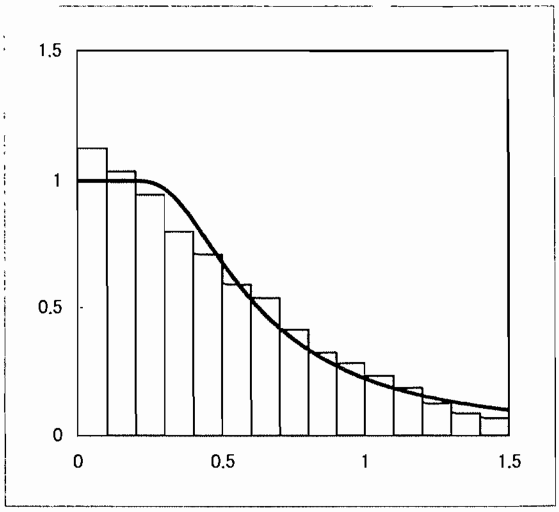
1985/86 WN in IO mode



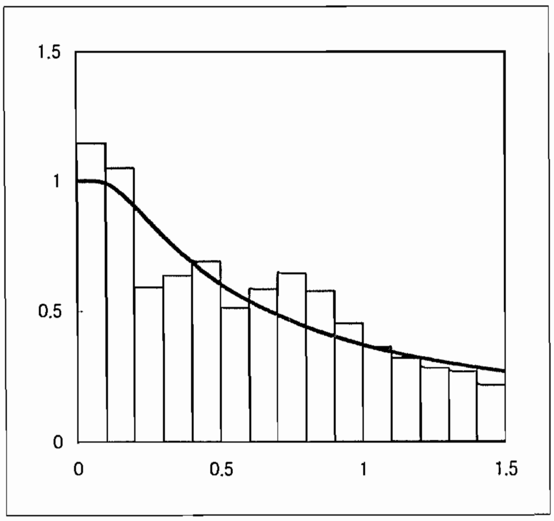
1985/86 EN in IO mode



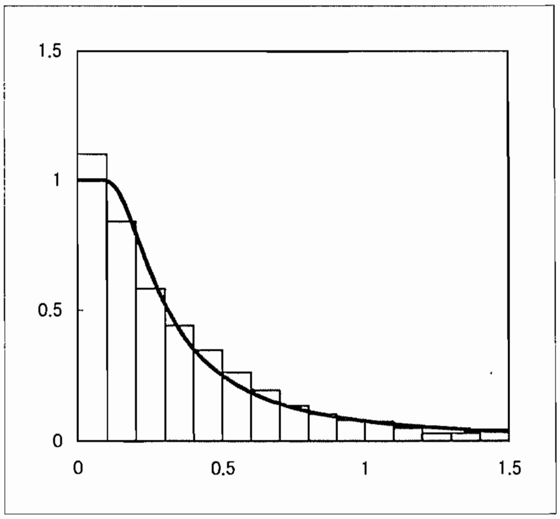
1985/86 WM in IO mode



1985/86 EM in IO mode

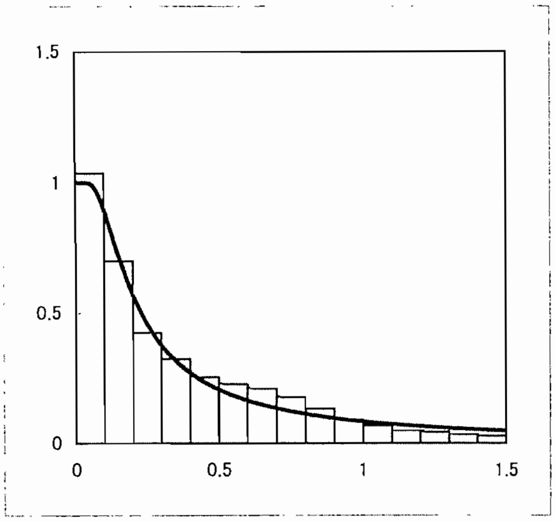


1985/86 Ws in IO mode

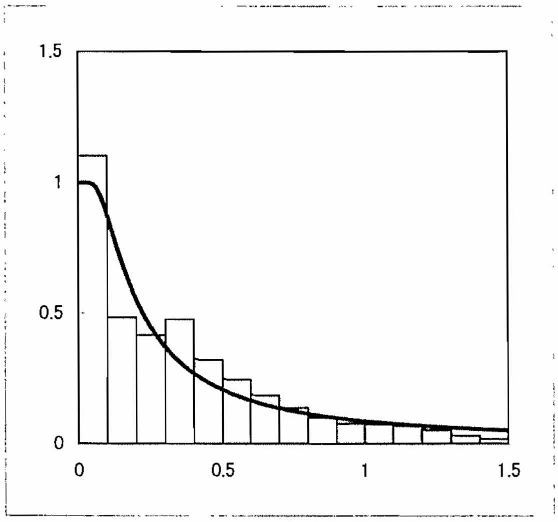


1985/86 ES in IO mode

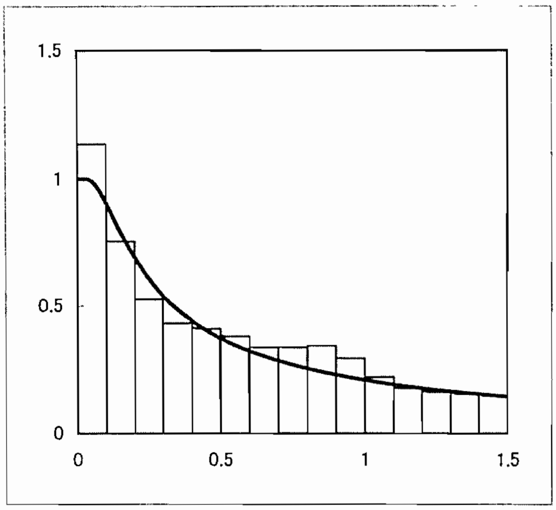
(Fig 1 continued)



