DIURNAL VARIATIONS IN BOTTOM TRAWL CATCHES OF COD AND HADDOCK AND ITS IMPACT ON ABUNDANCE INDICES

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Analysis of sampling data from Norwegian bottom trawl and acoustic surveys for cod and haddock in the Barents Sea and the Svalbard area indicate a complex set of factors at work, among them the vertical distribution of fish. In this paper catch data for cod and haddock collected during six different experiments carried out within a limited area of the same survey strata were examined according to time of day. Catches of cod and haddock for all length groups were higher by day, particularly catches of small haddock. The impact of diurnal variation in bottom trawl catches on estimated abundance indices from both bottom trawl and acoustic surveys is discussed.

INTRODUCTION

The Institute of Marine Research, Bergen, has carried out combined bottom trawl and acoustic surveys in the Barents Sea and the Svalbard area since 1981. Resulting data have been used to estimate abundance indices for cod (Gadus morhua L.) and haddock (Melanogrammus aeglefinus L.). Length and species composition data from trawl catches have been used to calculate bottom trawl indices and to convert echo abundance from acoustic surveys into estimates of fish density. In these estimates length and species compositions of cod and haddock from bottom trawl catches are assumed to represent the entire water column.

Bottom trawl surveys are performed continuously during a 24 hour period. There are no organized time schedule to insure equal numbers of day and night trawl stations within each strata between years and surveys. In calculation survey abundance indices, diurnal patterns are assumed to bias results equally from year to year (Godø and Wespestad 1990). Analyses of such bottom trawl survey results reveal a sampling problem involving a complex set of factors, among them the vertical distribution of fish (Hylen et al. 1986).

Trawl catches are known to vary throughout the day (Woodhead 1964, Beamish 1966, Jacobsen 1986, Shepherd and Forrester 1987, Erich & Grøger 1989). If variation in the vertical distribution of gadoids between surveys, and diurnal changes within a survey are known and accounted for, accuracy survey estimates will be increased.

Objectives of this study were: I) to quantify diurnal variations in length and species composition for trawl catches of both cod and haddock in a single restricted area, II) to evaluate the impact of diurnal variations on the accuracy of both bottom trawl and acoustic indices.

MATERIALS AND METHODS

Analyses presented are based on trawl catch data from six different experiments carried out in a the same restricted area (Fig. 1) during two seasons of five different years (1982, 1985, 1987, 1988, and 1989) (Table 1). Water depths ranged from 270 to 340 m. A standard Norwegian sampling trawl (Campelen 1800) for bottom fish and shrimp surveys in the Barents Sea and Svalbard areas was used. During 1982 and 1985 experiments, the trawl was rigged with bobbins ground gear; rockhopper gear was used in subsequent experiments (Engås & Godø 1989). Tow duration was generally 30 minutes at 3 knots (doppler log); a 60 minute towing time was used in February 1982 survey. Trawl geometry (wing spread and vertical opening) was monitored continuously during each tow using Scanmar instrumentation, except for the 1982 experiments. The vertical trawl opening was approx. 4 m. Navigation lights only were used onboard vessels while trawling.

Acoustic data, recorded onboard research vessels participating in the trawl experiments, were collected during 1987, 1988 and 1989. Acoustic equipment, used onboard the vessels, was the same used on standard surveys for cod and haddock in the Barents Sea (Hylen et al. 1986); standard instrument settings were maintained. Depth of the bottom channel was not the same in all experiments: 5 m in 1987, 2 m in October 1988, 4 m in February 1988 and October 1989. Therefore, direct comparison of bottom channel values between years is not possible. Integrator values have been assigned to the most abundant species using standard procedures, based upon species composition of trawl catches and identification of fish traces on echo recordings (Dalen & Nakken 1983). Cod, haddock and redfish (Sebastes spp.) were most abundant in the trawl catches. The redfish was, however, excluded from further analyses. Cod and haddock were divided into three length groups: Small (<30 cm), medium (30 to 49 cm) and large (≥50 cm).

Trawl catches were grouped by time of day (day, night, or twilight) according to the medium towing hour (calculated as the hour of starting the tow plus half the tow duration). Daily hours of sunrise, sunset, and duration of twilight were taken from the official Norwegian calendar, and then adjusted to specific longitude and latitude. Hauls between sunrise and sunset were classified as day hauls. Night hauls were taken after dusk, but before dawn. And, hauls taken during twilight periods at dawn and dusk were treated as a separate group in statistical analyses.

Results of trawl catches were tested using analysis of variance (ANOVA), pertaining to different experiments, times of day, and experiment/time interactions. These experiments were not designed to maximize information relative to different factors influencing catch size. Catch data was extracted as a byproduct from several trawl experiments carried out for different purposes. The "experiment" factor includes annual differences in stock level, vessel and gear (bobbins/rockhopper) effects, factors which could not be separated by the ANOVA procedure due to the experimental design. Separate tests were performed for autumn and late winter catches.

Day/night differences in species composition were analyzed using a statistical test designed for the analysis of composition data, CODA (Aitchison 1986). The null-hypothesis assumed no day/night differences in the proportion of cod relative to haddock.

RESULTS

Results from ANOVA (Table 2) show significant day/night differences in total numbers of cod and haddock from trawl catches, in both late winter and autumn. Significant diurnal differences were also found for all three length groups of both cod and haddock with two exceptions: small cod (<30 cm) in late winter, and large haddock ($\geq$50 cm) in autumn. As would be expected, there were also significant experiment effects in all cases, with the exception of large cod in autumn.

Figures 2 and 3 show the number of cod and haddock in the catches plotted against medium towing hour. A sudden increase in number of fish was seen at the onset of dawn, lasting until night. Diurnal changes in catch rate were more pronounced during autumn than in late winter (Tables 3 and 4), the variance in total catch was larger during day than by night. The most significant increase was observed in numbers of small fish during autumn, particularly for haddock (up to 30 times as high by day), but also for cod (up to 7 times as high). In late winter experiments small cod and haddock were insignificant in both day and night catches (Table 5 and 6).

The amount of cod relative to haddock in the trawl catches varied significantly by time of day in the autumn experiments (Table 7). The proportion of haddock was consistently higher during day. The same trend was not found in late winter. The shift in the cod/haddock ratio during autumn was largely due to large amounts of small haddock entering the trawl catches during daytime.

The variability in acoustic abundance of cod and haddock was large, both between years and within each experiment period (Table 8); no trend was found from year to year in day/night differences. When interpreting Table 8, it should be noted that the width of the bottom channel varied between years; the values presented cannot be directly compared. Within each year, the proportion of acoustic abundance measurements for the bottom channel were larger when the total acoustic abundance was low when abundance was high (Fig. 5a-d).

DISCUSSION

When trawl catch data is used to form catch dependent indices, or in the conversion of acoustic abundance to absolute abundance, the basic assumption is that each trawl catch provides representative estimates of density for each species over the entire length range. It is also assumed that length distributions obtained are the "true" ones (Hylen et al. 1986). In this study the above assumptions were not fully supported. Which leads to the following question: To what extent do the observed diurnal changes in the species and length composition from sampling trawl catches influence the accuracy of the stock assessments?

The trawl experiments presented in this paper were carried out continuously during a 24 hour period, and all within a limited area of the Barents Sea bottom trawl survey (Dalen & Smedstad 1983). Indices estimated have been based on the average trawl catch in each strata. There is no organized time schedule for hauling strata. The proportion of day and night hauls may vary from year to. Particularly in strata where few hauls are carried out, the distribution between day and night hauls may often vary and influence the indices.

In the strata where the experiments were carried out, 9 trawl stations are performed each year. The experiments showed large diurnal differences in the total number of cod and haddock; individual trawl catches showed differences in both species and length distribution. Trawl indices based upon day catches alone tend to give a much higher figure for total stock both for cod (up to 3 times as high) and haddock (up to 20 times as high). The increased catch rate by day is true for all length groups of both species, but in particular for fish less than 30 cm (up to 7 times as high for cod, and 30 times for haddock).

No diurnal migrations are expected, in or out of the investigated area. Although differences in fish reactions towards the gear may change during day (Wardle 1986), observed diurnal differences in total catch and catch composition are thought mainly due to a species and size dependent vertical migration. Therefore, trawl catches would not be representative of the whole water column regarding both species and size distribution. Representation is, however, one important assumption for using bottom sampling trawl catches in conversion of echo abundance to fish density.

The variance in the number of cod and haddock caught by the sampling trawl were found to be higher by day than by night. Shepherd and Forrester (1987) found that trawl hauls carried out by night, provide a better correlation with fisheries dependent stock estimates than hauls taken by day in the Northwest Atlantic. To found indices in the Svalbard area and the Barents Sea on night hauls alone is attractive in that this would lead lower catch variances to narrower confidence limits for stock estimates. However, this would be of limited usefullness, because small cod and haddock are almost lacking in the night catches. A primary objective of the trawl and acoustic surveys in the Barents Sea (Dalen & Smedstad 1983) is to improve indices of recruiting year class strength for cod and haddock. Fishing by day, when these size groups are available to the sampling gear, is critical to the accuracy of the young fish assessment.

Vertical distribution of cod and haddock in the Barents Sea has been observed to extend higher up in the water column when stocks are abundant than when stocks are low (Engås & Godø 1986, Hylen et al. 1986). The same trend was observed the present experiments. Numbers of fish standing above the headline of the trawl (approx. 4 m) were larger when the total acoustic abundance was high. As before stated, species and size dependent diurnal vertical migration makes the fish distribution in the trawl zone untypical for the total stock. This tendency is expected to increase as the extent of vertical distribution widens, accuracy of the trawl indices will become more biased when stocks are high.

In combined trawl and acoustic surveys, length and species distributions from trawl catches are used to convert acoustic values to total numbers. Bias in trawl catch composition will introduce bias to acoustic stock estimates. Therefore, large amounts of small cod and haddock entering trawl catches by day greatly influence estimates of target strength (TS) and conversion factor ($CF = 10^{(-TS/10)}/4\pi$). As an example, the catch data from the October 1988 experiment was used to calculate the average TS and CF for cod and haddock on the assumption a) that the day catches were representative for the stocks, b) that the night catches were representative for the stocks. The TS is calculated from the equation $TS = 21.8 \log L - 74.9$, where L is the root mean square length of the fish in cm (Hylen et al. 1986). Alternative a) gave TS of -45.8 and CF of 3027, while b) gave TS of -38.5 and CF of 564. The length frequency of the day catches used to convert echo abundance to total fish number will in this case lead to an estimate over 5 times higher than if only night catches were used. Although day and night hauls are used during surveys, this example indicates the inaccuracy that diurnal changes in length frequency for bottom trawl catches may introduce in abundance estimates for cod and haddock.

CONCLUSION

Survey time is limited and expensive and has to be fully utilized to maximize output. Trawl sampling has to be carried out throughout day and night. Although for practical reasons, it may be impossible to keep the number of day and night hauls within each reasons, it may be impossible to keep the number of day and night hauls within each strata constant between years, diurnal differences should be taken into account when interpreting data from trawl surveys. Day and night catches should be compared, and when large differences are noted within certain periods, areas, etc., special care should be taken in the weighting of results.

Acoustic sampling should always be carried out parallel to trawl sampling. Echo records give information on the extent of the vertical fish distribution, and may indicate the precision of near-bottom trawl sampling. Pelagic trawling should be used more frequently in periods/areas with a wide vertical distribution to gather better information on species and size composition above bottom. However, more research is needed to evaluate differences in catching efficiency of the bottom and pelagic sampling trawls (Engås and Godø 1987).

Detailed knowledge of the distribution and behavior of the fish stocks in the survey area is of vital importance in every assessment program to maximize the information that may be extracted from the survey data. Factors influencing survey results are many, and further trawl experiments and mini-surveys should be carried out parallel to the standard surveys in an attempt to model and quantify different sources of error.

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Figure legends

Figure 1. Areas covered by routine cod and haddock surveys (shaded) and the experimental trawling area (black).

Figure 2. Total number of cod in the catches from the different trawling experiments plotted against time of day.

Figure 3. Total number of haddock in the catches from the different trawling experiments plotted against time of day.

Figure 4. The length distribution of cod and haddock in the catches from one selected late winter experiment (February 1988).

Figure 5. The length distribution of haddock in the catches from one selected autumn experiment (October 1989).

Figure 6. The echo abundance in the bottom channel in % of total echo abundance.

Table 1. Trawl experiments included in the analyses.

Survey no.	Vessel	Season	No. of hauls	Duration of hauls	Ground gear	Acoustic data
1	Masi/Vikheim	March 1982	13	60 min.	Bobbins	No
2	Eldjarn/Raiti	Oct. 1985	17	30 min.	Bobbins	No
3	Masi/G.O.Sars	Febr. 1987	25	30 min	Rockhopper	Yes
4	T.O.Senior/M.Sars	Febr. 1988	16	30 min.	Rockhopper	Yes
5	Anny Kræmer/M.Sars	Oct. 1988	21	30 min.	Rockhopper	Yes
6	Anny Kræmer/Eldjarn	Oct. 1989	23	30 min.	Rockhopper	Yes

Table 2. ANOVA results for no. of cod and haddock in the trawl catches.

		MODEL EFFECT					
		Experiment		Time of day		Exp * time	
		F	Pr > F	F	Pr > F	F	Pr > F
COD							
< 30 cm	Spring	12.2	<0.001	1.7	0.199	1.0	0.423
	Autumn	4.0	0.023	19.9	<0.001	4.3	0.004
30-49 cm	Spring	17.1	<0.001	4.0	0.025	4.6	0.003
	Autumn	8.9	<0.001	8.9	<0.001	3.0	0.025
≥ 50 dm	Spring	64.0	<0.001	8.3	<0.001	5.2	0.001
	Autumn	2.3	0.106	5.2	0.008	0.3	0.904
Total	Spring	8.5	<0.001	6.0	0.004	4.9	0.002
	Autumn	0.9	0.407	22.5	<0.001	3.2	0.019
HADDOCK							
< 30 cm	Spring	26.6	<0.001	10.9	<0.001	12.5	<0.001
	Autumn	22.5	<0.001	25.4	<0.001	2.2	0.075
30-49 cm	Spring	17.5	<0.001	5.6	0.006	7.0	<0.001
	Autumn	85.7	<0.001	5.5	0.007	6.4	<0.001
≥ 50 cm	Spring	13.3	<0.001	11.1	<0.001	6.3	<0.001
	Autumn	9.6	<0.001	0.1	0.926	1.4	0.250
Total	Spring	17.8	<0.001	6.0	0.004	6.9	<0.001
	Autumn	36.3	<0.001	27.2	<0.001	2.6	0.047

Table 3. Mean total number of cod divided by time of day.

		Day		Night		Twilight	
		N	x ± SD	N	x ± SD	N	x ± SD
October	1985	7	65.9 ± 21.8	9	54.1 ± 22.8	1	39.0
	1988	9	91.4 ± 38.7	10	37.7 ± 18.0	2	56.5 ± 26.1
	1989	9	114.7 ± 42.3	10	34.8 ± 14.5	4	57.7 ± 27.5
February	1982	4	197.5 ± 44.8	7	121.3 ± 39.5	2	102.0 ± 26.9
	1987	8	133.3 ± 50.2	17	132.5 ± 48.9	3	126.7 ± 23.7
	1988	6	368.8 ± 230.4	9	139.9 ± 68.3	1	464.0

Table 4. Mean total number of haddock divided by time of day.

		Day		Night		Twilight	
		N	x ± SD	N	x ± SD	N	x ± SD
October	1985	7	1141.9 ± 273.0	9	434.0 ± 164.0	1	1089.0
	1988	9	610.3 ± 498.8	10	93.7 ± 57.9	2	392.5 ± 202.9
	1989	9	243.2 ± 132.4	10	11.3 ± 13.9	4	129.5 ± 110.9
February	1982	4	27.8 ± 7.3	7	12.7 ± 4.6	2	35.0 ± 2.8
	1987	8	637.5 ± 189.3	17	455.1 ± 100.1	3	571.3 ± 188.5
	1988	6	1453.8 ± 1271.2	9	648.3 ± 565.8	1	3713.0

Table 5. Mean number of different length groups of cod (± s.d.) in day and night catches.

