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Estimates of tag extrusion and initial tagging mortality in an internal tagging experiment

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Introduction

In addition to determining migration patterns of fish, mark-recapture experiments may also be used for estimation of certain population parameters, particularly stock size and exploitation rates (Ricker 1958). Estimates of these parameters may be affected by systematic errors in the rate of tag recaptures due, for example, to extra mortality amongst marked fish resulting from the effects of the tag and its application (Ricker's Type A error), or to a sudden loss of tags (a variant of Ricker's Type B error). In such cases accurate parameter estimation requires some adjustment of recapture data. This report documents the occurrence of such errors in herring tagging experiments along southwestern Newfoundland during 1970-71 and describes several techniques by which such biases were evaluated and quantified.

Description of Tagging Procedure

Extensive tagging studies were conducted by the St. John's, Newfoundland Biological Station (Winters 1971) in 1970-71 to test the hypothesis of Hodder (1966, 1969) that the herring fisheries which developed along southwestern Newfoundland and in the southern Gulf (Fig. 1) during the

mid-1960's were not based so much on different stocks but rather mainly on parts of the same stock complex at different times and places along its seasonal migration route. Complementary tagging studies in the southern Gulf of St. Lawrence were conducted by the St. Andrews Biological Station (Beckett 1971). The nature of the herring fisheries in these areas (bulk catches processed for meal and oil) necessitated the use of internal magnetic tags, 19 mm long, 4 mm wide and 1 mm thick as the main method of marking; these were to be recovered by magnetic separators normally installed in the processing lines of reduction plants.

Live herring for tagging purposes were obtained from bar-seines. An average bar-seine set could generally supply enough fish for 2-3 days tagging operations. Herring were barred within small coves until required for tagging, when appropriate quantities of herring (5000-10,000 fish) were transferred to holding pounds. The tagging operation took place in small boats secured to the side of these holding pounds from which live herring were dipped into small tagging tanks in the boat capable of holding 50-75 herring each. Herring were removed individually from the tanks and held belly-up while a small incision was made in the belly of the herring through which the magnetic tag was inserted and pushed forward into the abdominal cavity. Before being released the tagged herring was flexed several times to ensure that the tag was completely inside the body cavity.

A summary of the tagging and release information of the various tagging experiments carried out along southwest Newfoundland is given in Table 1.

Results

Estimation of initial tagging mortality and effective number tagged

Examination of tagged fish recovered by an electronic tag detector installed in the reduction plant at Isle aux Morts, Nfld. (Winters, in prep.) has shown that the mortality caused by the incision wound and the presence of the tag in the body cavity of herring was probably not significant. However, one would expect that the impoundment and handling of the herring during the tagging process would result in a deterioration of condition (through scale loss, abrasions, etc.) which should be reflected in a lower recapture rate for those fish held for extended periods. Although it was impossible to determine the extent of these losses directly it is possible to obtain indirect estimates of such mortality. All the fish of each liberation were tagged from the same batch of herring held in the holding pounds or the bar seine up to two or three days. It was noted that the longer these fish were impounded the greater their scale loss and the poorer their physical condition. Consequently it is reasonable to assume that any differences between returns from the first day's tagging of each liberation and subsequent returns are due to initial mortality resulting from effects of handling and impoundment and will reduce the effective number of fish tagged.

Table 1 lists tag recaptures by day of tagging for each liberation of tagged fish in the 1970 and 1971 tagging experiments. As expected the percentage returns decreased after the first day's releases for each liberation and this is attributed to initial mortality caused by deterioration in the body condition.

An estimate of this mortality (Ricker's Type A) can be obtained from a method described by Ricker (1958) and Dickie (1963). If two groups of tags from a common impounded group are released in subsequent days we may write the catch equation for the first day's releases and returns in logarithm form as follows:

$$\ln n_t = \ln PR + \ln N_t + \ln \frac{F}{Z}\,(1-e^{-(Z)t})$$

$$= \ln PR + \ln N_t + \ln A$$

where n_t = number of tagged fish returned during time t
N_t = number of tagged fish present at the beginning of time t
F = instantaneous rate of fishing mortality during time t
Z = instantaneous rate of total mortality during time t
R = fraction of the tagged fish which survive or retain their tags up to the beginning of time t = o
P = the fraction of total recaptures during time t which are returned.