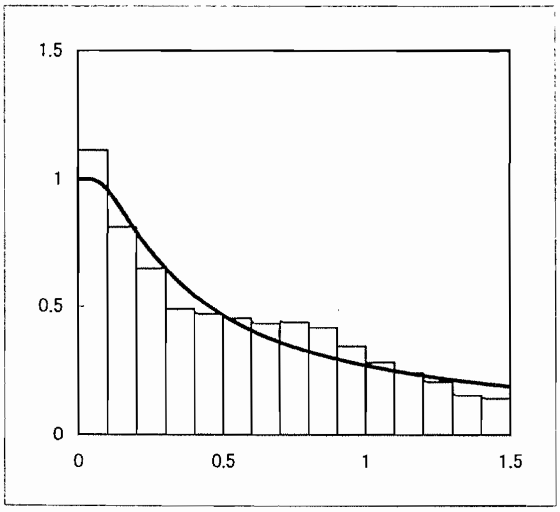
1986/87 K27 in closing mode



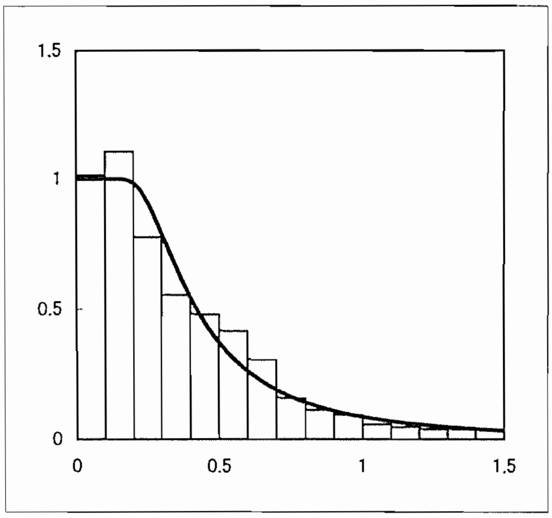
1986/87 K27 in IO mode



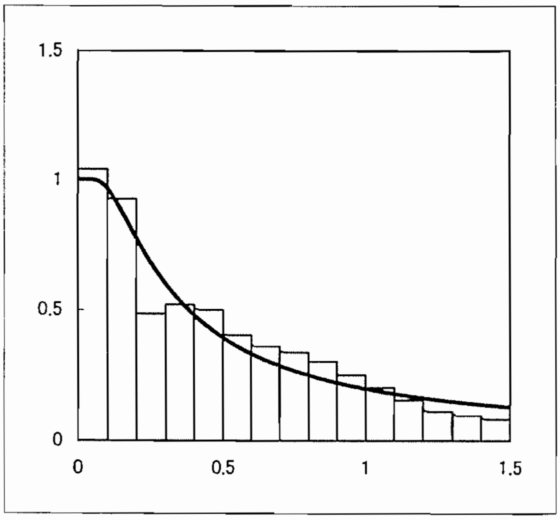
1986/87 SM1in closing mode



1986/87 SM1in IO mode

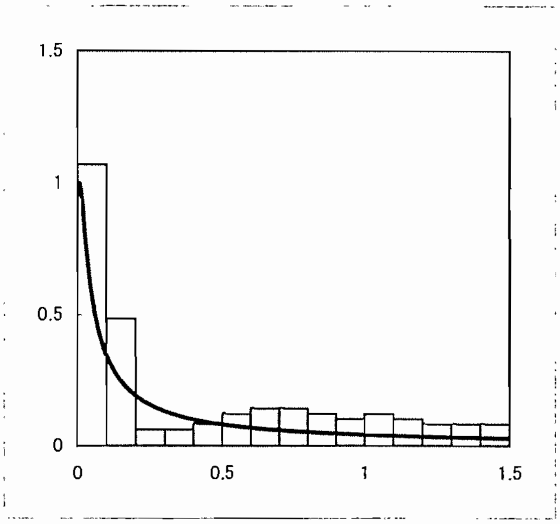


1986/87 SM2 in closing mode

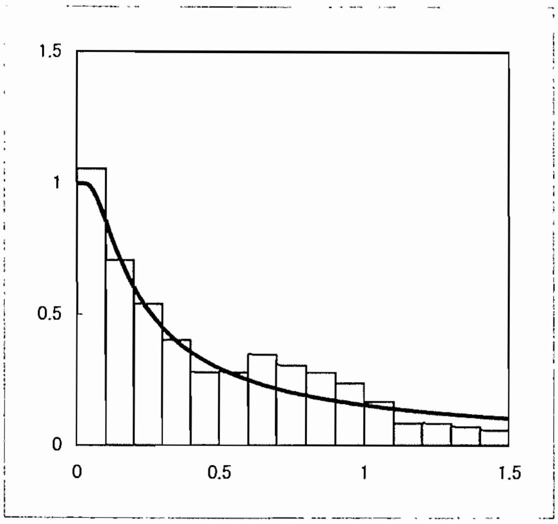


1986/87 SM2 in IO mode

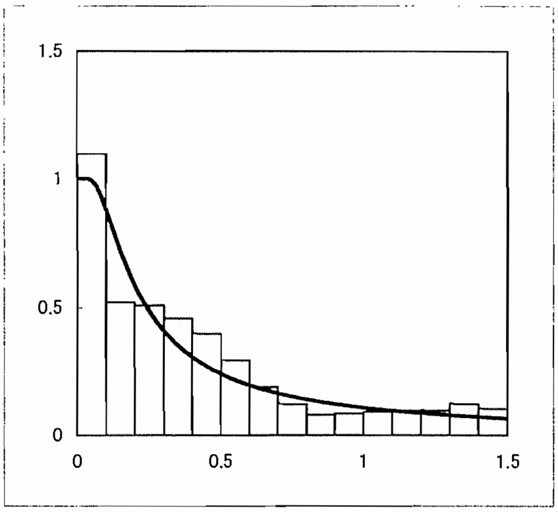
(Fig 1 continued)



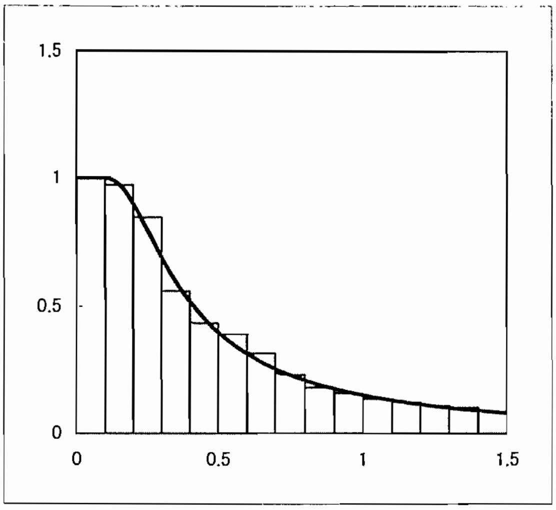
1987/88 north strata in closing mode



1987/88 north strata in IO mode

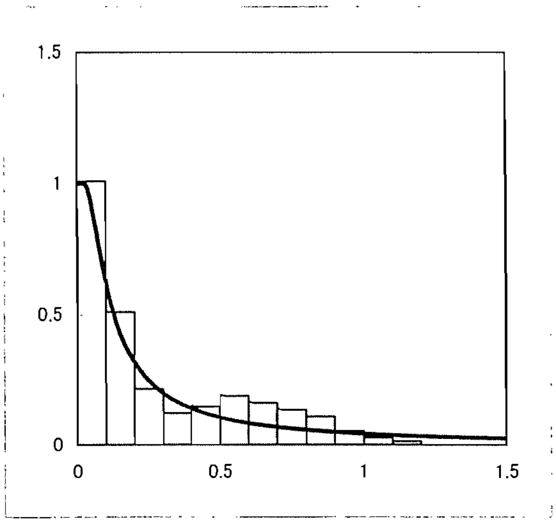


1987/88 south strata in closing mode

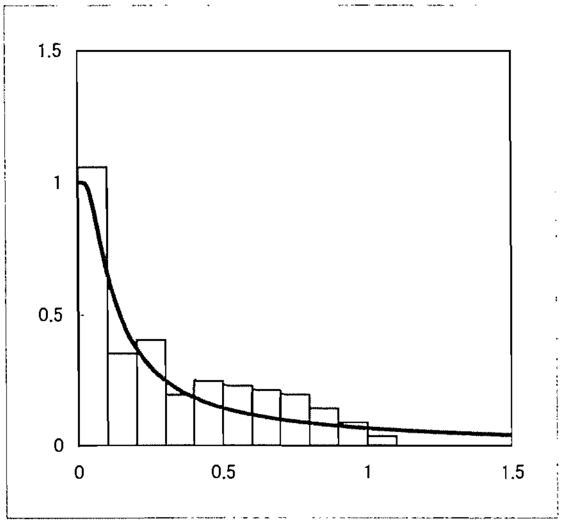


1987/88 south strata in IO mode

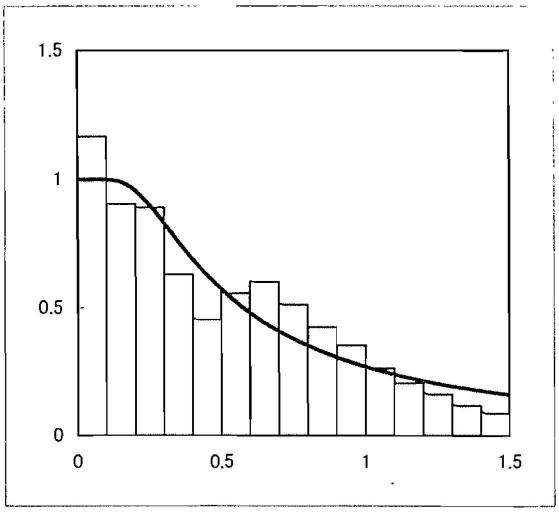
(Fig 1 continued)