		DAY				NIGHT			
		N	< 30 cm	30-49 cm	≥ 50 cm	N	< 30 cm	30-49 cm	≥ 50 cm
Feb.	1982	4	0	22.0 ± 8.0	176.0 ± 38.7	6	0	10.0 ± 3.6	103.2 ± 42.5
	1987	8	16.2 ± 10.4	102.4 ± 40.9	14.6 ± 8.3	17	12.7 ± 8.5	102.2 ± 43.5	17.5 ± 6.4
	1988	6	15.5 ± 10.3	253.5 ± 171.2	100.0 ± 63.4	9	8.2 ± 4.1	96.2 ± 52.4	35.3 ± 16.4
Oct.	1985	7	16.7 ± 9.2	21.4 ± 7.5	27.7 ± 10.8	9	17.7 ± 10.3	16.8 ± 8.7	19.6 ± 8.5
	1988	9	58.2 ± 36.4	12.8 ± 6.9	20.6 ± 7.2	10	13.3 ± 10.1	9.4 ± 4.7	15.0 ± 8.9
	1989	9	57.2 ± 25.7	34.2 ± 12.7	22.8 ± 12.1	10	8.4 ± 6.4	13.4 ± 8.2	13.0 ± 5.1

Table 6. Mean number of different length groups of haddock (± s.d.) in day and night catches.

		DAY				NIGHT			
		N	< 30 cm	30-49 cm	≥ 50 cm	N	< 30 cm	30-49 cm	≥ 50 cm
Feb.	1982	4	0	5.0 ± 2.0	23.0 ± 6.7	6	0	4.7 ± 3.7	10.7 ± 5.8
	1987	8	62.1 ± 13.6	546 ± 179.6	29.2 ± 12.3	17	25.3 ± 17.0	407.0 ± 86.2	22.7 ± 9.8
	1988	6	26.2 ± 15.2	1316.7 ± 1203.7	110.3 ± 63.4	9	21.4 ± 11.9	606.8 ± 537.9	24.4 ± 18.4
Oct.	1985	7	918.3 ± 250.3	216.4 ± 95.5	7.6 ± 3.5	9	316.9 ± 125.6	110.9 ± 37.2	5.6 ± 4.1
	1988	9	566.9 ± 498.1	35.0 ± 15.1	8.4 ± 6.3	10	46.3 ± 42.8	33.7 ± 17.9	13.7 ± 10.8
	1989	9	234.2 ± 129.2	4.6 ± 2.2	4.7 ± 2.5	10	7.7 ± 13.8	1.2 ± 1.3	2.5 ± 1.8

Table 7. The proportion of cod and haddock in day and night catches.

		Day			Night			Difference day/night (CODA sign.level)
		N	Cod	Haddock	N	Cod	Haddock	
October	1985	7	0.06	0.94	9	0.11	0.89	p < 0.001
	1988	9	0.15	0.84	10	0.31	0.69	p < 0.001
	1989	9	0.34	0.66	10	0.78	0.22	p < 0.001
February	1982	4	0.88	0.12	7	0.90	0.10	NS
	1987	8	0.18	0.82	17	0.22	0.78	NS
	1988	6	0.22	0.78	9	0.21	0.79	NS

* dusk

Table 8. Total echo abundance and echo abundance in bottom channel day and night.

			M-value day	M-value night	Difference day/night (t-test)
February	1987[1]	Bottom channel	1.2 ± 1.0	6.2 ± 4.2	p < 0.001
		Total	24.9 ± 13.9	30.5 ± 18.0	p = 0.05
	1988[2]	Bottom channel	23.2 ± 23.1	43.6 ± 49.3	NS
		Total	275.8 ± 333.4	143.1 ± 185.5	NS
October	1988[3]	Bottom channel	0.4 ± 0.7	1.5 ± 1.8	p < 0.001
		Total	18.1 ± 13.9	12.7 ± 8.4	p = 0.02
	1989[2]	Bottom channel	6.2 ± 3.2	3.7 ± 2.5	NS
		Total	16.3 ± 9.6	13.0 ± 6.5	NS

1 Depth of bottom channel 5 m
2 Depth of bottom channel 4 m
3 Depth of bottom channel 2 m

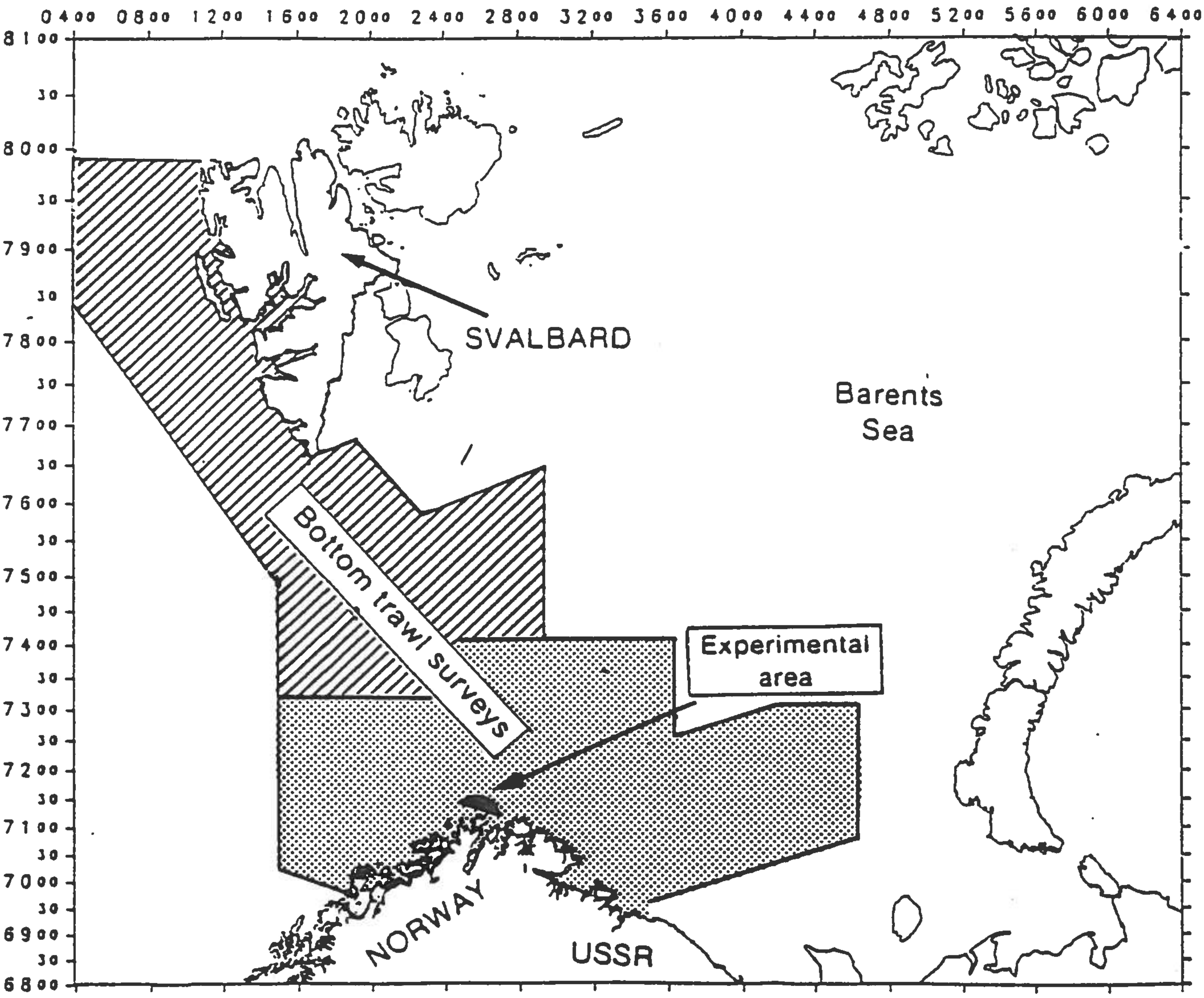
SVALBARD
Barents Sea
Bottom trawl surveys
Experimental area
NORWAY
USSR

Fig 2a

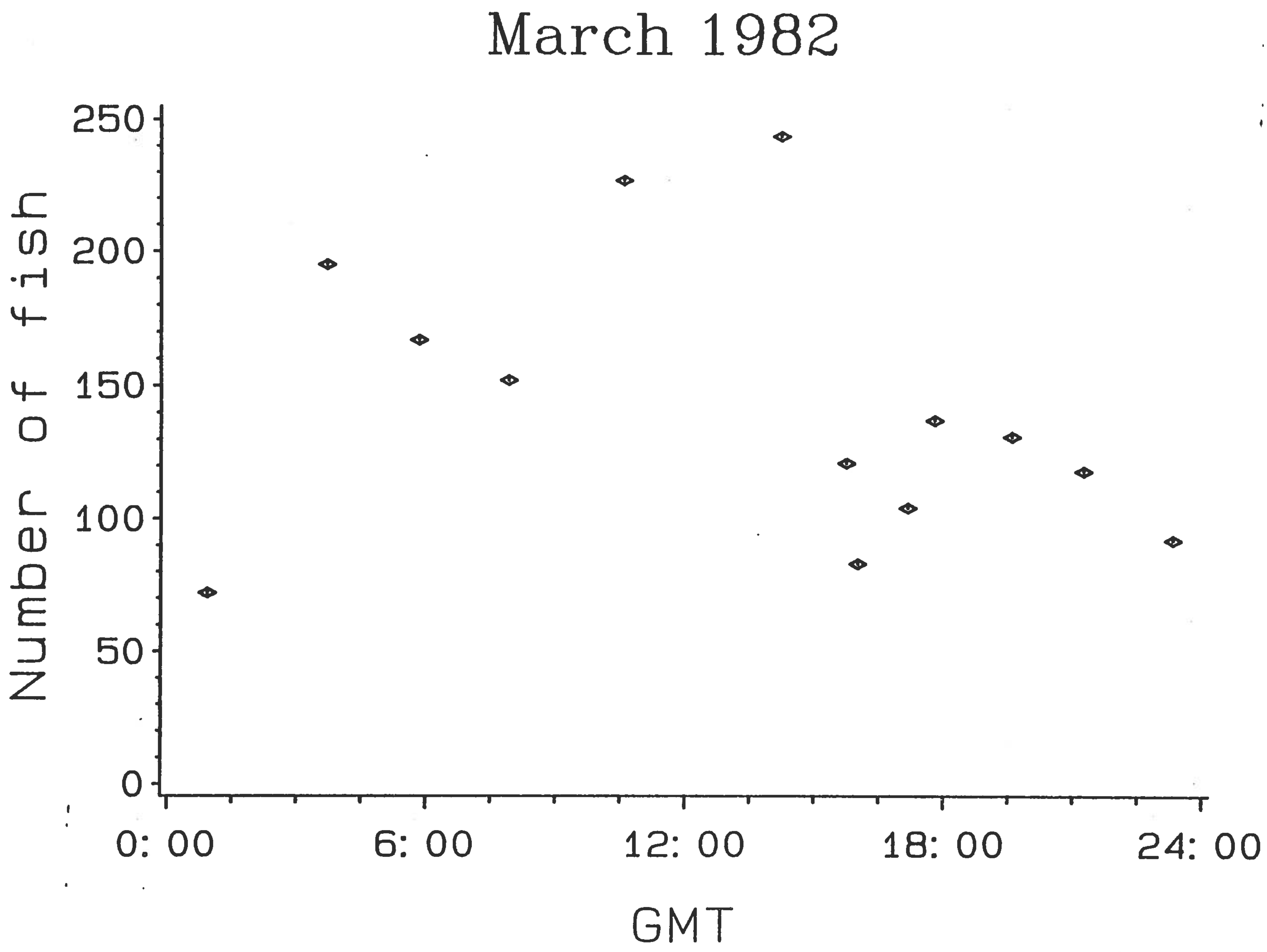
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Fig 26