Similarly for the second day's releases we may write:

$$\ln n_t^1 = \ln P^1R^1 + \ln N_t^1 + \ln A$$

If sustained total mortality rates from these two groups are the same, then we obtain by subtraction:

$$\ln n_t - \ln n_t^1 = \ln PR - \ln P^1R^1 + \ln N_t - \ln N_t^1.$$

Table 1. Summary of recapture data by liberation series and day of release for the 1970 and 1971 tagging experiments along southwest Newfoundland.

Liberation series	Date tagged	Number tagged	Number recaptured	Recapture rate (%)
A1	March 3/70	1100	44	4.00
	4	4600	157	3.41
	5	2700	49	1.81
Total		8400	250	2.98
A2	March 7/70	4500	113	2.51
	8	300	2	0.67
Total		4800	115	2.40
A3	March 11/70	2000	120	6.00
	12	7000	239	3.41
	13	2800	30	1.07
Total		11800	389	3.30
Grand Total - A		25000	768*	3.07
B	Jan. 25/71	4200	389	9.26
	26	5800	77	1.33
Grand Total - B		10000	466	4.66

*includes 14 tags of unknown tag number.

Thus, the difference in the position of parallel lines drawn through logarithms of returns of two groups of tags reflects both difference in numbers initially released and differences in the magnitude of Type A errors (Dickie 1963). Consequently if we assume PR = 1 we obtain from the above equations a value for $- \ln P^1R^1$ which is an estimate of the relative initial tagging mortality for the second day's releases.

The logarithms of annual returns for each day of a liberation series are plotted in Fig. 2 for the 1970 and 1971 tagging experiments. Straight lines have been fitted by eye for each tagged group. We may reasonably conclude that total mortalities within releases of the same liberation series are the same and consequently the relative magnitude of Type A errors can be evaluated, using the above equation, by comparing differences in positions of lines between the different days' releases. The results (Table 2) reveal that initial tagging mortality does occur and increases substantially with the duration of impoundment. For example, when the March 4, 1970 returns are corrected for the difference in the initial numbers tagged, tags from that day's releases were returned only 88% as commonly as the March 3, 1970 releases; similarly for the 1971 Bay de Loup experiment tags from the second day's releases were returned only 19% as commonly as the first day's releases. Estimates of initial tagging mortality by the above method agree well with estimates derived from the ratio of percentage returns from subsequent days' releases compared to that of the initial day for each liberation series.

The estimates of relative tagging survival (P^1R^1) given in Table 2 have been used to calculate the maximum effective number of fish tagged by simple multiplication of P^1R^1 with the number released during that day and accumulated for the liberation series (Table 3).

A second estimate of the effective number of fish tagged has been derived by calculating the number of tagged fish needed to have been released to provide the observed number of tag returns from that liberation if the best days' return rate from that liberation applied (Table 3), i.e. if A = % returns from best day; and B = total tags recaptured, then the effective number of fish tagged = B/A x 100. The two estimates of effective number of fish tagged agree reasonably well and indicate that during the 1970 tagging experiment minimum estimates of initial tagging mortality ranged from 4-49% with an average for the entire experiment of 32% compared with 45.5% for the 1971 releases.

Table 2. Calculation of the relative magnitude of Type A errors by the method of Ricker (1958) and Dickie (1963). The ratio of percentage tag returns is calculated from the data given in Table 1.