1988/89 north strata in closing mode



1988/89 north strata in IO mode



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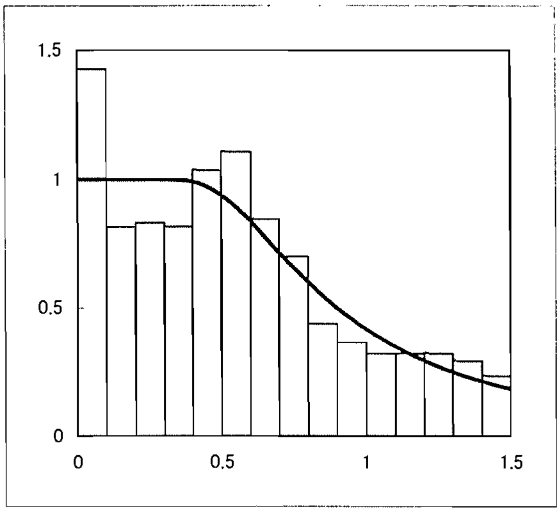
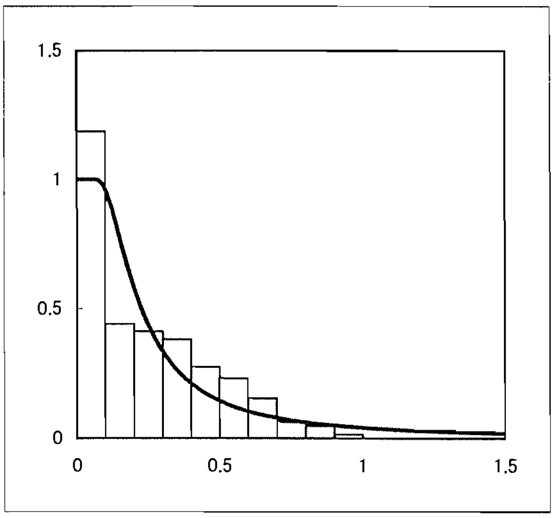
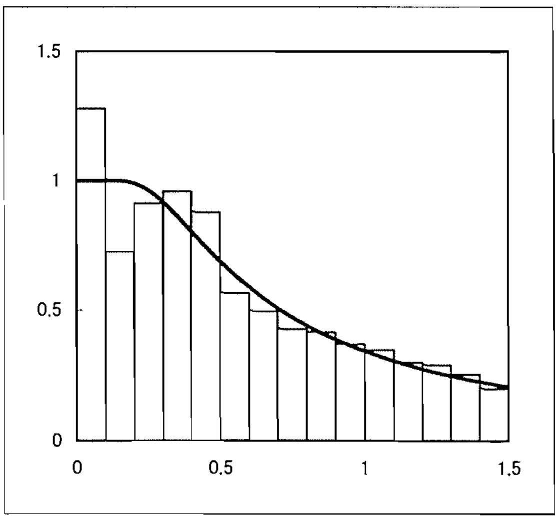


1988/89 south strata in IO mode

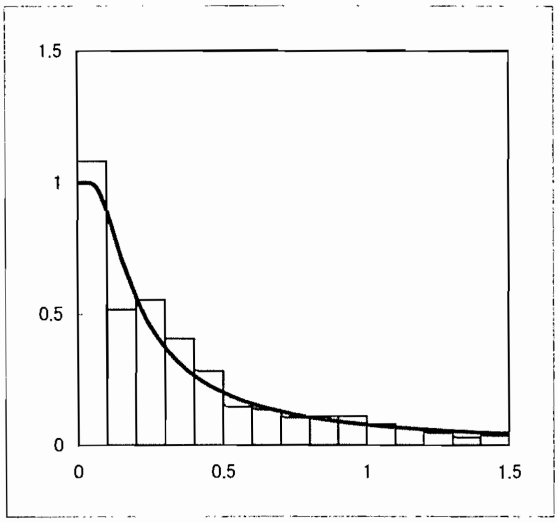


1988/89 Prydz Bay in closing mode

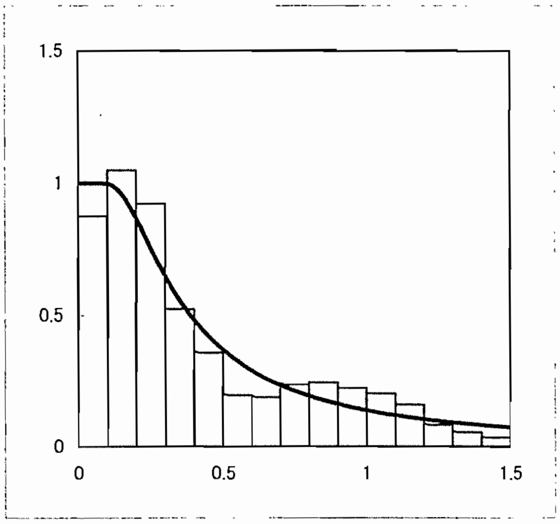


1988/89 Prydz Bay in IO mode

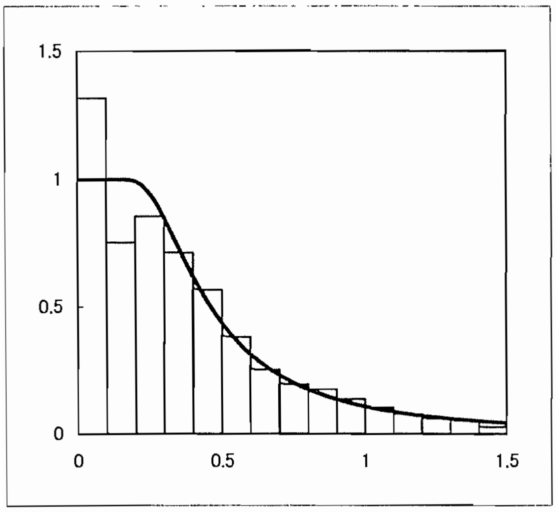
(Fig 1 continued)



1989/90 north strata in closing mode



1989/90 north strata in IO mode



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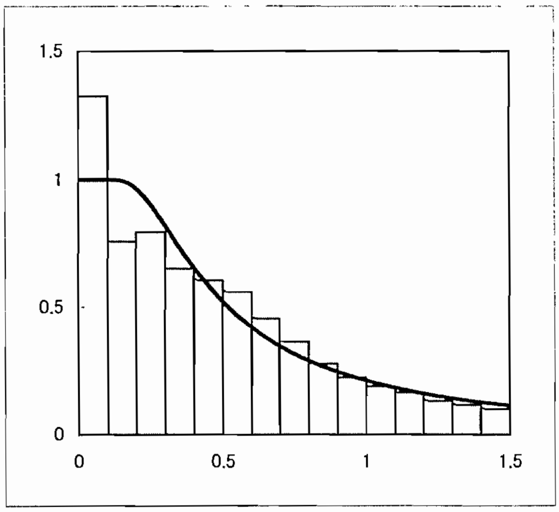