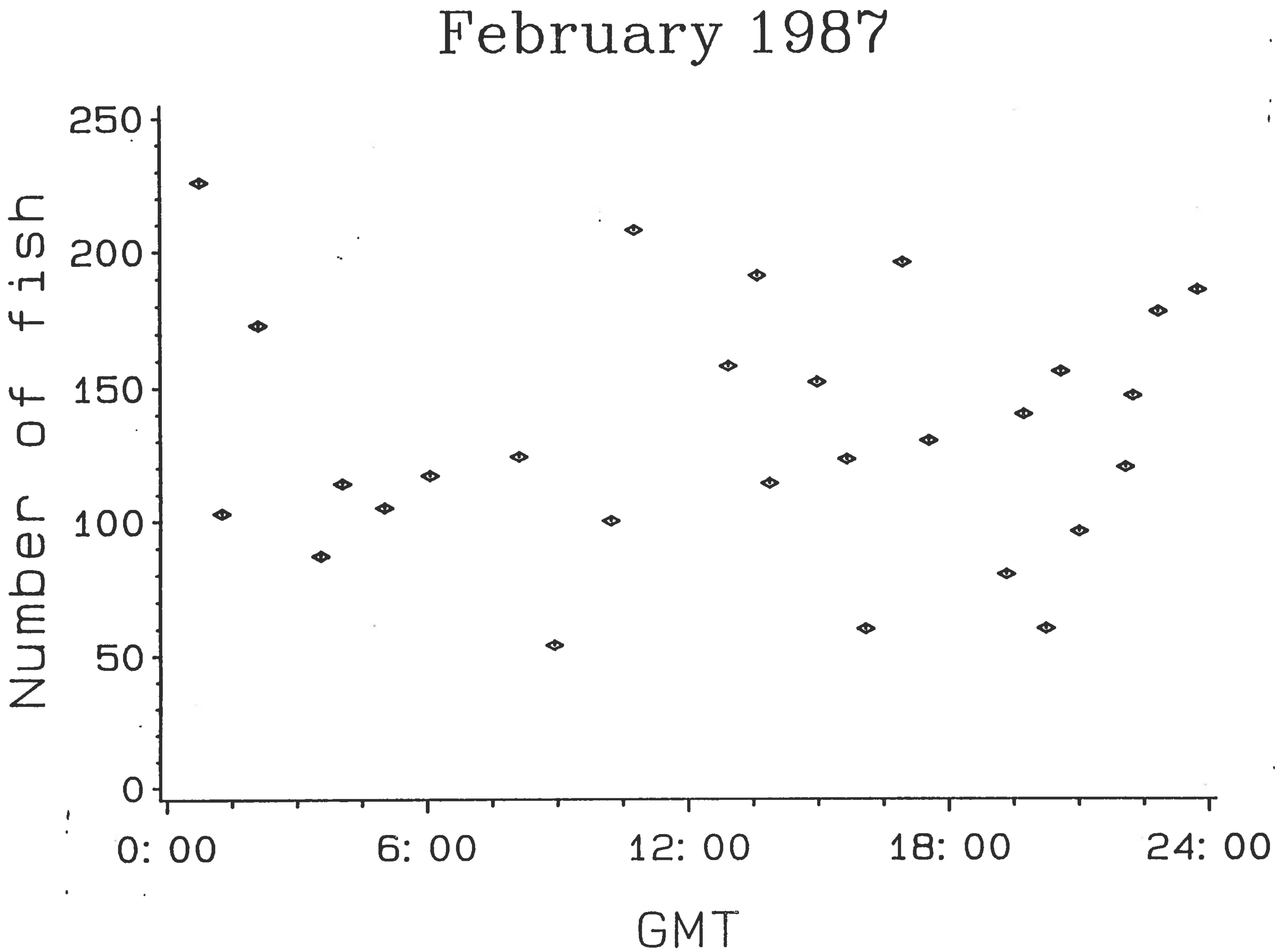

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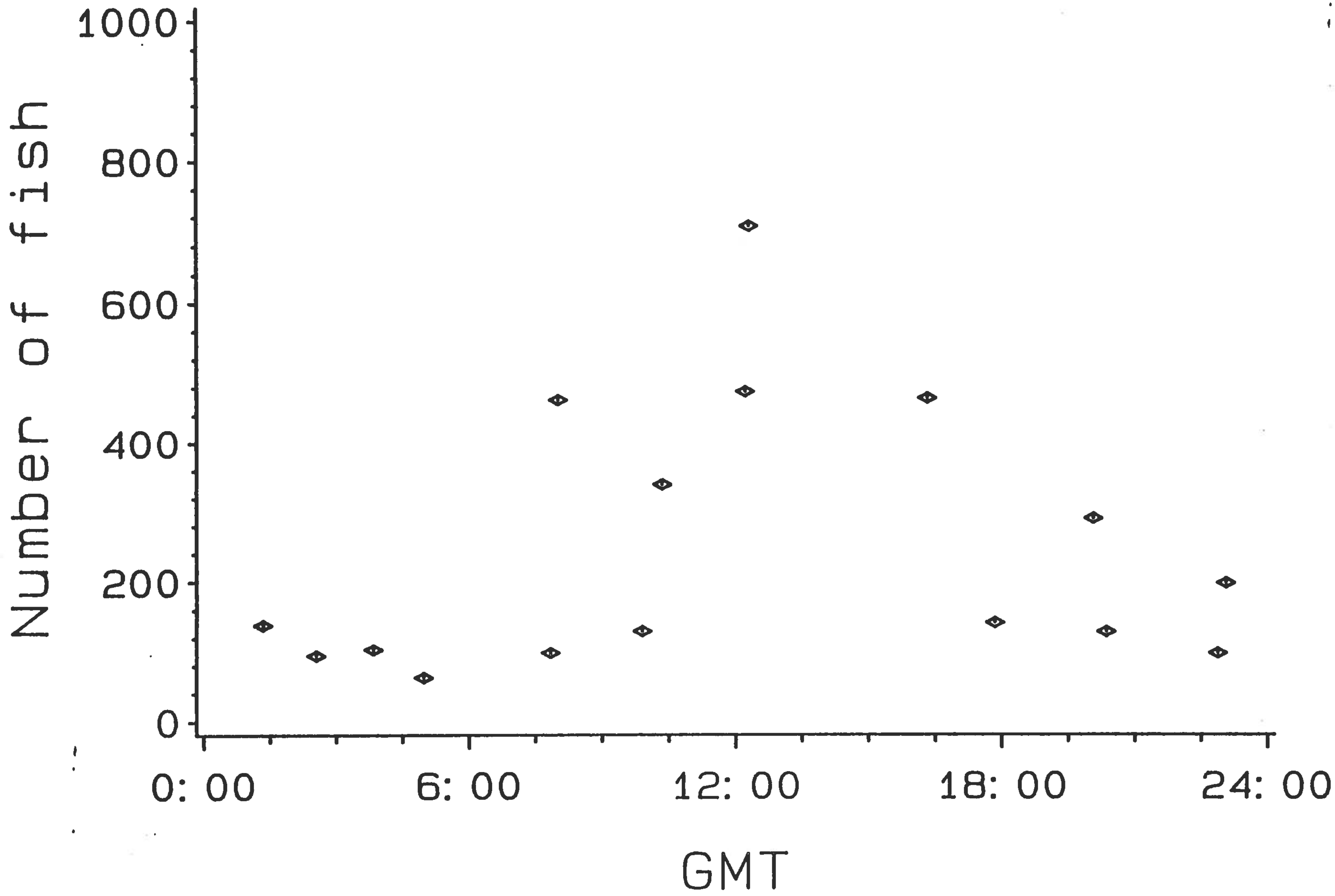
Fig 2c

February 1988



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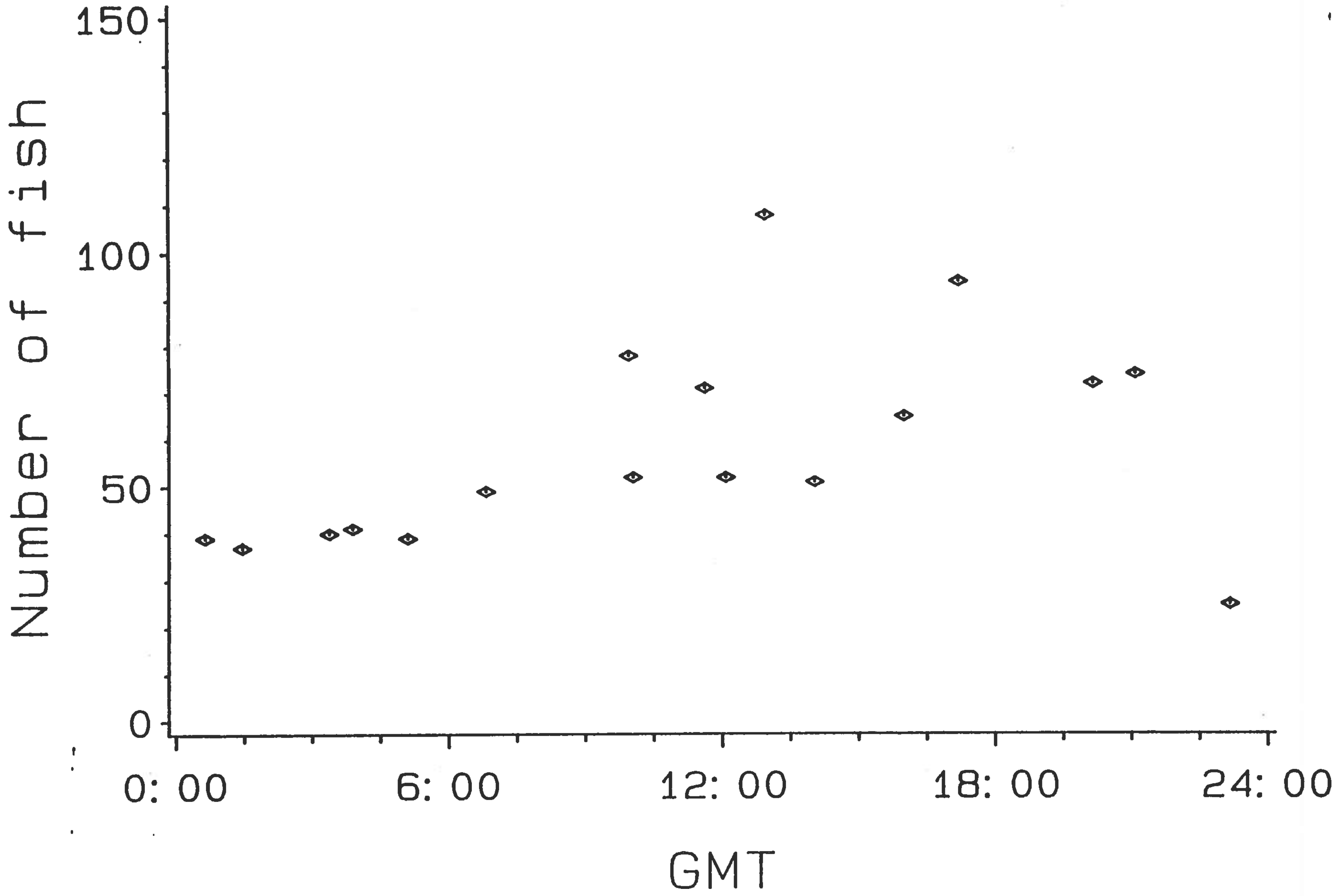

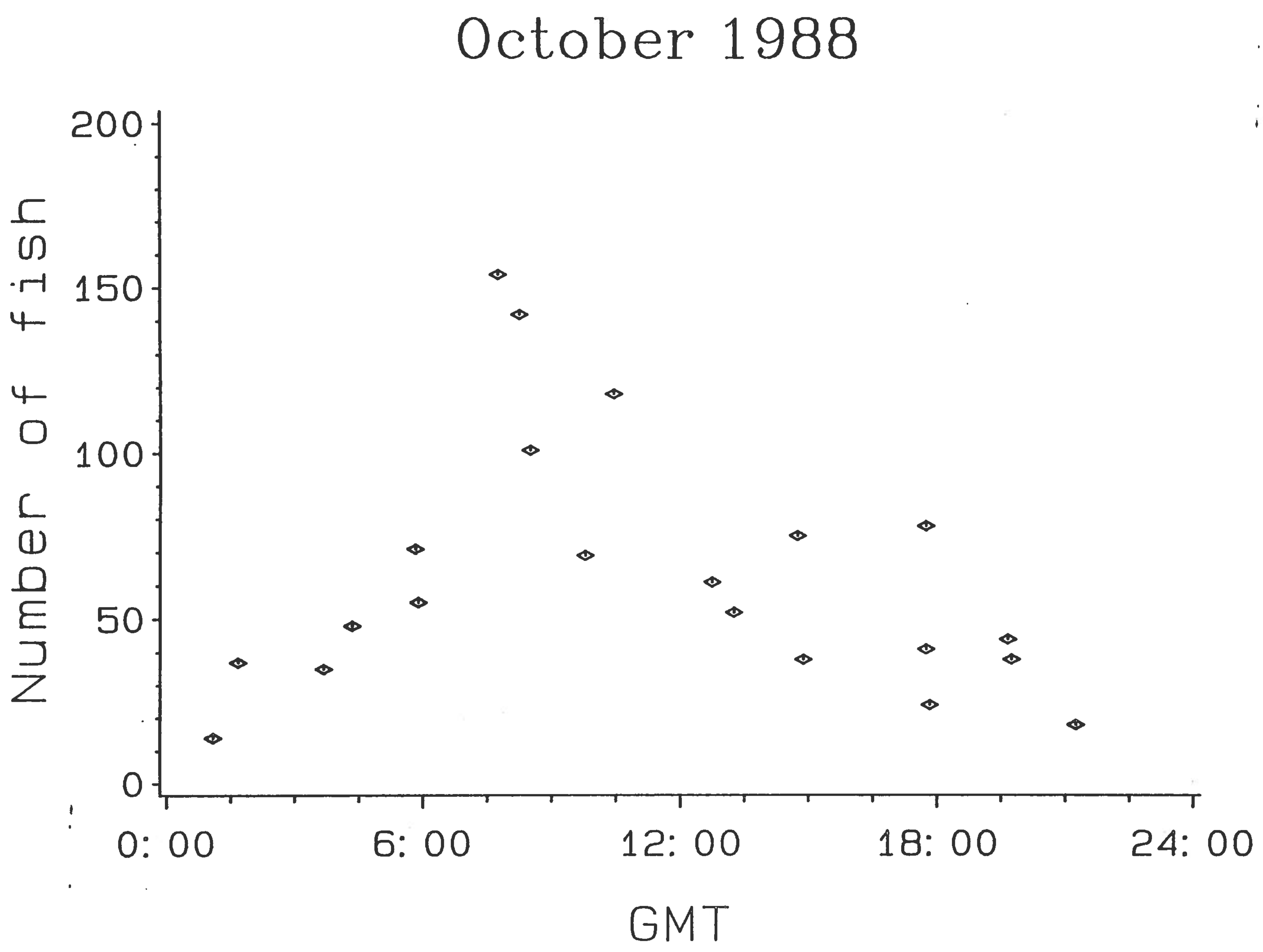
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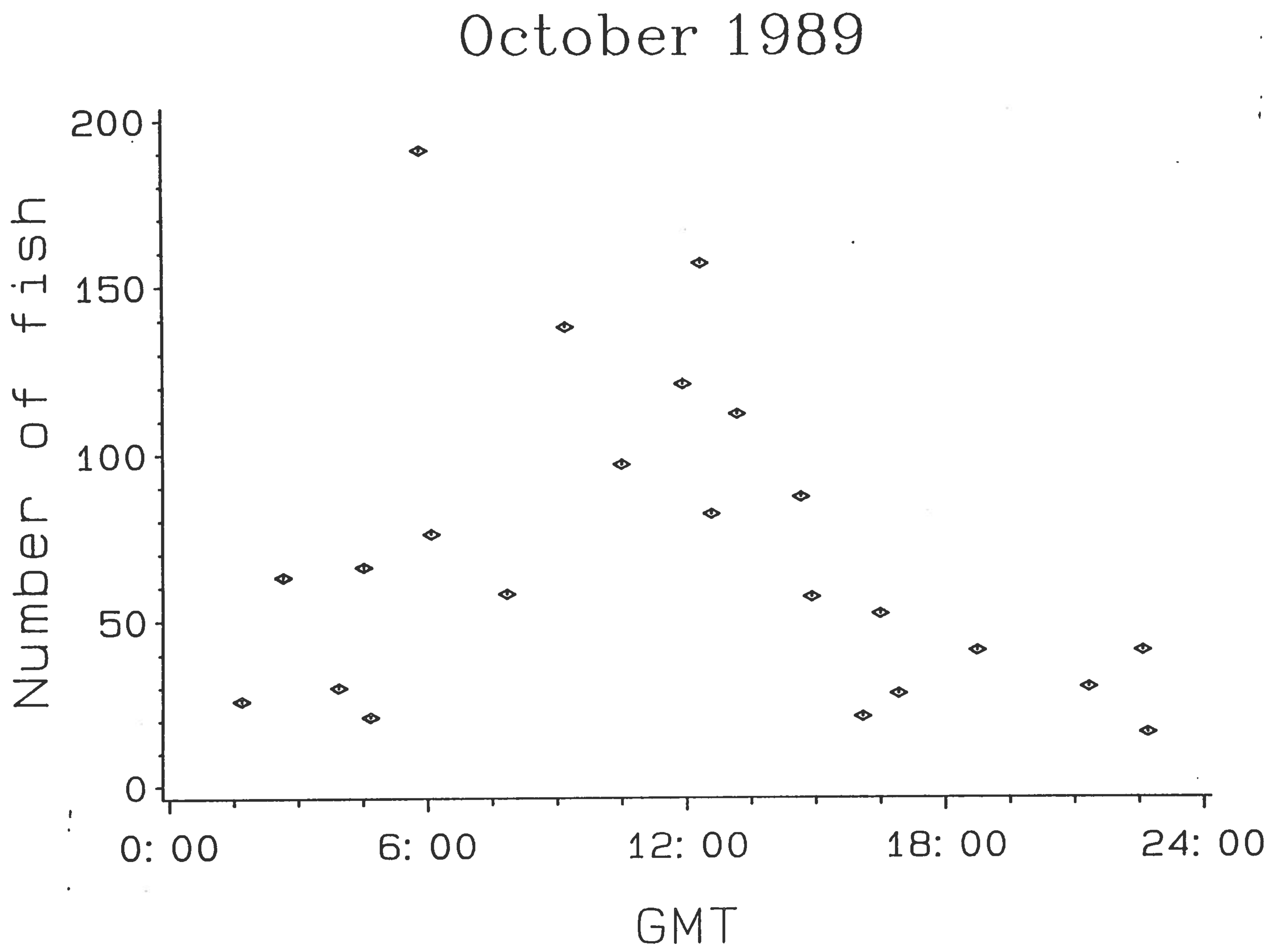

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Fig 2a

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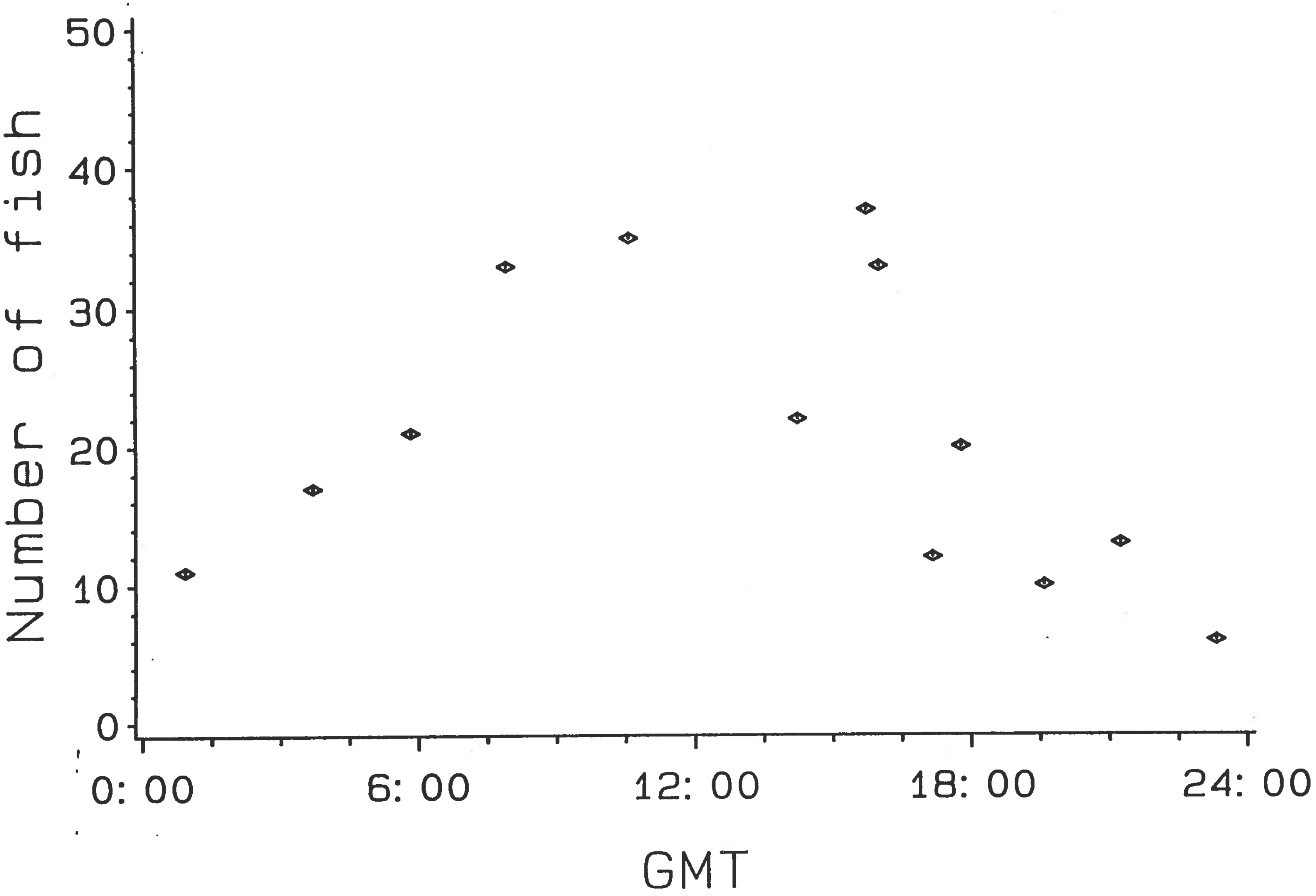