Liberation	Day released	N_0	ln N_0	Calc. ln n_{1972}	$-\ln P^1R^1$	P^1R^1	Ratio of percentage returns
A I	Mar 3/70	1100	7.00	0.80			
	Mar 4/70	4600	8.43	2.10			
	Difference		-1.43	-1.30	0.13	.88	.85
A I	Mar 3/70	1100	7.00	0.80			
	Mar 5/70	2700	7.90	0.95			
	Difference		-0.90	-0.15	0.75	.47	.45
A III	Mar 11/70	2000	7.60	1.85			
	Mar 12/70	7000	8.85	2.25			
	Difference		-1.25	-0.40	0.85	.43	.57
A III	Mar 11/70	2000	7.60	1.85			
	Mar 13/70	2800	7.94	0.60			
	Difference		-0.34	1.25	1.59	.20	.18
B I	Jan 25/71	4800	8.48	3.30			
	Jan 26/71	5200	8.56	1.70			
	Difference		-0.08	1.65	1.68	.19	.14

Table 3. Estimation of effective number of fish tagged for the 1970 (A) and 1971 (B) tagging experiment.

Liberation series	% returns from best day (A)	Total tag recaptures (B)	Effective no. of fish tagged			Actual number released	Estimated minimum initial mortality rate
			(B/A x 100)	Calc. from P^1R^1	Average		
A1	4.00	250	6250	6400	6350	8400	24.4
A2	2.51	115	4600	-	4600	4800	4.2
A3	6.00	389	6500	5600	6050	11800	48.7
Total		754			17000	25000	32.0
B	9.26	466	5050	5800	5450	10000	45.5

Estimate of tag extrusion during spawning

Examination of tagged herring recovered by the tag detection unit (Winters, in prep.) suggested that tag loss during the spawning season was substantial, particularly for those tags which had not become attached to internal organs. According to Ricker (1958) such a tag loss will produce a recapture curve which will be either concave upwards or best fitted by two straight lines. Tag returns from the 1970 and 1971 tagging experiments along southwest Newfoundland and in the southern Gulf of St. Lawrence have been separated by area and expressed in terms of tag recoveries per unit effort from effort data given in Winters and Hodder (in press). These have been transformed to natural logarithms and are plotted against time in Fig. 3. The tag recovery rate in southwest Newfoundland during the winter of 1970, the only recovery period in that experiment completely prior to spawning, is substantially greater than would be expected from the trend in the rates of tag recovery in periods subsequent to spawning. A straight line (A) has been fitted to these latter points and is joined by a line (B) from the point representing the 1970 recovery rate. A line drawn parallel to line B from line A would thus represent the expected recovery rate if no tag loss were incurred during spawning. A comparison of the observed and expected recovery rates in this manner reveals that tag recoveries in 1972, for example, were only 4% what they would have been in the absence of tag loss during spawning. Similar tag losses are evident from the trend of tag recoveries from the 1971 tagging experiment along southwest Newfoundland but not from the two tagging experiments in the southern Gulf of St. Lawrence in 1970. The apparent lack of tag loss during spawning in the Magdalen Island releases is due to predominance of ripe and running fish (spring-spawners) in the herring used for tagging and thus tag loss during spawning would have already occurred before those fish became subject to exploitation during their feeding season in the American Bank area in July and August. The fish used in the Gaspé tagging experiment were predominantly post-spawners (autumn-spawners)(Beckett, personal communication) and thus loose tags would have had a full year before the next spawning season to become attached to some internal structure. The lack of substantial tag loss indicated by the trend in recovery rates of tags released in the Gaspé experiment may therefore be explained on this basis.

A second estimate of tag extrusion during spawning may be obtained from a comparison of the effective number of fish tagged and released before spawning and those marked fish containing tags which are alive after the completion of spawning, adjusting for interim fishing and natural mortality rates. The 1970 tagging along southwest Newfoundland fits the requirements since those fish were tagged just prior to spring-spawning and substantial returns from this experiment were obtained in the 1971 winter fishery along southwest Newfoundland which began 1-2 months after fall spawning had ended.