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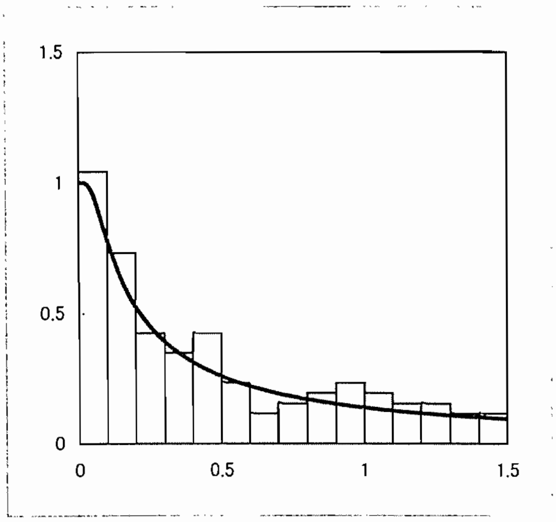
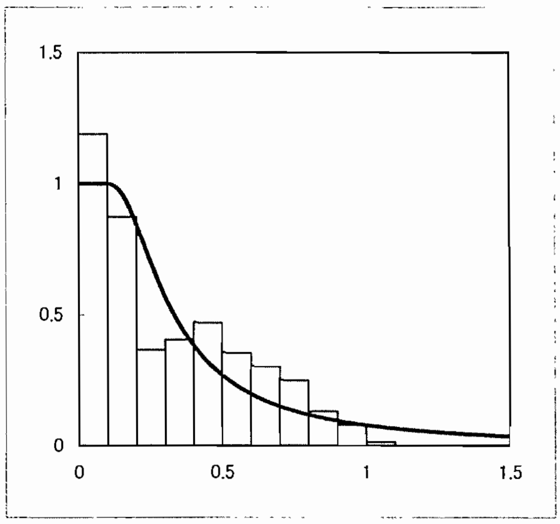
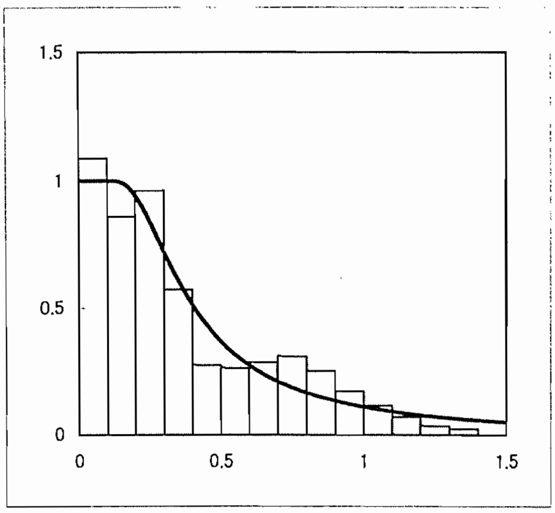
(Fig 1 continued)



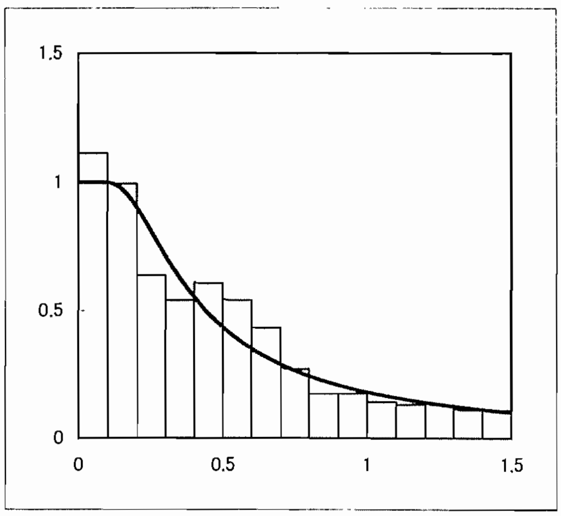
1990/91 north strata in closing mode



1990/91 north strata in IO mode

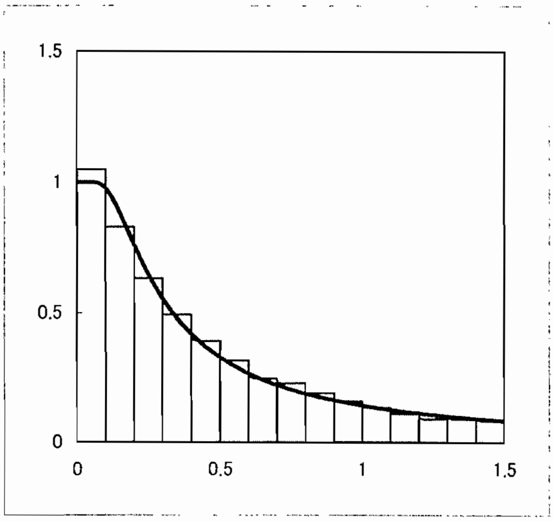


1990/91 south strata in closing mode

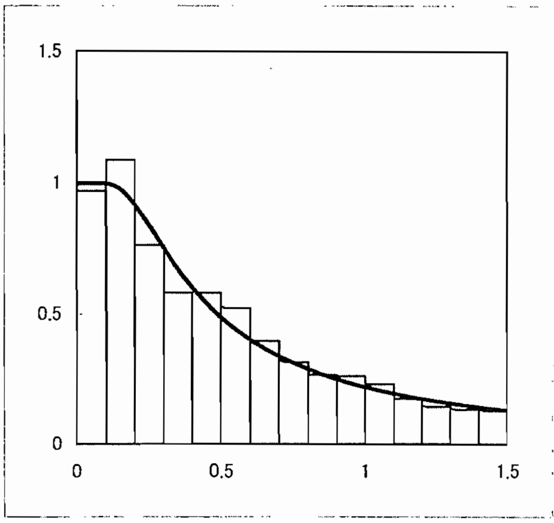


1990/91 south strata in IO mode

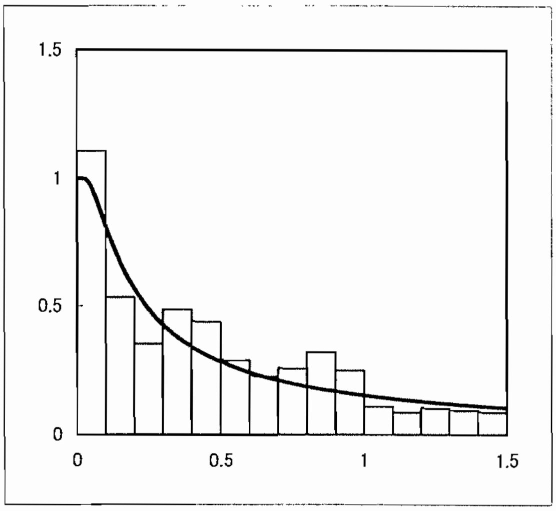
(Fig 1 continued)