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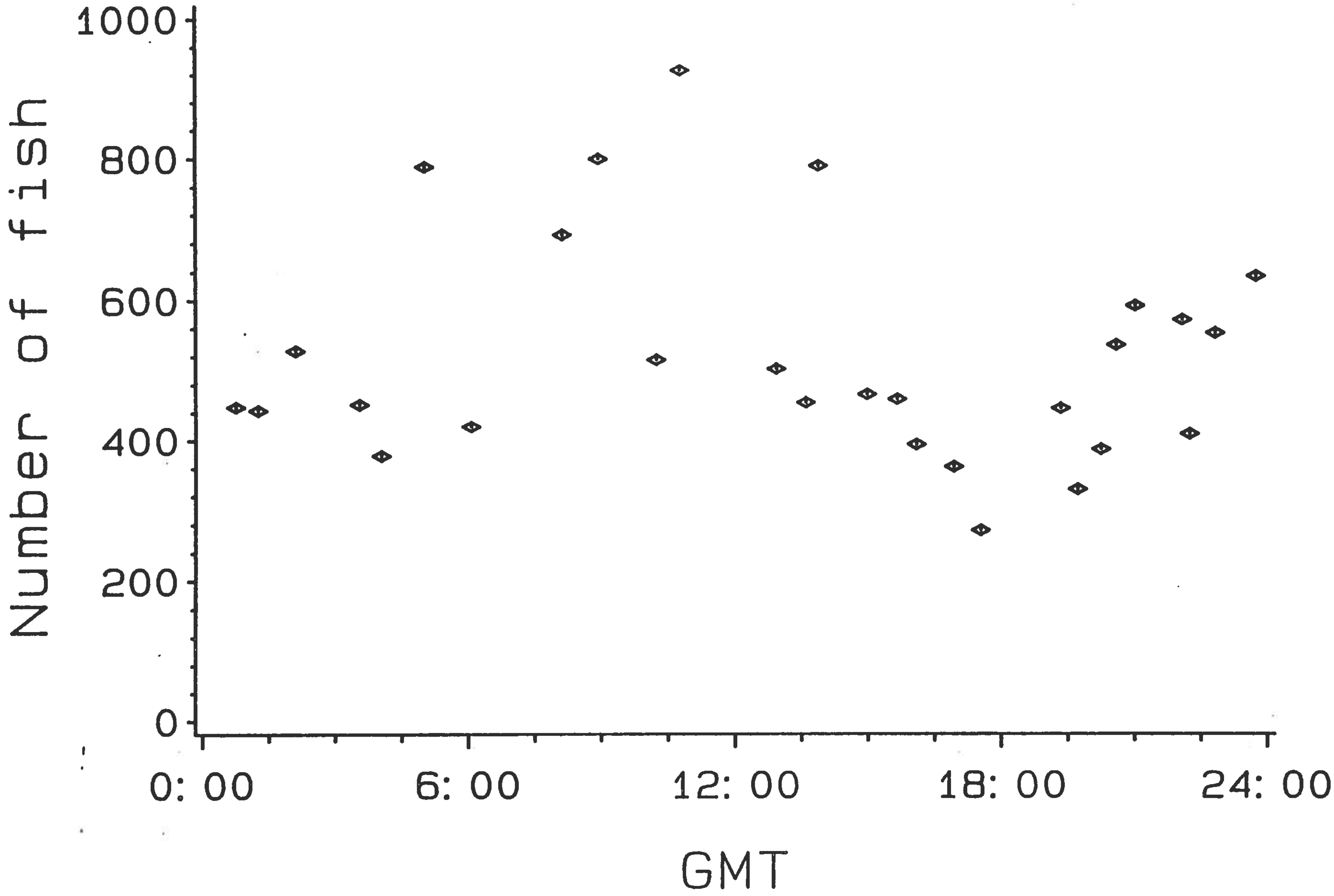

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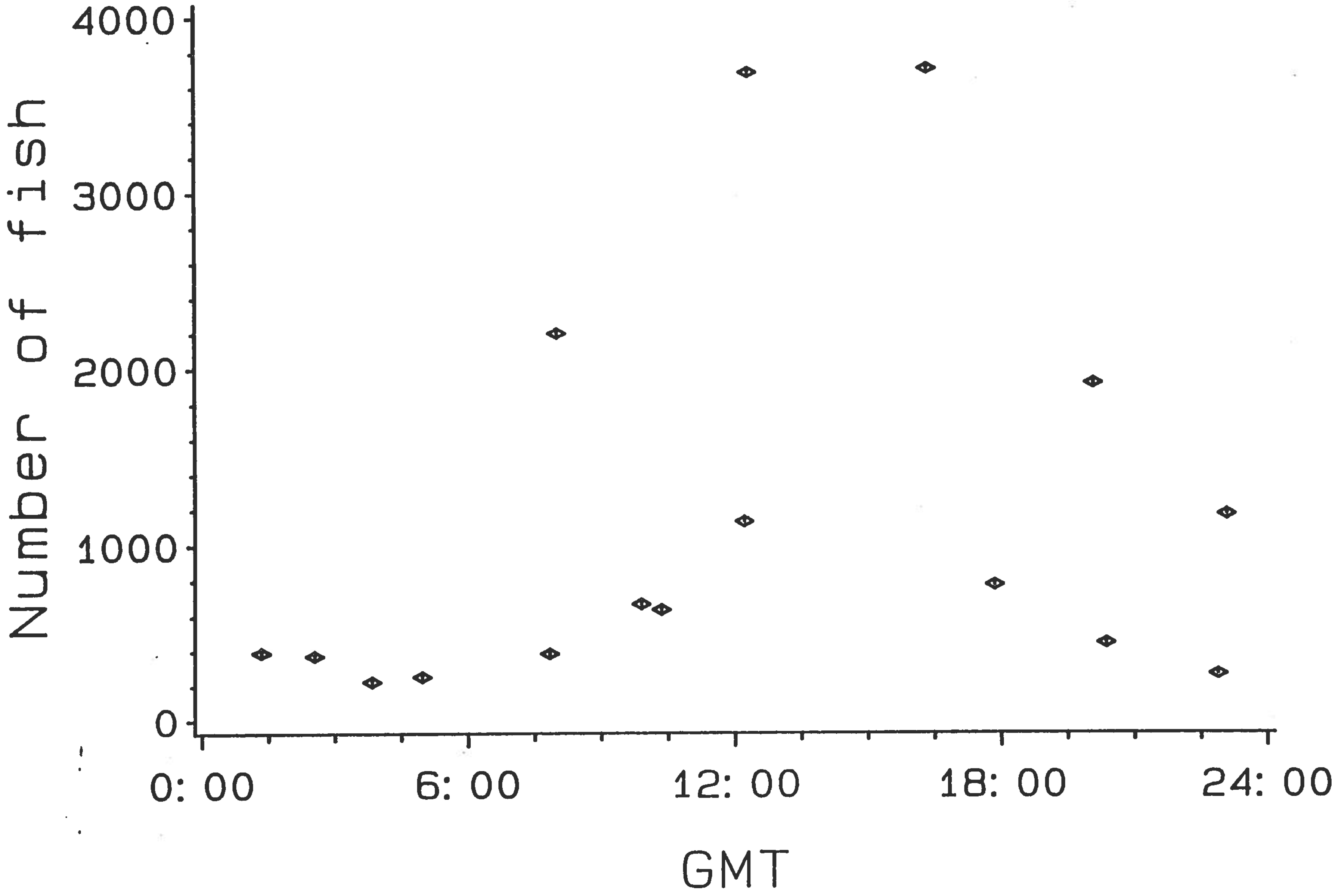
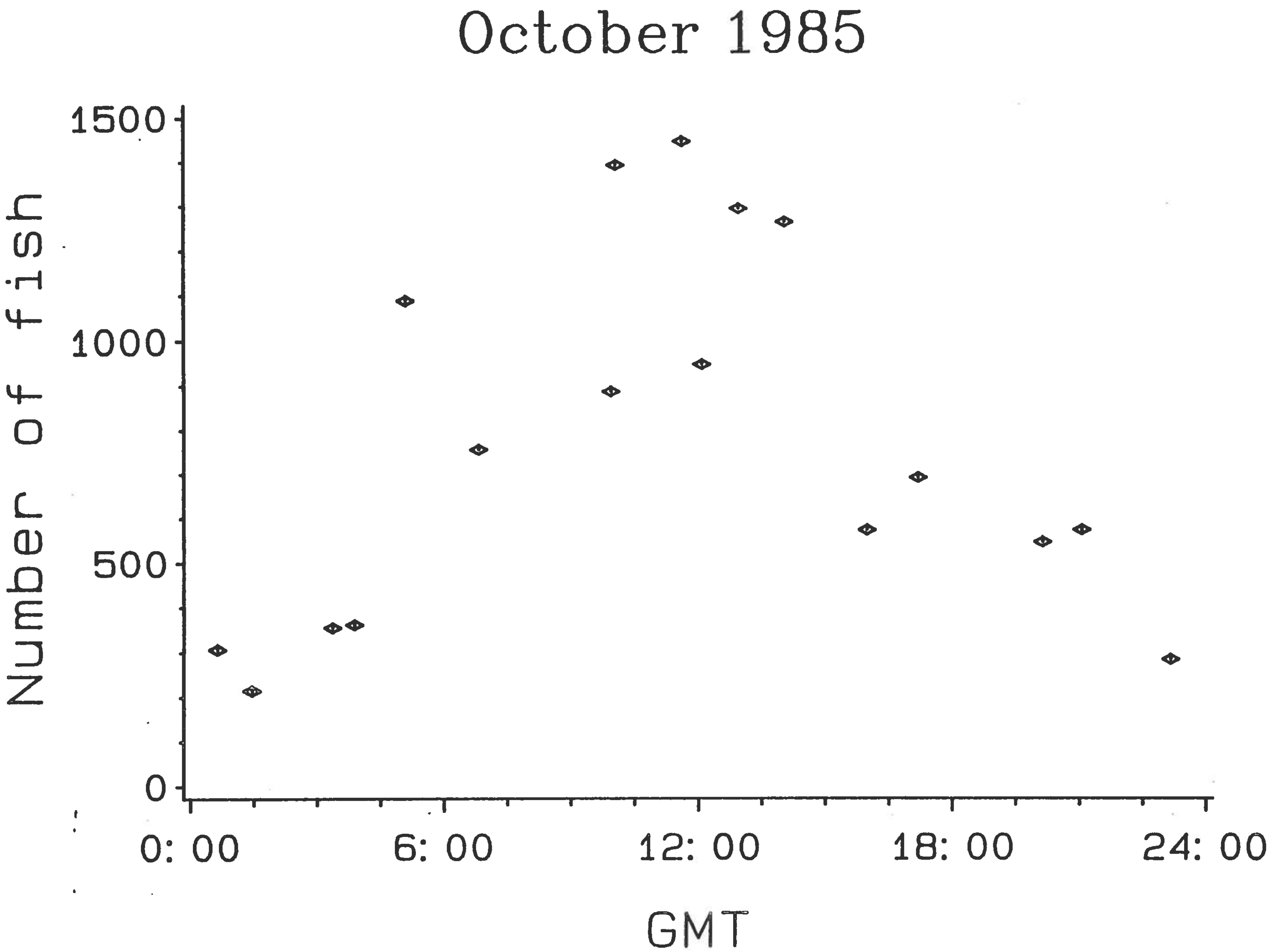
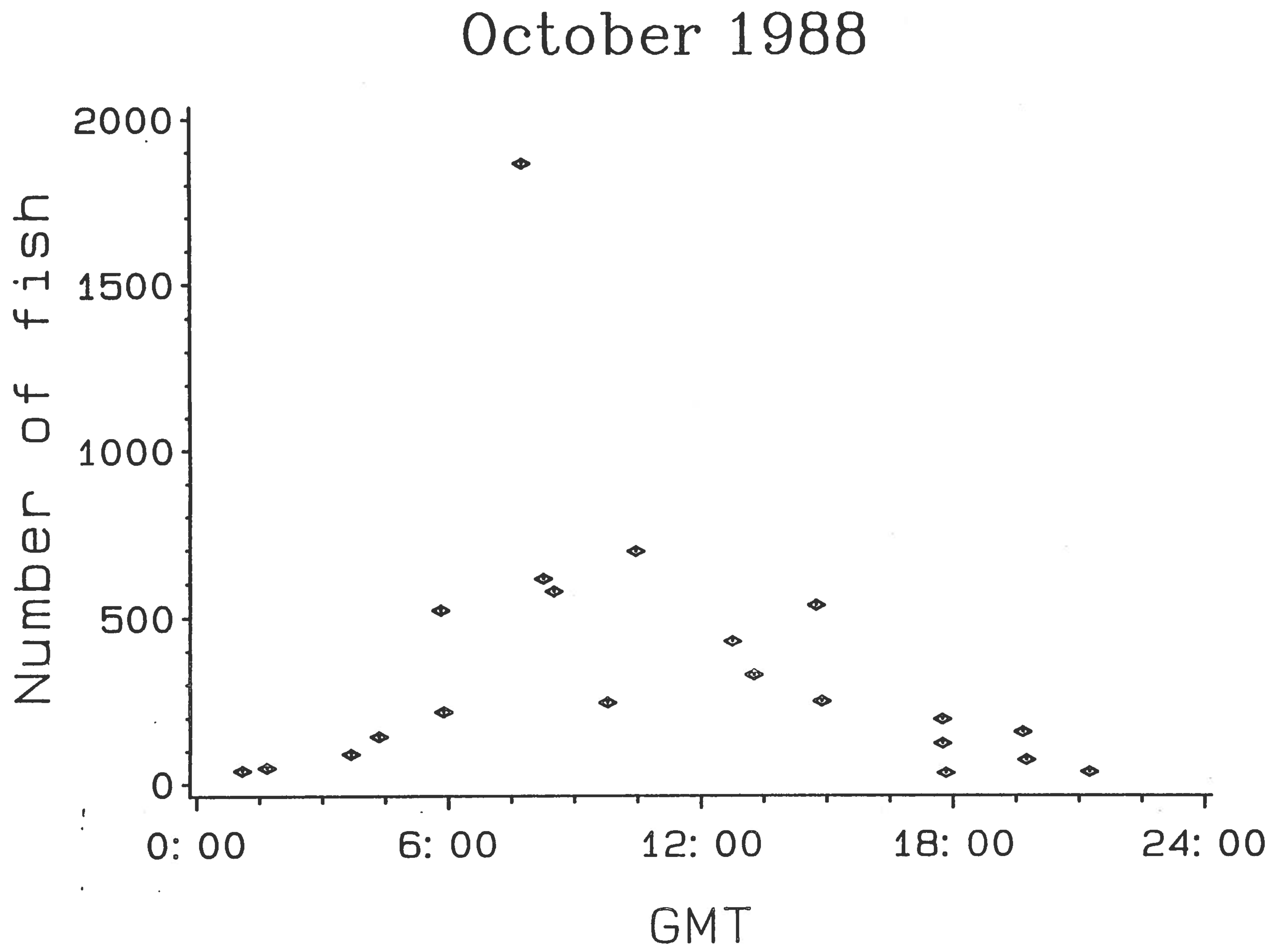