An estimate of the surviving tagged fish containing tags from the 1970 releases can be derived from a comparison of the exploitation rates (R/M) during the recovery period in southwest Newfoundland in 1970 and 1971, providing effort data are available to adjust the tag returns to an equivalent exploitation rate (assuming that the catchability coefficient remained constant). Effort data are available for these years (Winters and Hodder, in press) and the relevant data are summarized below:

	No. of tagged fish (M)	Tag recaptures		Catch (m. tons) (C)	Catch/effort (m. tons/day) (CPE)	Effort (Op. days) (E)
		Total (r)	Effective (R = r/e)			
1970	17,000	391	1150	25,000	41.5	602
1971	?	126	185	104,000	24.6	4230

We may thus calculate the number of fish of the 1970 tagging experiment, surviving to the beginning of the 1971 winter fishery as follows:

$$\frac{E_{71}.R_{70}}{E_{70}.M_{70}} = \frac{R_{71}}{M_{71}}$$

Whence $$M_{71} = \frac{R_{71}.E_{70}.M_{70}}{E_{71}.R_{70}}$$

$$= \frac{185 \times 602 \times 17000}{4230 \times 1150}$$

$$= 389.$$

From the data given in Winters and Hodder (in press) a total mortality of approximately 0.60 is evident for the period mid-March, 1970, to November 1, 1970, implying that over 9300 tagged herring containing tags from the 1970 releases would have survived to the beginning of the 1970-71 winter fishery in November if no tags were lost during spawning. The above estimate of 389 surviving fish therefore suggests that 96% of the internal tags from the 1970 tagging experiment along southwest Newfoundland were extruded and effectively removed from the marked population during spawning in the southern Gulf of St. Lawrence. This estimate is identical to that obtained above from a comparison of pre- and post-spawning tag return rates per unit of effort.

Discussion and Conclusions

Substantial initial tagging mortality resulting from deteriorating body condition due to effects of holding fish prior to tagging operations and tag application has been demonstrated for a variety of species including herring (Jensen 1955), North Sea sole (Kotthaus 1963), salmon (Haitt 1963) and haddock (McDermott and Livingstone 1963). For example, Jensen (1955) graded live herring into four categories according to degree of scale loss and compared subsequent returns of tagged fish from the four categories. The results indicated that the return rate from the category containing fish in the poorest condition was less than 10% of that of the best condition category. An increase in severity of scale loss related to duration of impoundment was also very evident in tagging experiments carried out along southwest Newfoundland and the analyses of subsequent tag recaptures reinforce previous conclusions that maximum tagging efficiency will only be achieved in experiments involving a minimum of handling activity and impoundment time prior to release of the tagged fish. A secondary conclusion from these studies is that information on the condition of tagged fish upon release could be of great value in evaluating and adjusting for such biases introduced into recapture data.

An additional critical factor affecting the magnitude of long-term returns from internal herring tagging experiments is the proximity of the tagging period to the spawning season. Results obtained in this study, and confirmed by examination of recaptured tagged fish (Winters, in prep.), suggest that nearly all of the loose tags in the body cavity are extruded during the spawning act. That being so, the most appropriate time to conduct an internal tagging experiment is shortly after spawning has been completed.