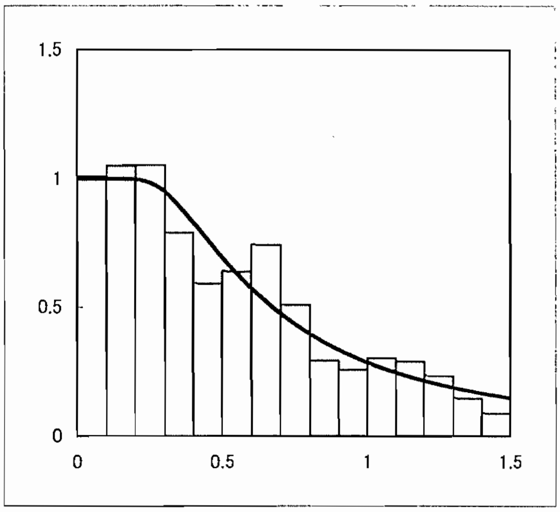
1991/92 north strata in closing mode



1991/92 north strata in IO mode

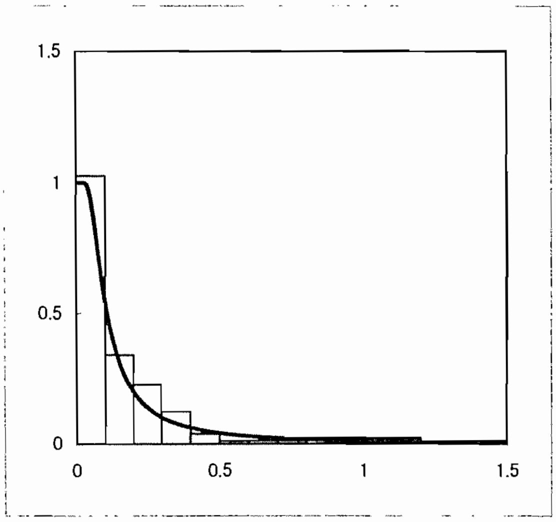


1991/92 south strata in closing mode

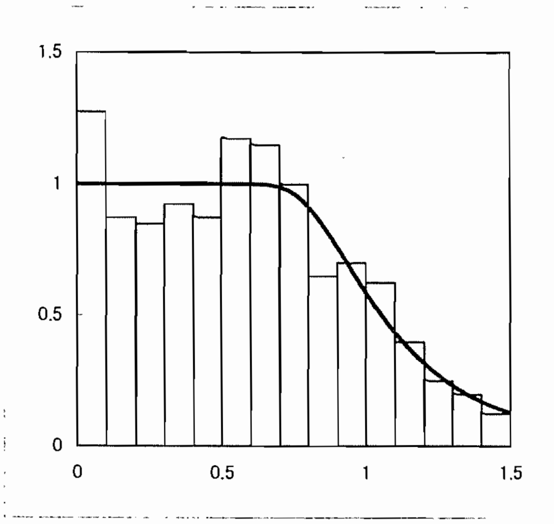


1991/92 south strata in IO mode

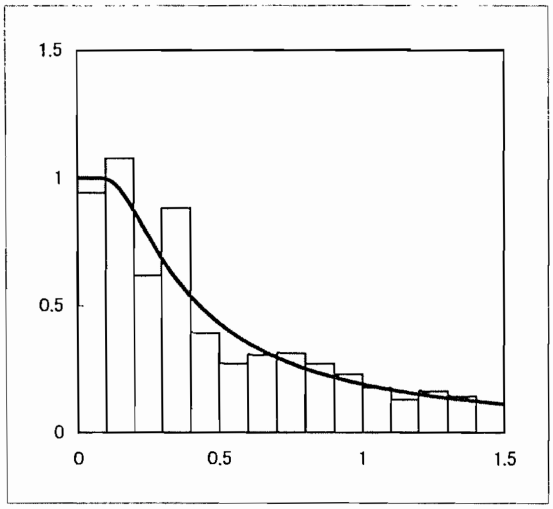
(Fig 1 continued)



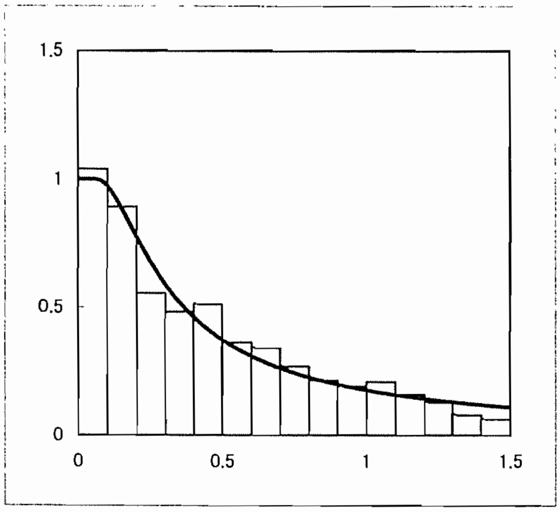
1992/93 north strata in closing mode



1992/93 north strata in IO mode

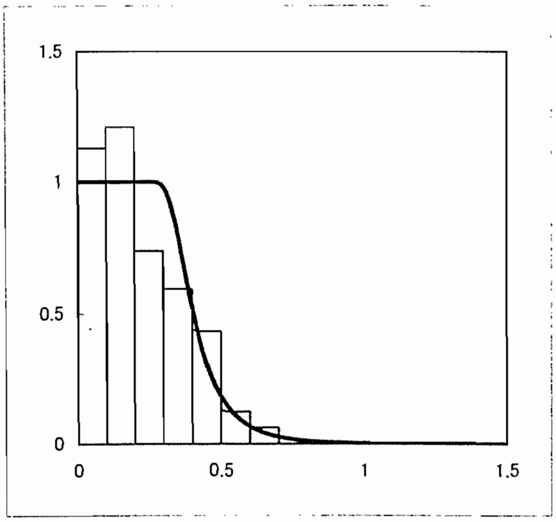


1992/93 south strata in closing mode

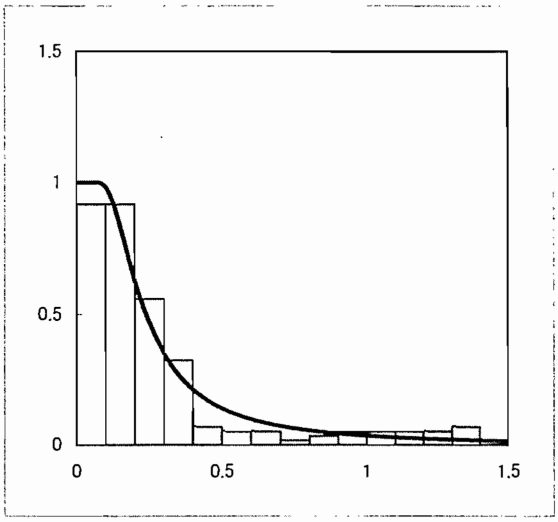


1992/93 south strata in IO mode

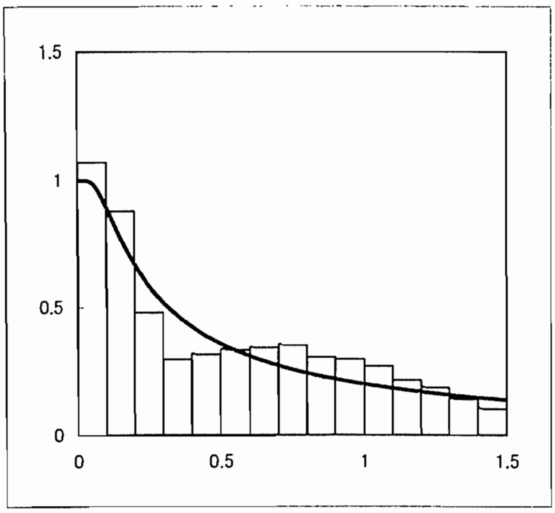
(Fig 1 continued)