Fig. 3d



October 1985
Number of fish
1500
1000
500
0
0: 00
6: 00
12: 00
18: 00
24: 00
GMT

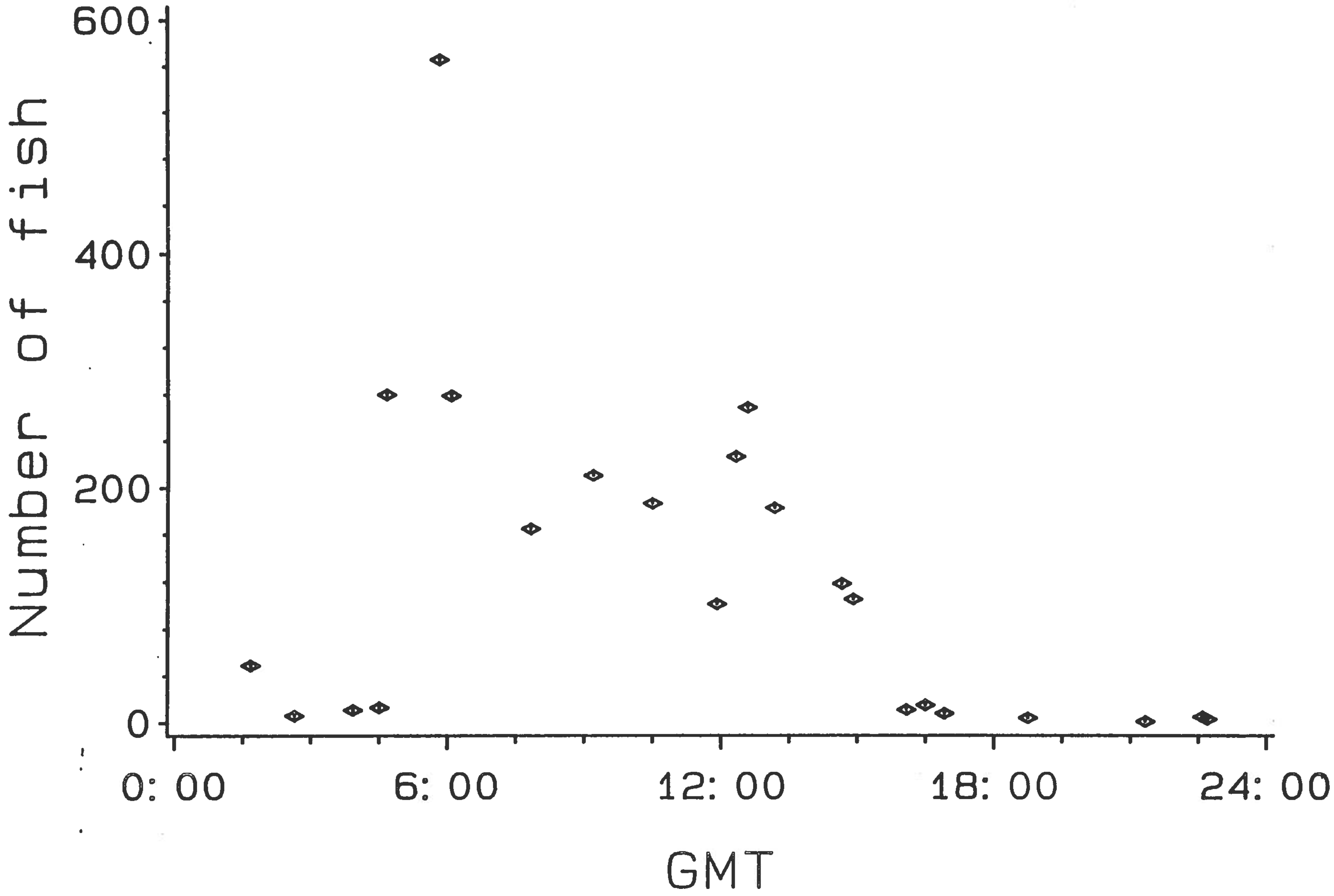
FIG 3e



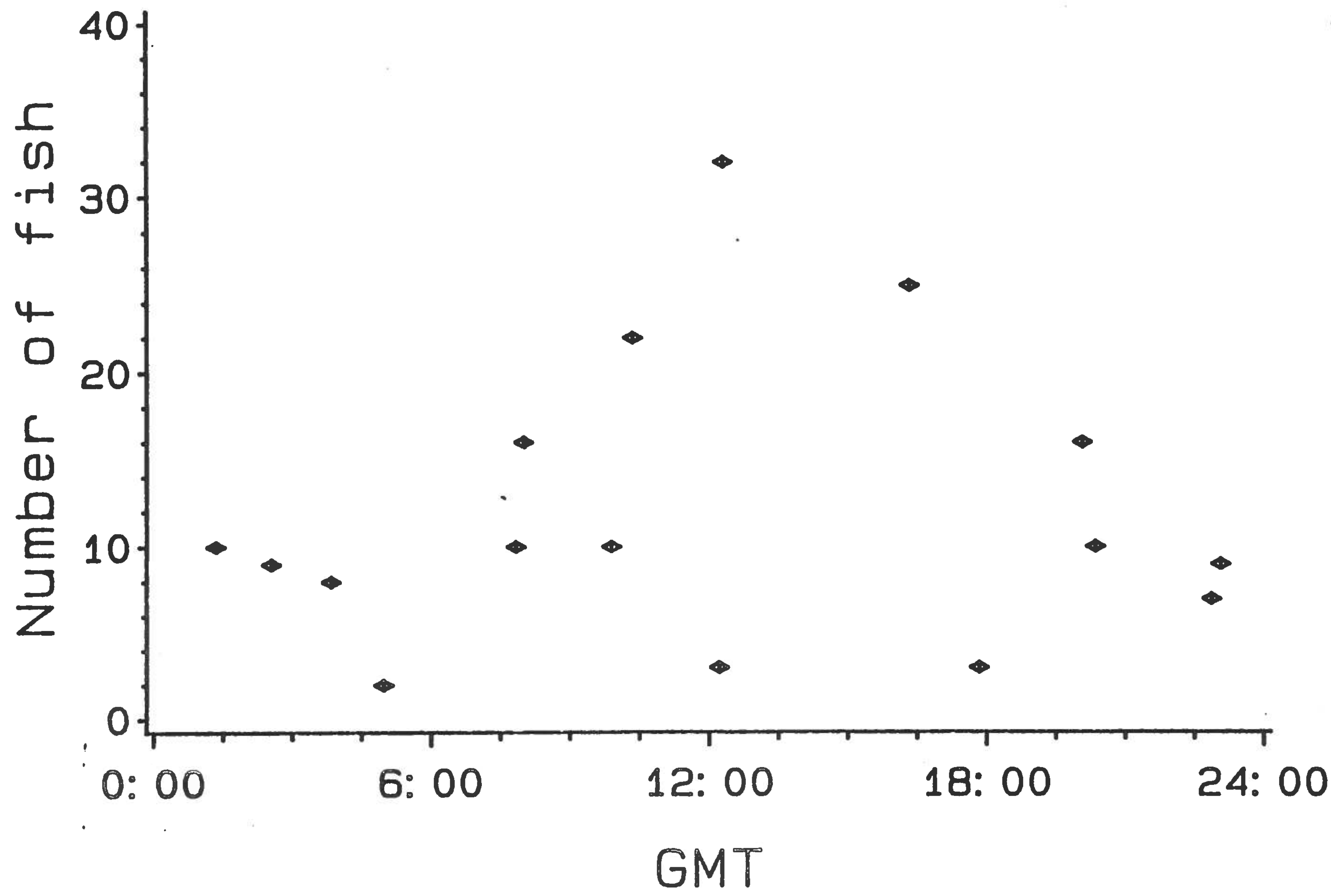
October 1988
Number of fish
2000
1500
1000
500
0
0: 00
6: 00
12: 00
18: 00
24: 00
GMT