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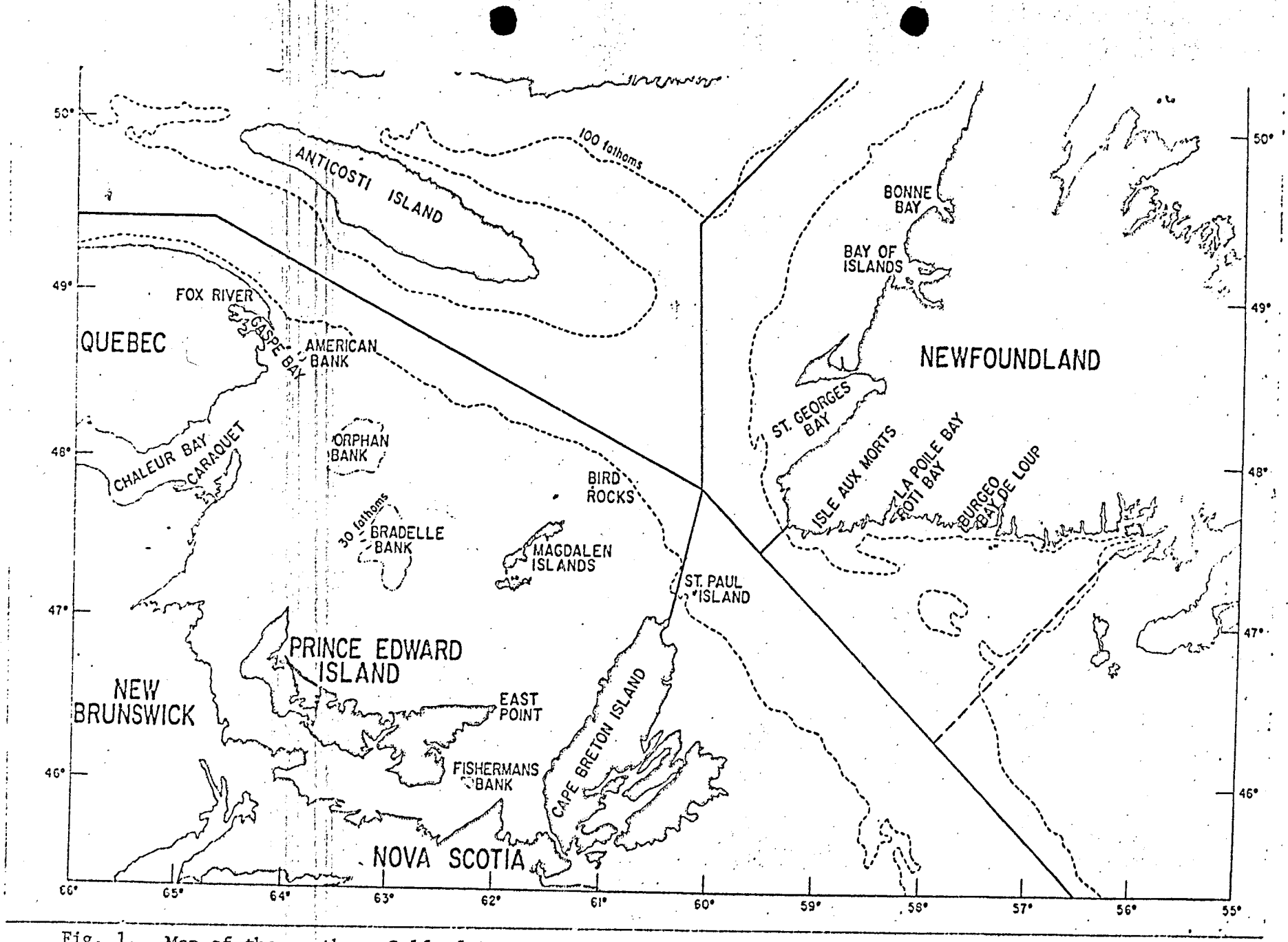

Fig. 1. Map of the southern Gulf of St. Lawrence and Southwest Newfoundland

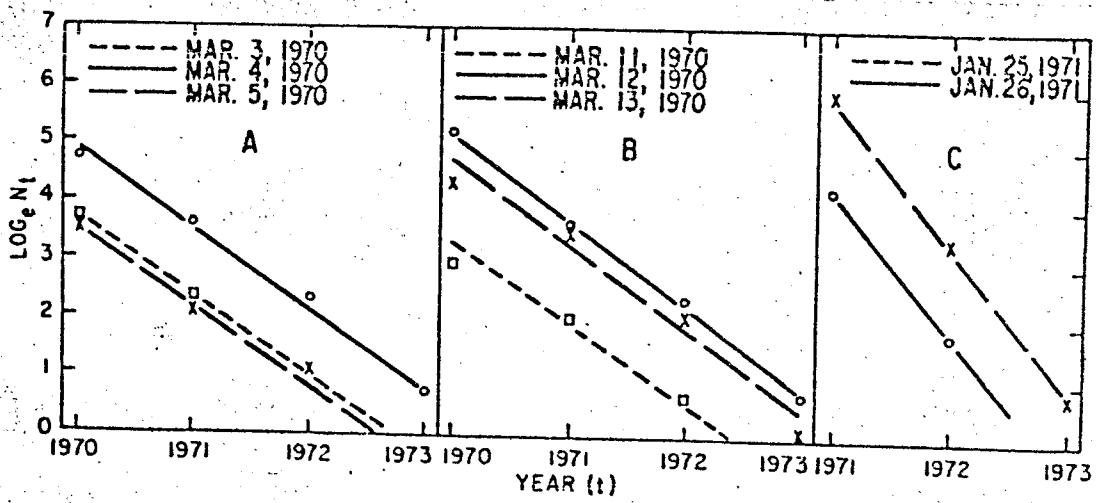

Fig. 2. Logarithm of annual recoveries from tag releases in Area J in 1970 (A,B) and 1971 (C).