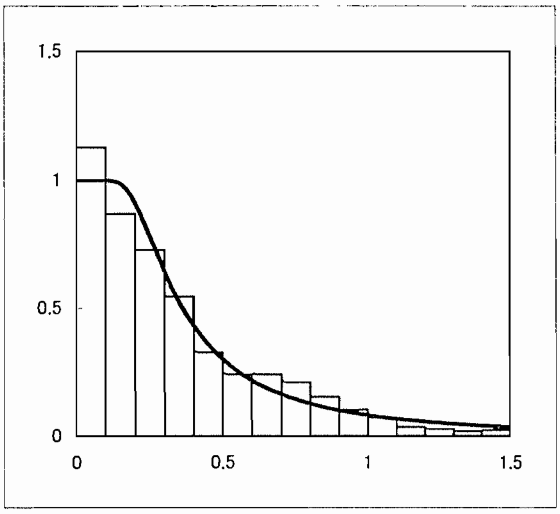
1993/94 north strata in closing mode



1993/94 north strata in IO mode

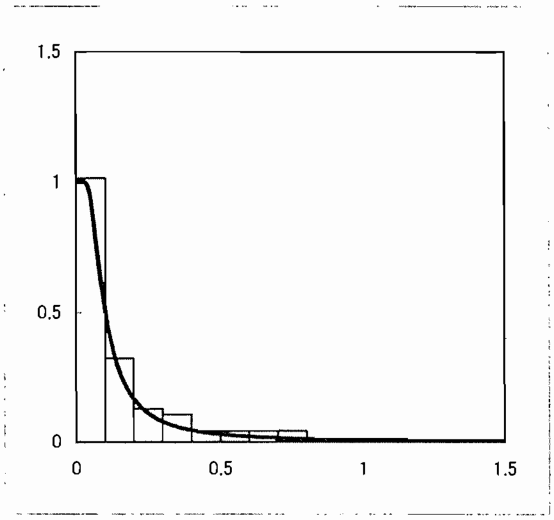


1993/94 south strata in closing mode

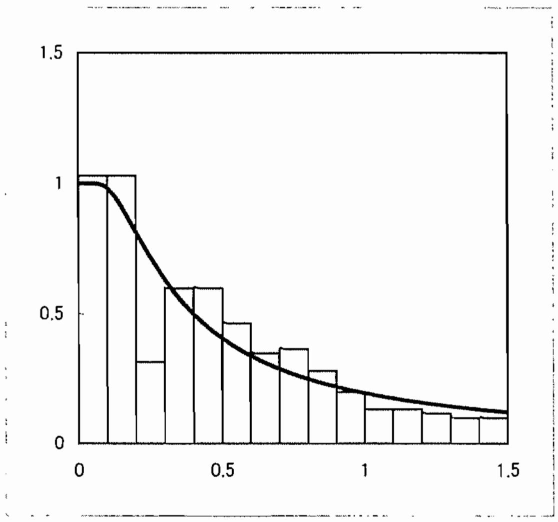


1993/94 south strata in IO mode

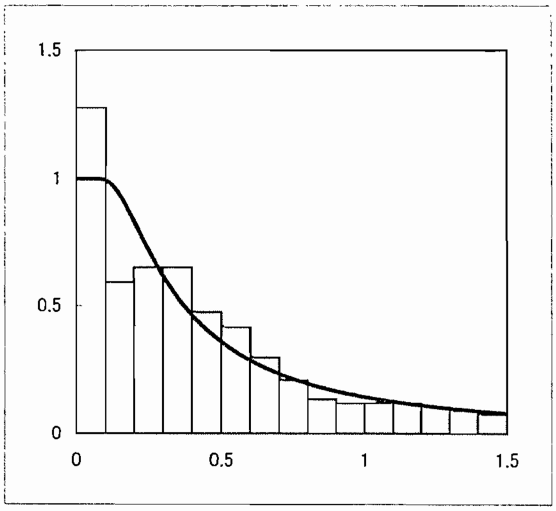
(Fig 1 continued)