Fig 3f

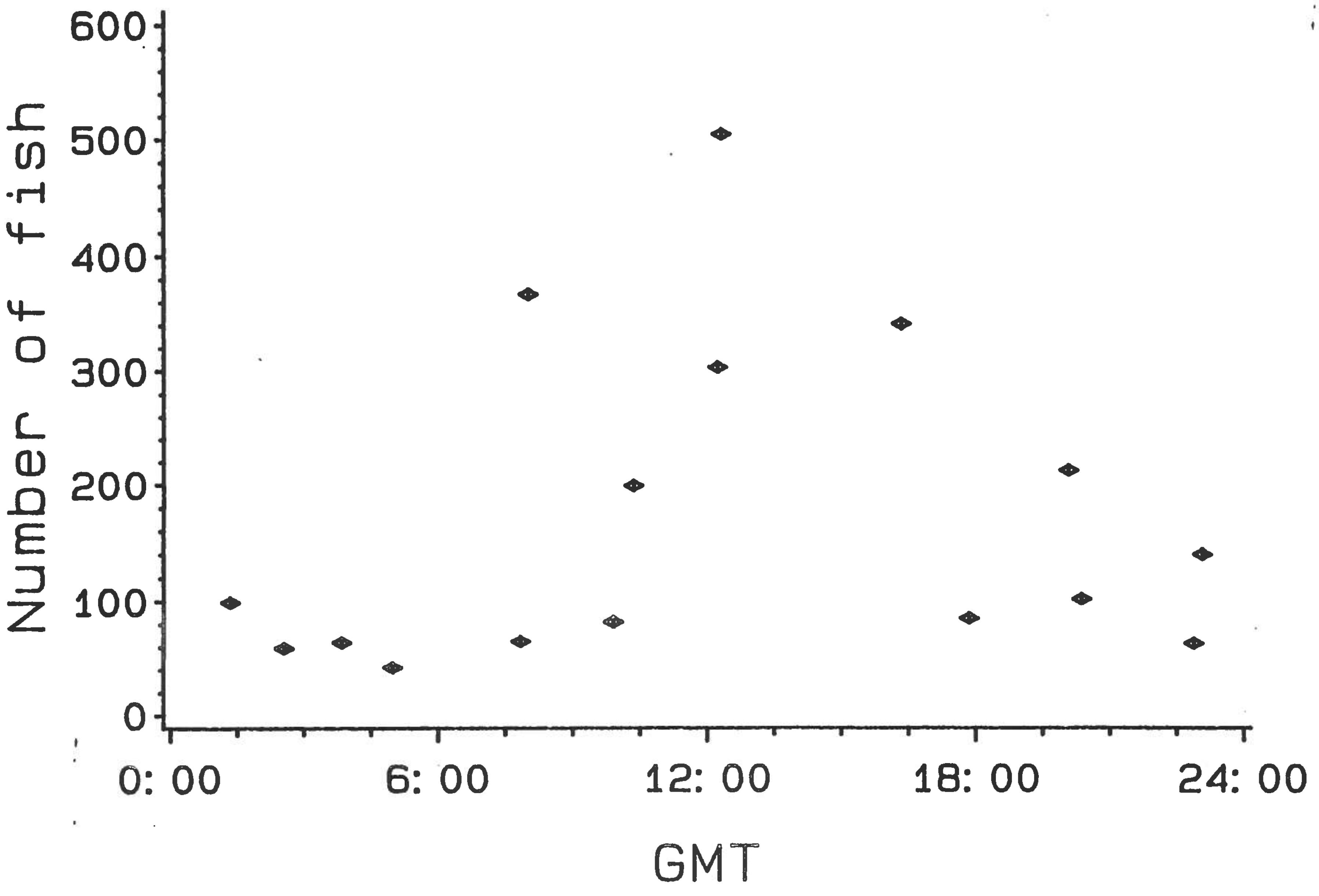
October 1989



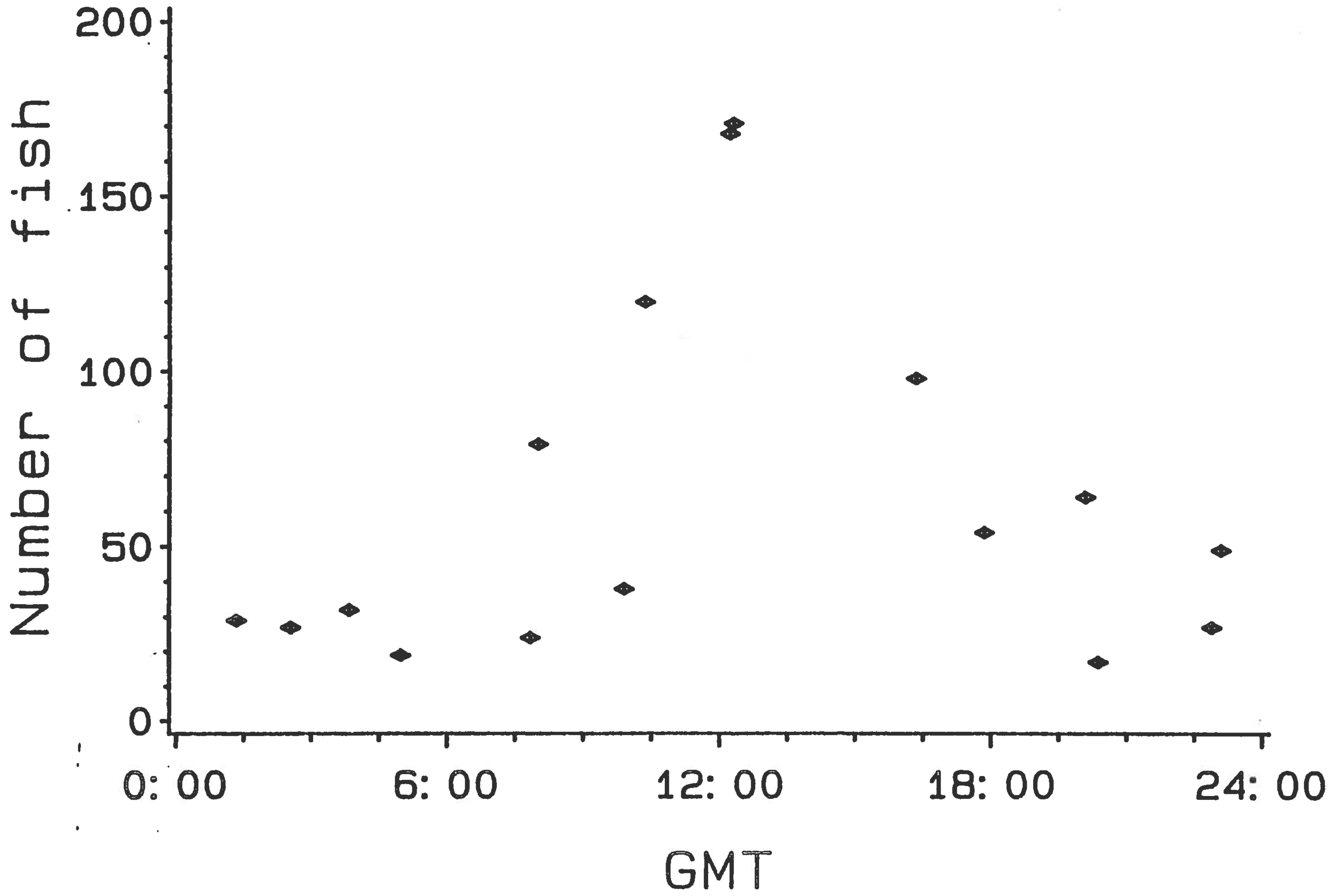
No. of small cod Febr. 1988



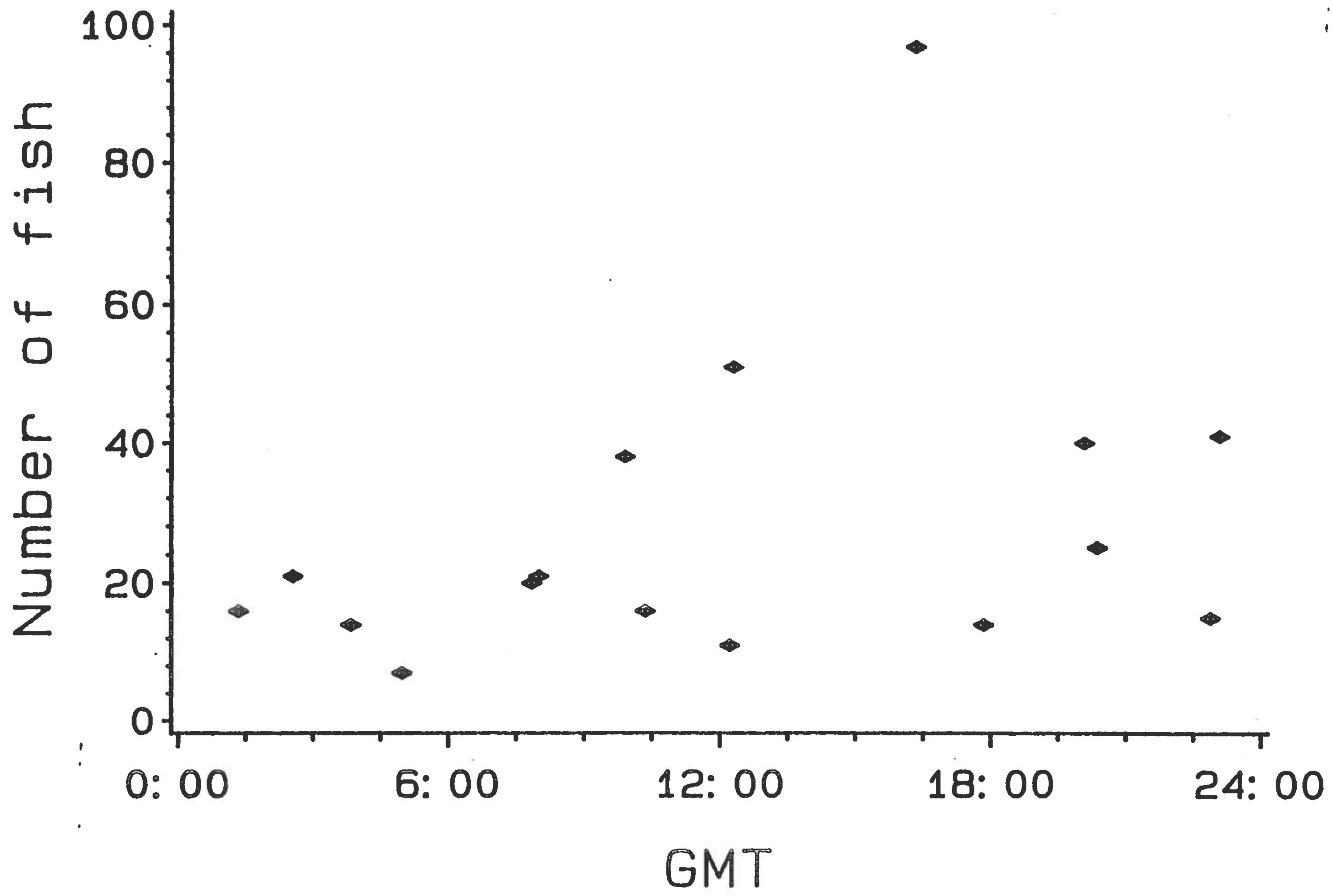
No. of medium cod Febr. 1988



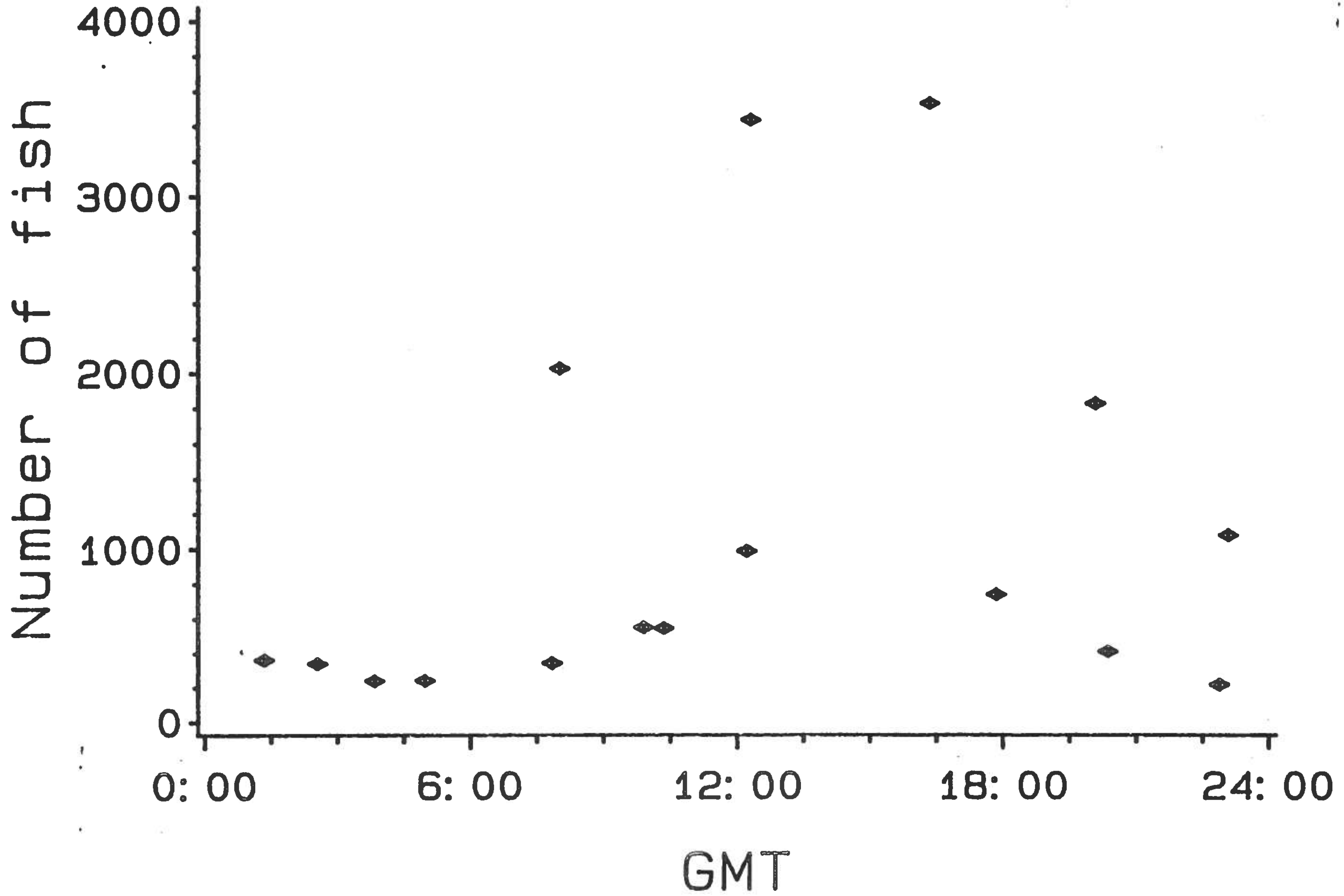
No. of large cod Febr. 1988



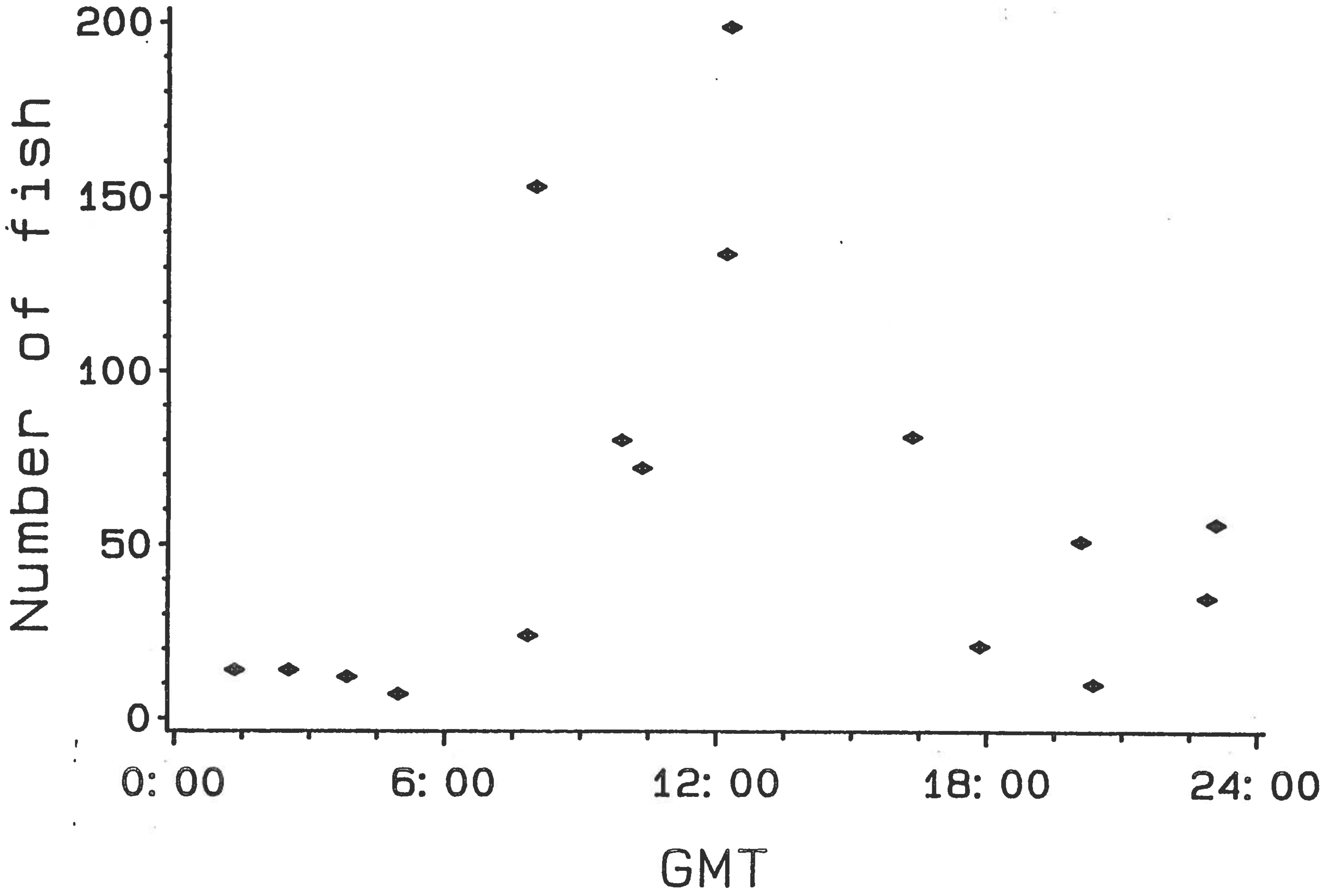
No. of small haddock Febr. 1988



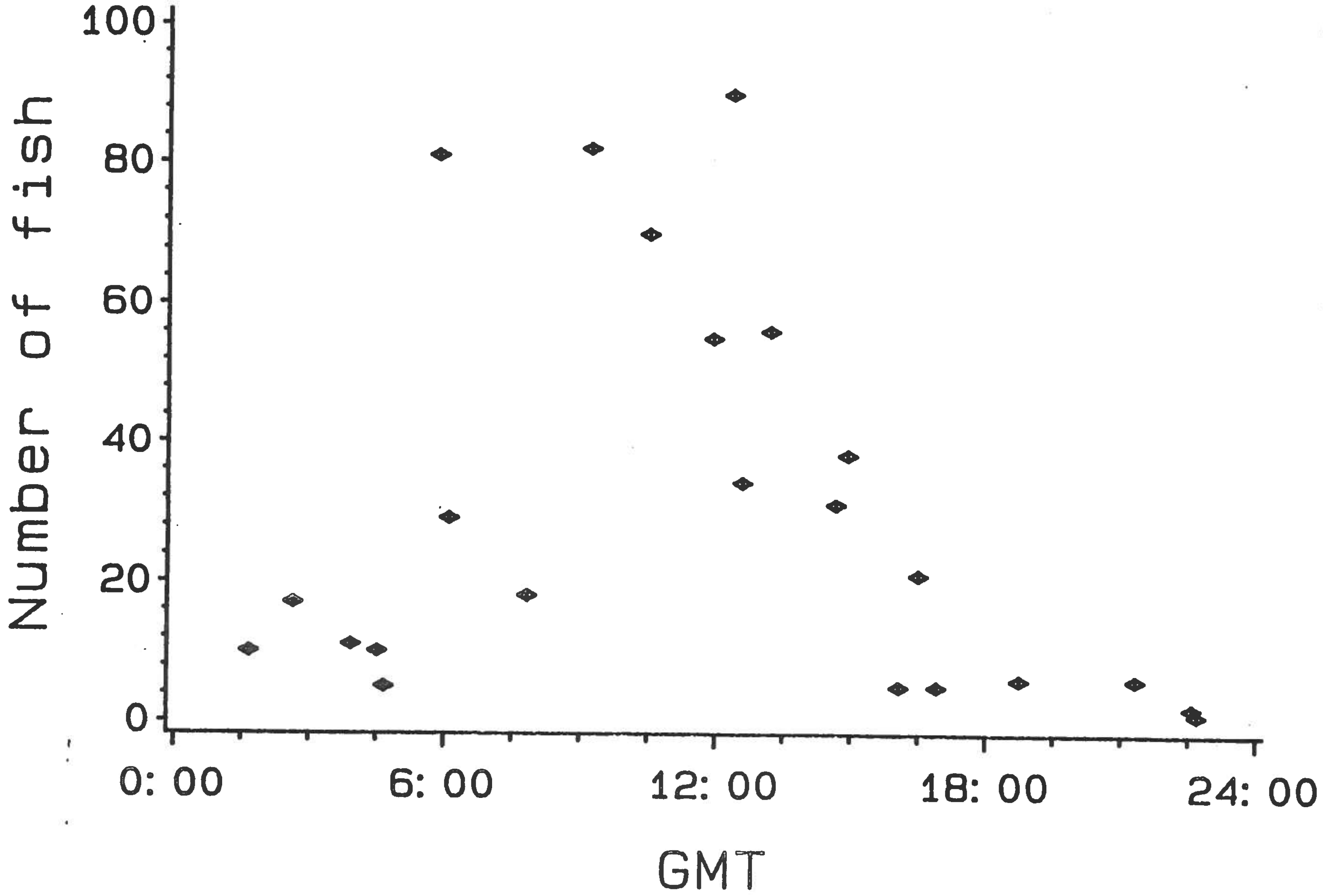
No. of medium haddock Febr. 1988



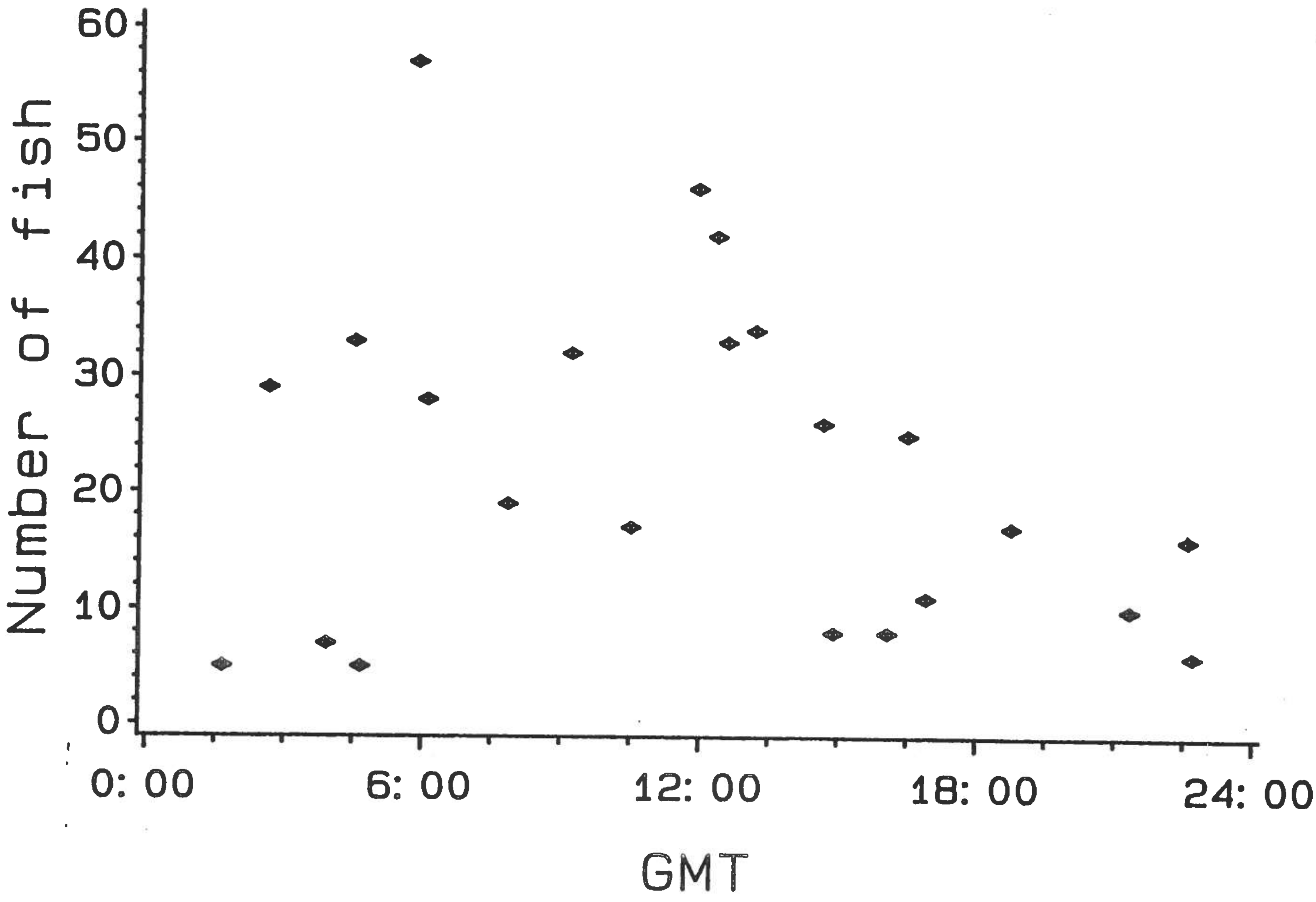