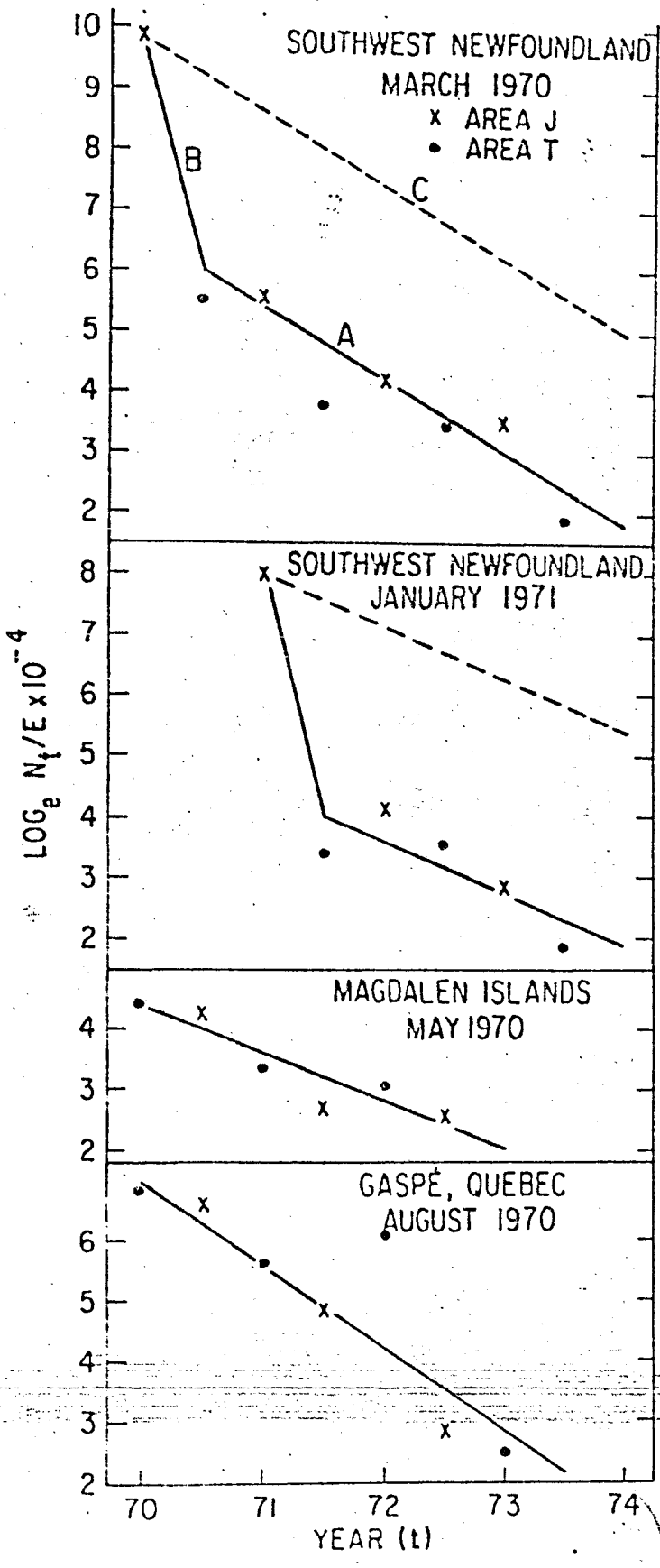

Fig. 3. Logarithmn of annual tag recoveries per unit effort from tagging experiments in the southern Gulf and along Southwest Newfoundland