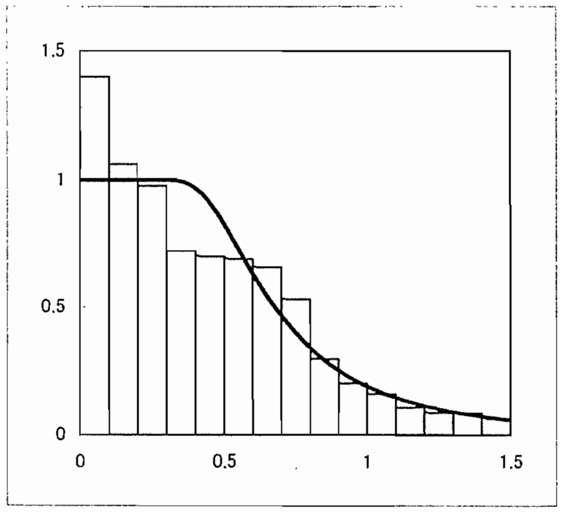
1994/95 north strata in closing mode



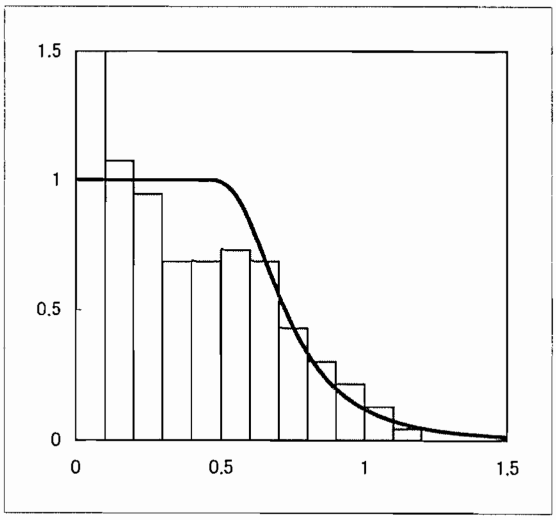
1994/95 north strata in IO mode



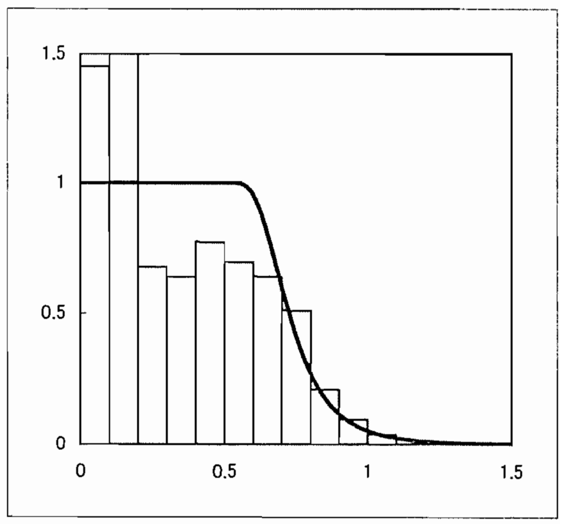
1994/95 south strata in closing mode



1994/95 south strata in IO mode

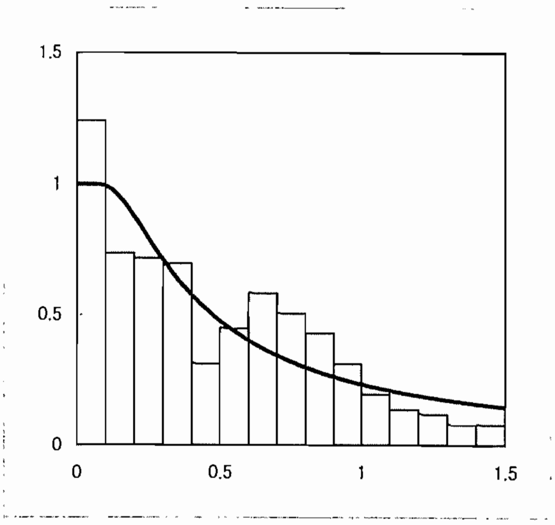


1994/95 Prydz Bay in closing mode

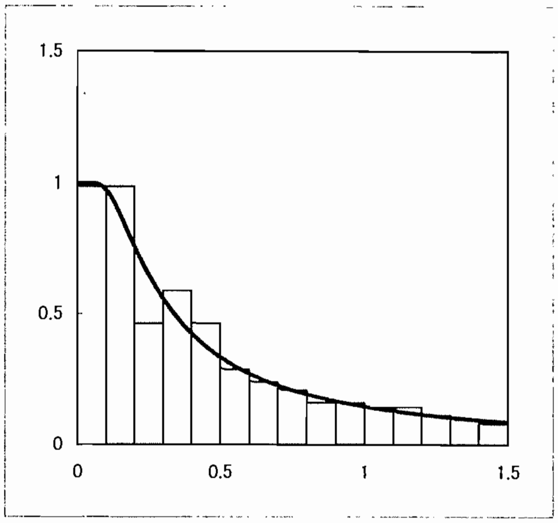


1994/95 Prydz Bay in IO mode

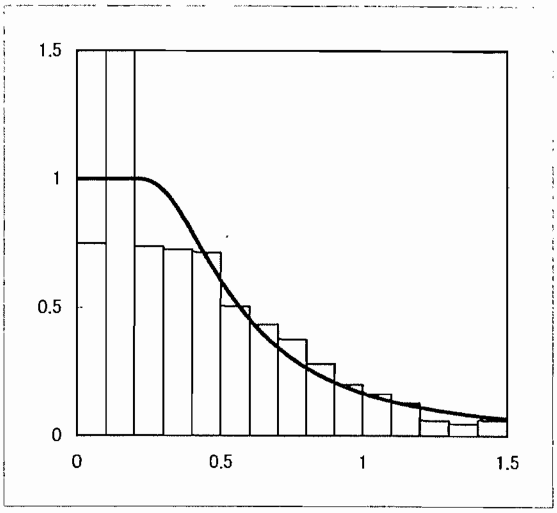
(Fig 1 continued)



1995/96 north strata in closing mode



1995/96 north strata in IO mode



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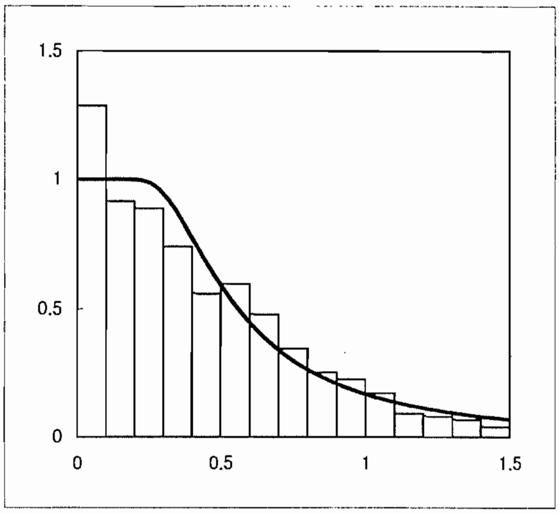
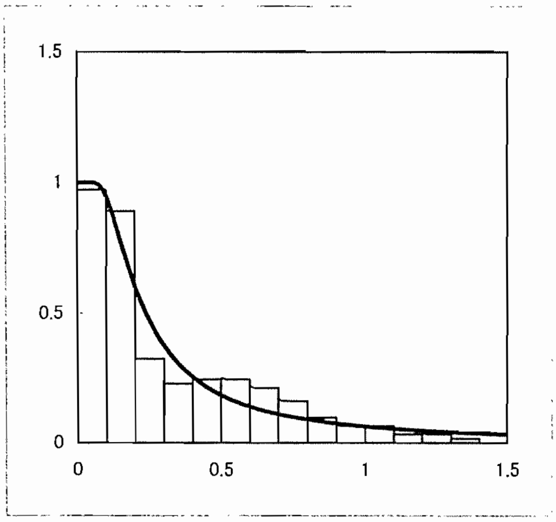
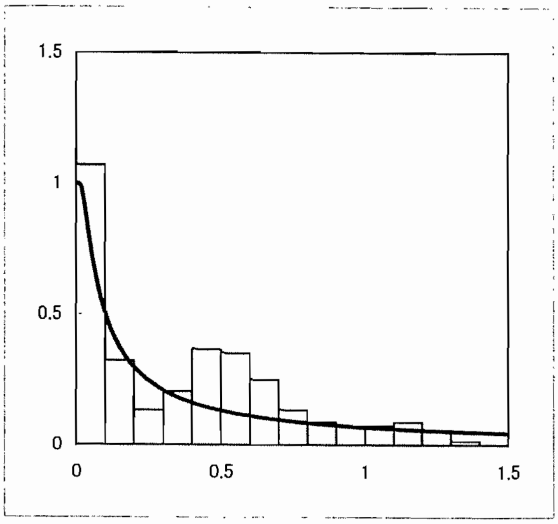


1995/96 south strata in IO mode

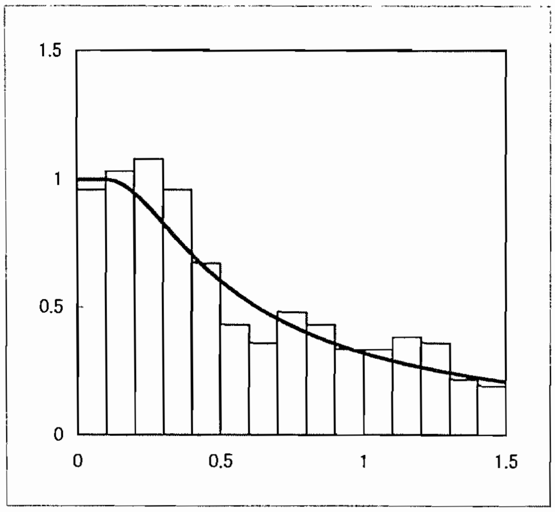
(Fig 1 continued)