No. of large haddock Febr. 1988



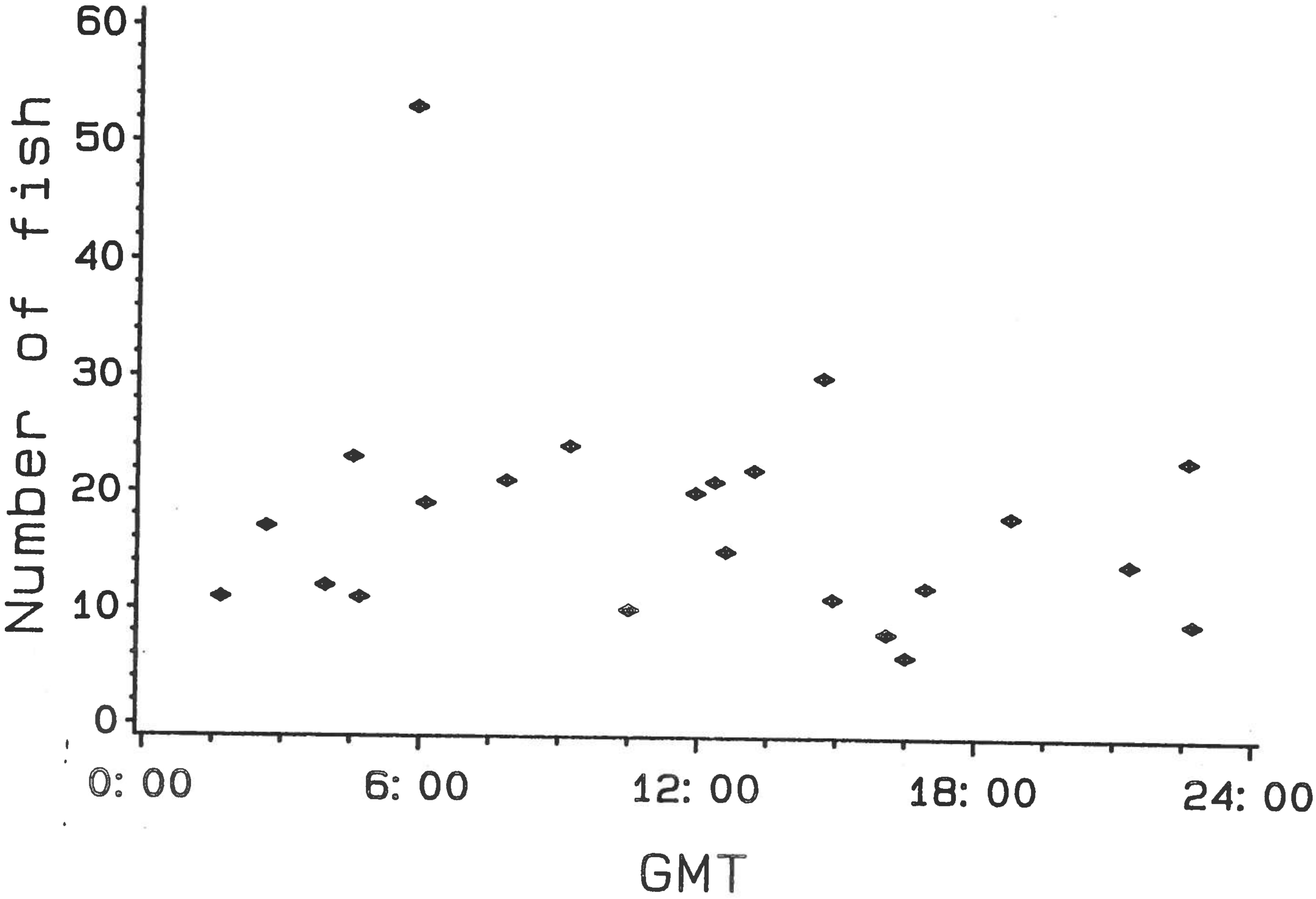
No. of small cod October 1989



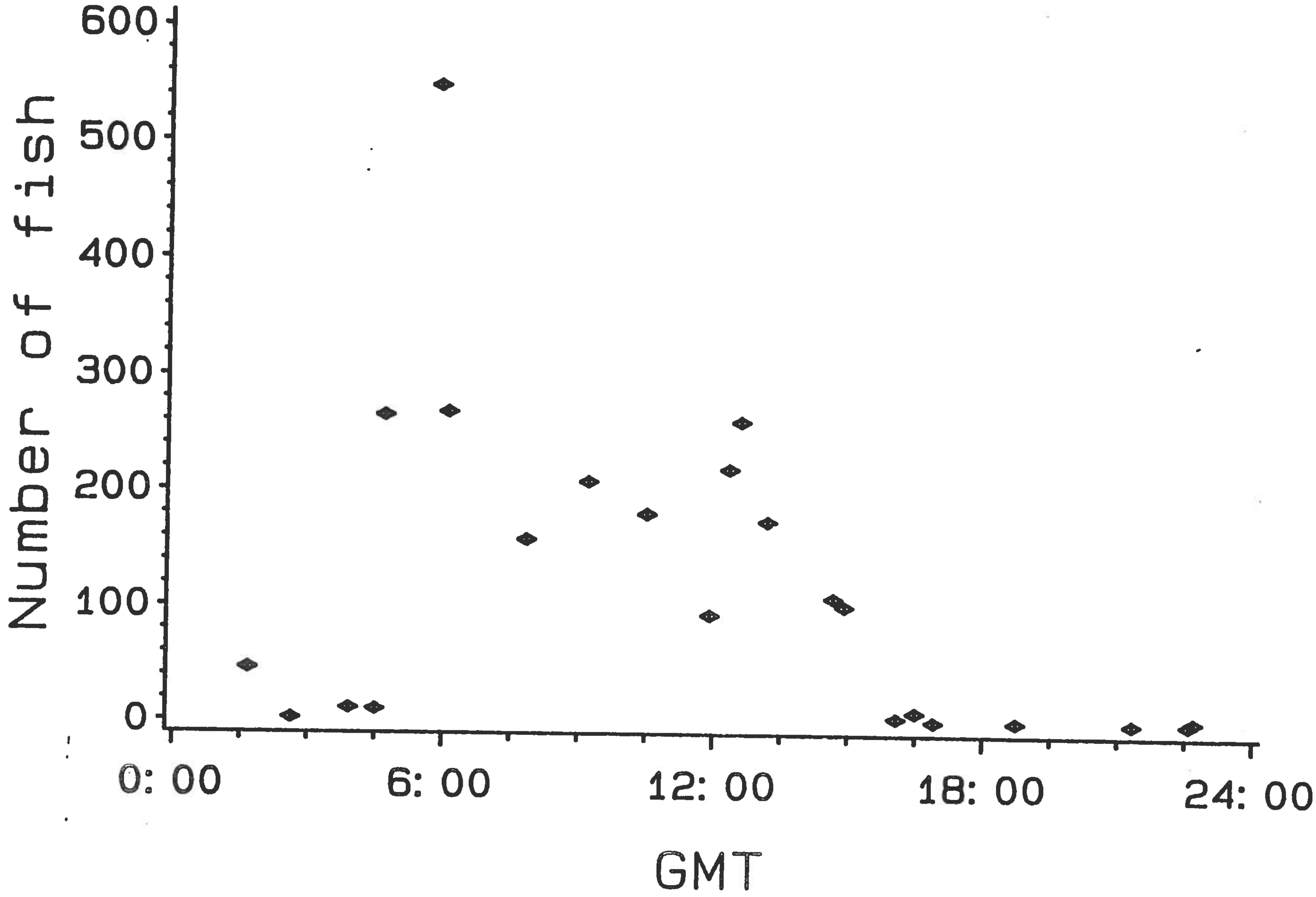
No. of medium cod October 1989



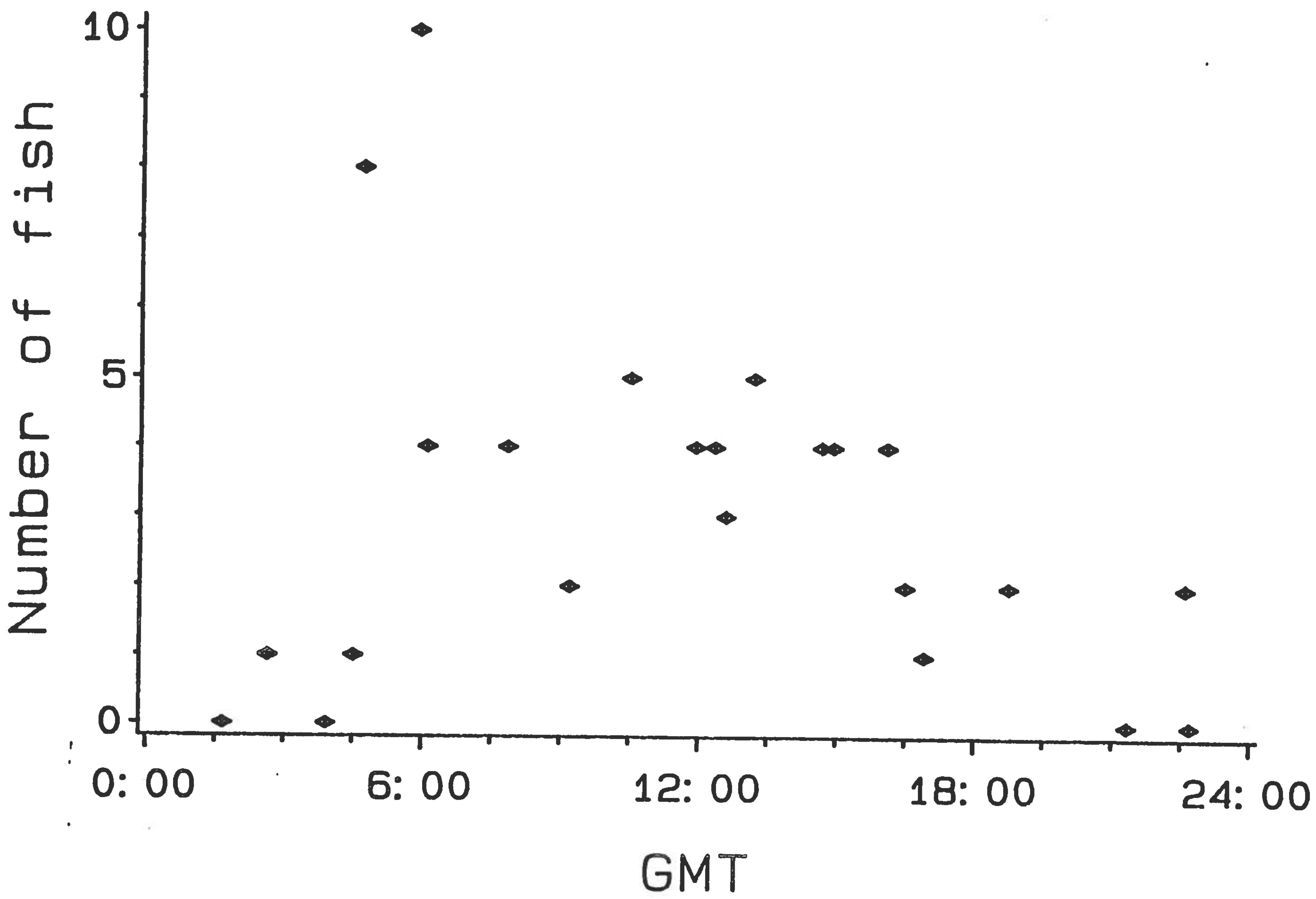
No. of large cod October 1989



No. of small haddock October 1989



No. of medium haddock October 1989



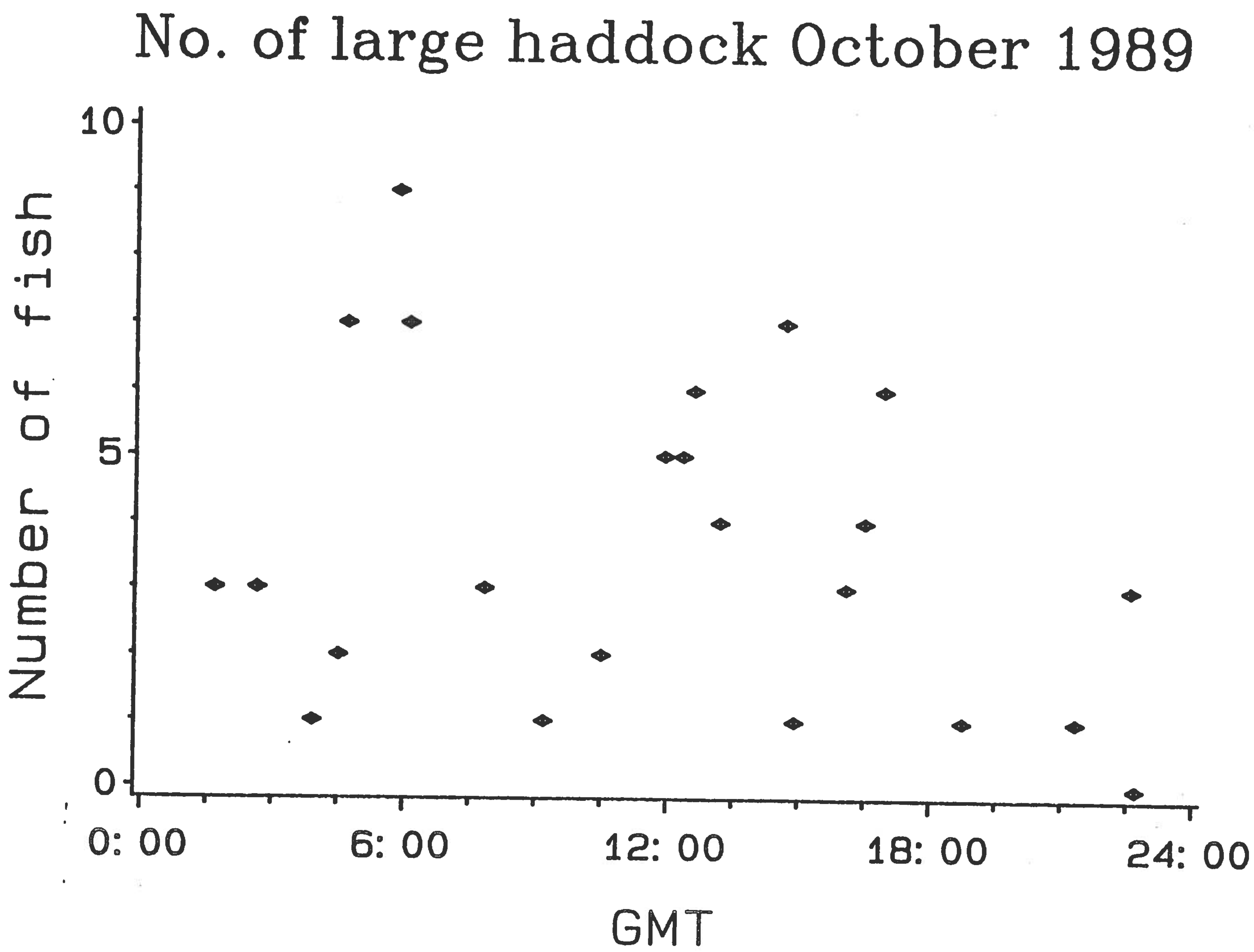

No. of large haddock October 1989
Number of fish
10
5
0
0: 00
6: 00
12: 00
18: 00
24: 00
GMT

Fig 6

February 1987

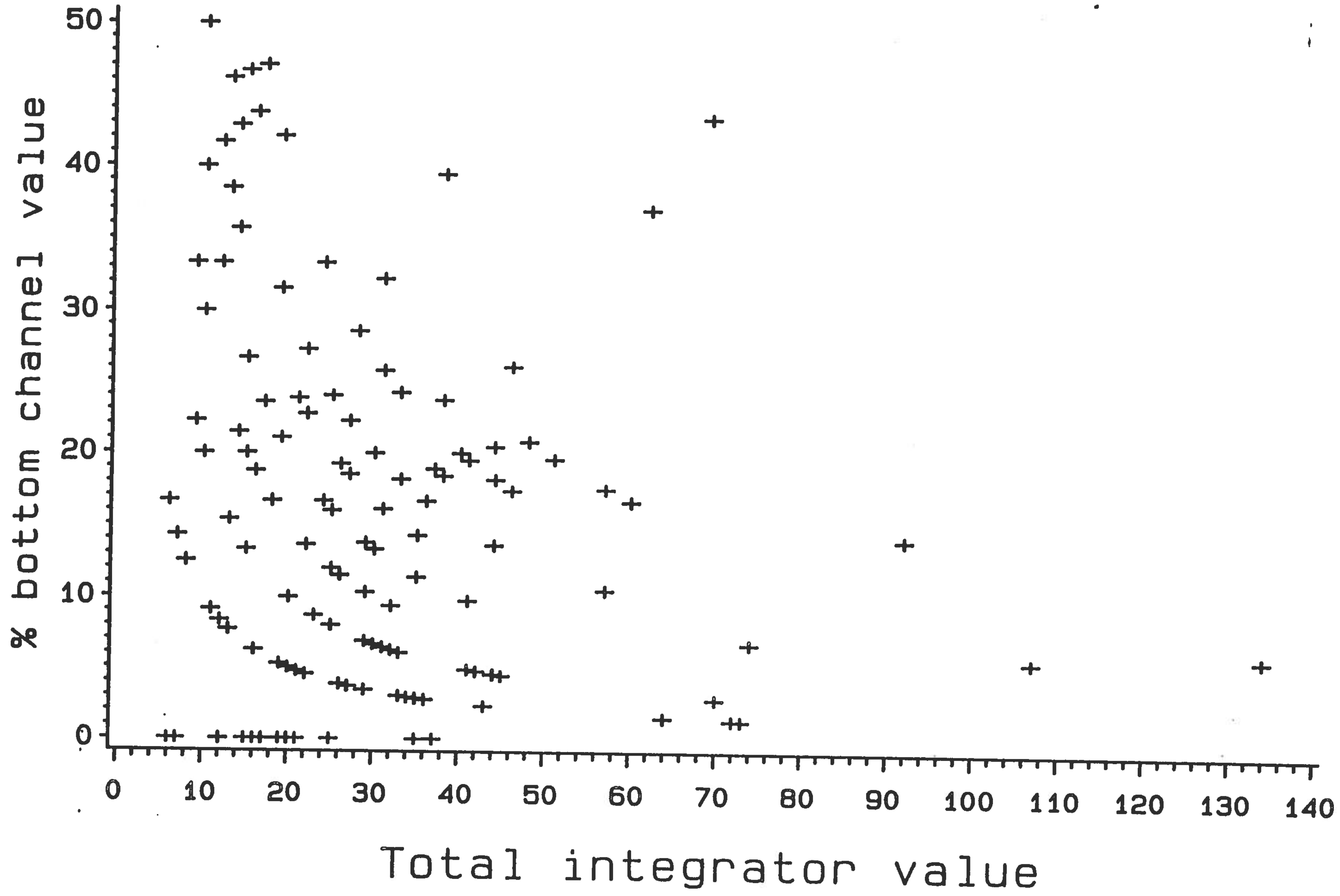
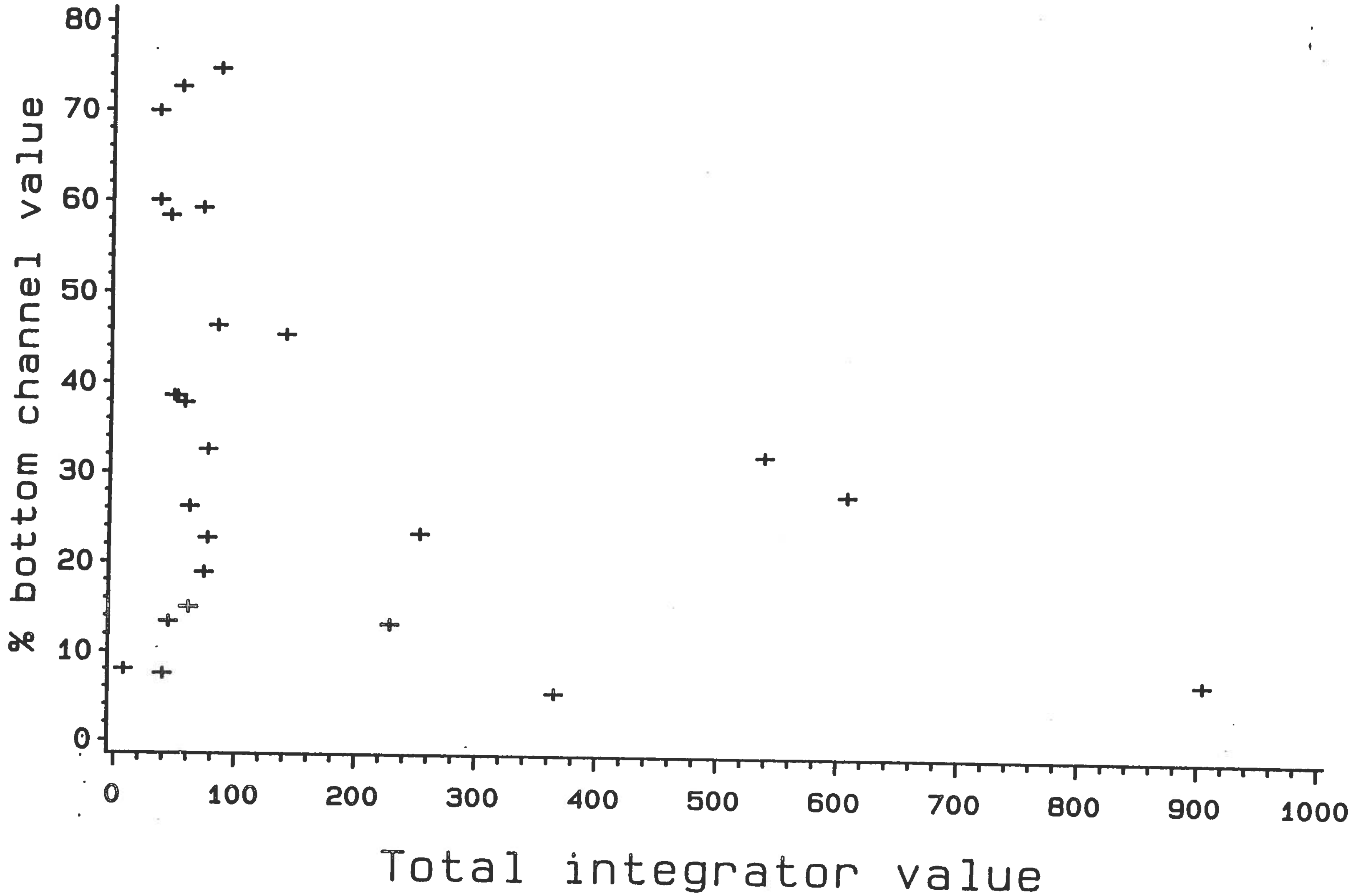
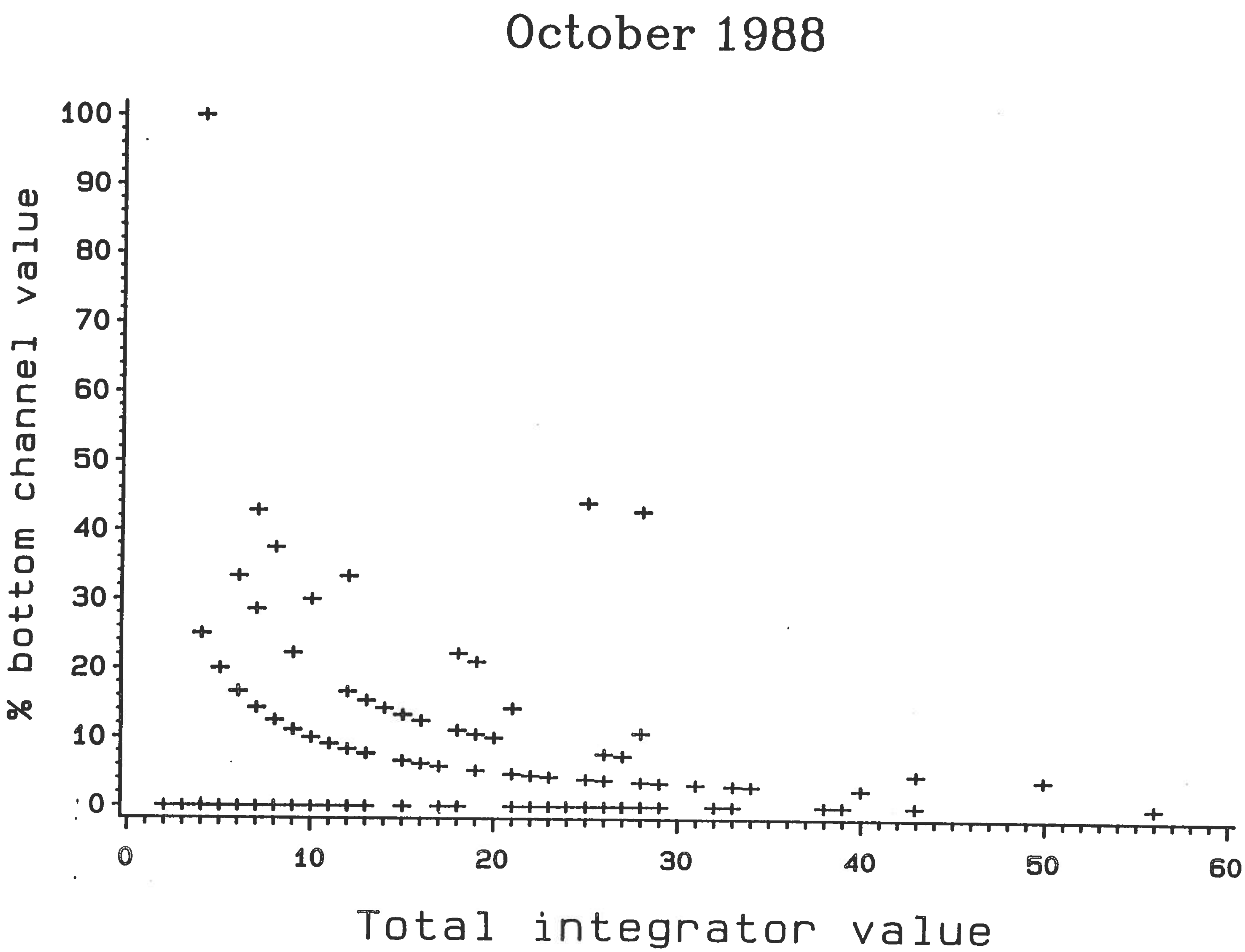
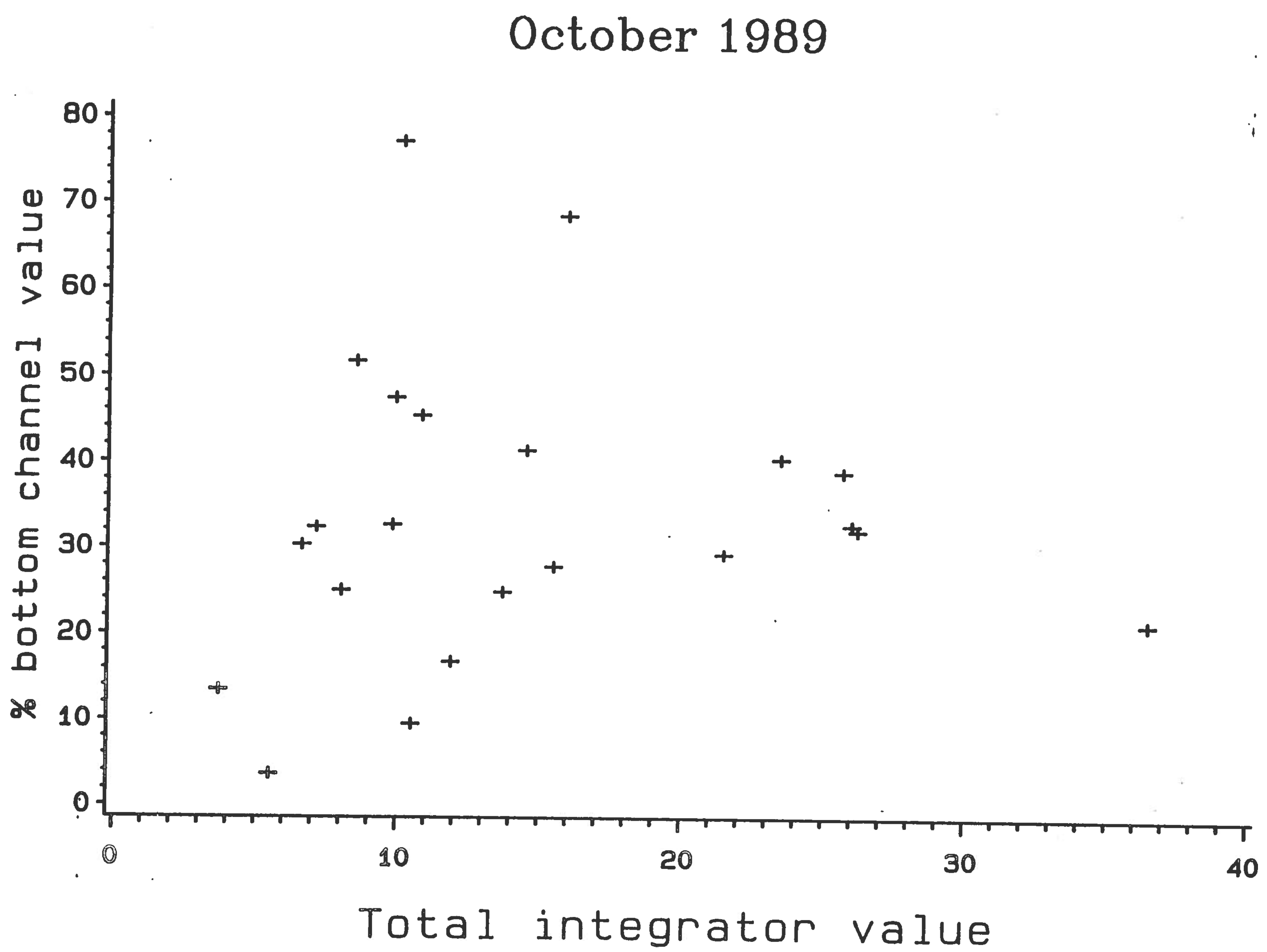


Fig 4

February 1988




October 1988
% bottom channel value
0
10
20
30
40
50
60
70
80
90
100
Total integrator value
0
10
20
30
40
50
60



October 1989
% bottom channel value
0
10
20
30
40
50
60
70
80
Total integrator value
0
10
20
30
40