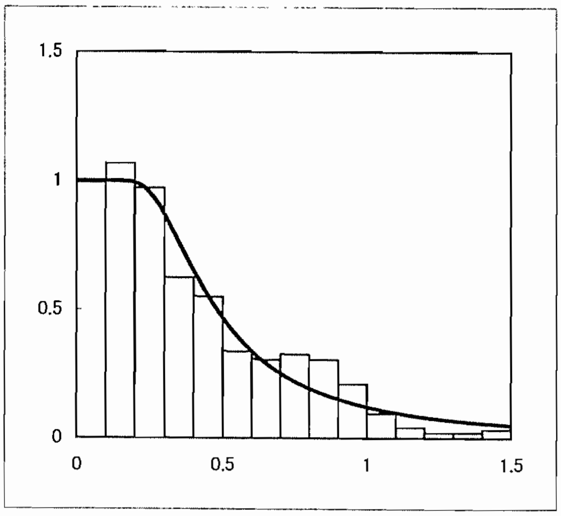
1996/97 north strata in closing mode



1996/97 north strata in IO mode

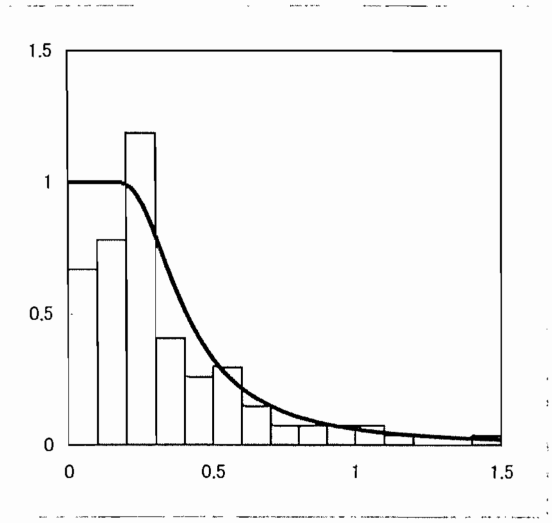


1996/97 south strata in closing mode

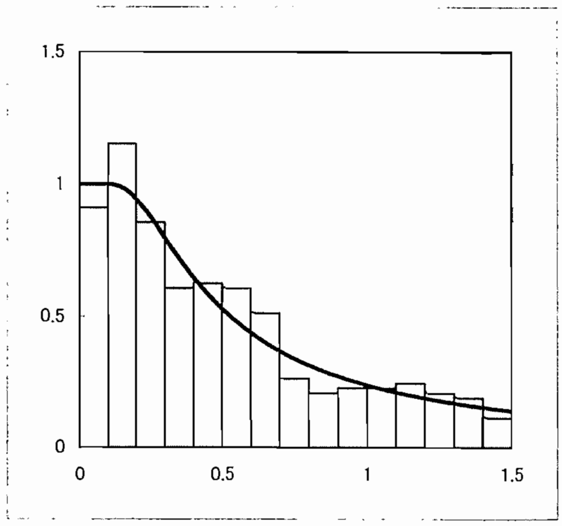


1996/97 south strata in IO mode

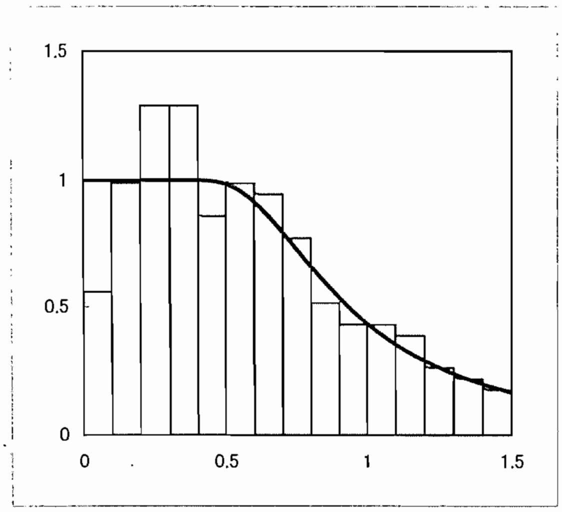
(Fig 1 continued)



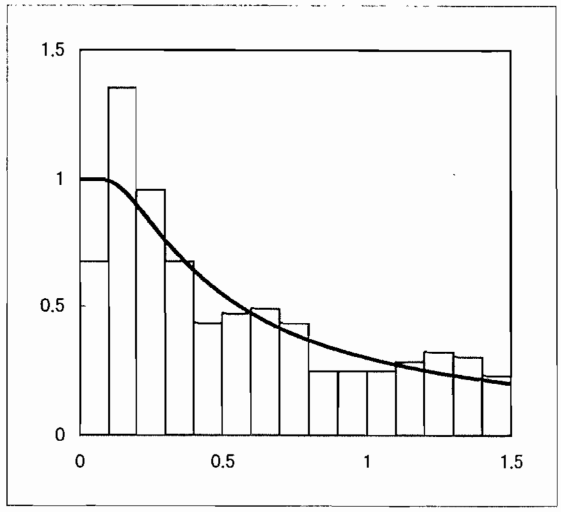
1997/98 north strata in closing mode



1997/98 north strata in IO mode

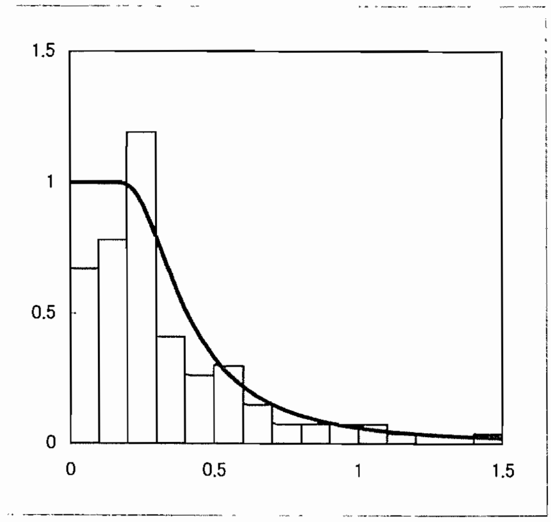


1997/98 south strata in closing mode



1997/98 south strata in IO mode

(Fig 1 continued)



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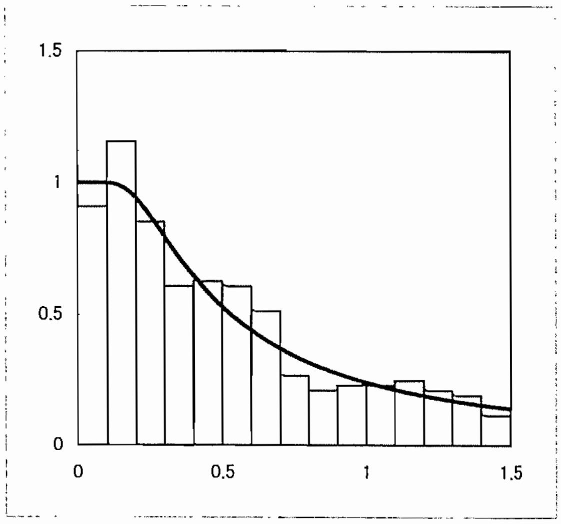
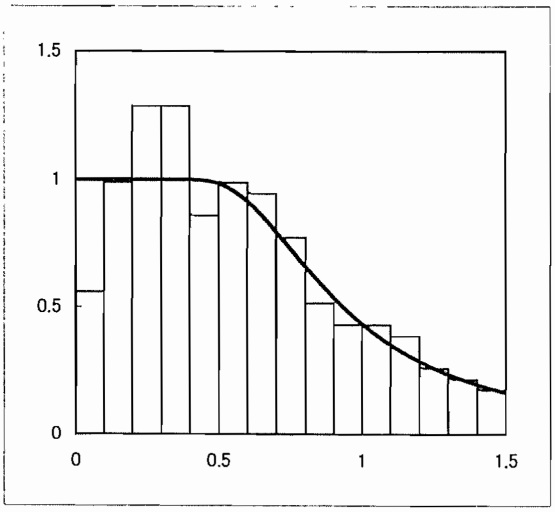


1998/99 north strata in IO mode



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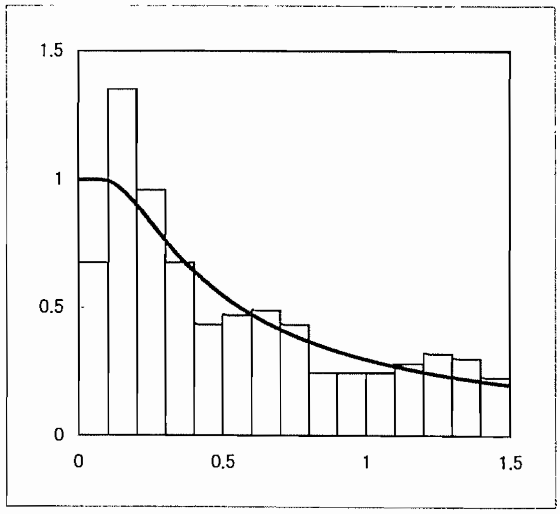

1998/99 south strata in IO mode

(Fig 1 continued)