PRELIMINARY ANALYSIS OF BLUEFIN TAGGING DATA

by

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and

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SUMMARY

Recoveries of tags from bluefin tuna tagged in the Northwest Atlantic were analysed in order to determine patterns of short distance migration and mortality rates. The results indicate that there is a definite seasonal pattern of movement of bluefin off the northeast coast of the U.S. Bluefin enter into the fishery at the beginning of the season off the New Jersey coast and then they move northeast into the Rhode Island - Cape Cod region, arriving by the end of the season. High estimates of rates of exploitation and mortality were obtained. Exploitation ranged from 0.18 to 0.48, instantaneous fishing mortality from 0.20 to 0.77, and instantaneous other mortality from 0.70 to 1.56. No attempt was made to correct for nonreporting, tag shedding, and tagging mortality. It was suggested that a portion of the estimates of instantaneous other mortality could be caused by migration from the fishery.

ANALYSES PRELIMINAIRES DES DONNEES DE MARQUAGE DU THON ROUGE

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RESUME

Les récupérations de marques effectuées sur des thons rouges marqués dans l'Atlantique nord-ouest ont été analysées afin de définir les modes de migration sur de courtes distances et les taux de mortalité. Les résultats indiquent l'existence d'un mode saisonnier bien déterminé de déplacement du thon rouge au large de la côte nord-est des Etats-Unis. La pêcherie du thon rouge commence en début de saison au large de la côte du New Jersey, puis les bancs se déplacent en direction nord-est vers la région du Rhode Island et du Cape Cod où ils parviennent en fin de saison. Des estimations élevées des taux d'exploitation (de 0,18 à 0,48) et de mortalité (taux instantané de mortalité due à la pêche, 0,20 à 0,77 - taux instantané de mortalité due à d'autres causes, 0,70 à 1,56) ont été obtenues. Nous n'avons pas tenté d'effectuer les corrections dues au manque de données, au rejet de marques, et à la mortalité due au marquage. Il a été suggéré que le taux instantané estimé de mortalité due à d'autres causes pourrait partiellement s'expliquer par l'émigration des poissons hors de la pêcherie.

ANALISIS PRELIMINAR DE DATOS DE MARCADO DE ATUN

por

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RESUMEN

Se analizaron las recuperaciones de marcas procedentes de atún marcado en el Noroeste del Atlántico, a fin de determinar las pautas de migraciones a corta distancia y los índices de mortalidad. Los resultados revelan que existe una pauta clara de desplazamiento estacional del atún frente a la costa nordeste de los Estados Unidos. El atún entra en la pesquería a comienzos de temporada frente a la costa de New Jersey, y después se desplaza hacia el nordeste, a Rhode Island (región de Cape Cod), llegando a finales de temporada. Se obtuvieron unos índices estimados elevados de explotación y mortalidad. La explotación osciló de 0,18 a 0,48, la mortalidad de pesca de 0,20 a 0,77 y otro tipo de mortalidad instantánea de 0,70 a 1,56. No se efectuaron correcciones relativas a falta de información, desprendimiento de marcas y mortalidad por marcado. Se sugirió que una porción de las estimaciones de mortalidad instantánea por otras causas podría ser debida a la migración de la pesquería.

PRELIMINARY ANALYSIS OF BLUEFIN TAGGING DATA

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INTRODUCTION

This is a report on bluefin tuna tagging data assembled by the senior author Frank Mather. The main intent of the report is to provide an initial survey of the data which will provide a basis for further more detailed analysis. The data in this study are based upon taggings and recoveries that were made by a variety of organizations and individuals at various locations along the middle Atlantic bight of North America from July 1954 to August 1970 (these dates are recapture dates and so for the most recent years any recapture estimates may be slightly modified with additional recovery data). Because of the variety of methods, locations, and dates, we need to assemble the data by relatively homogeneous release groups. The criterion for constructing a release group was to develop relatively homogeneous time-location strata of recoveries having a minimum of 20-30 tags recovered. The consideration of these release groups allowed us to work with homogeneous groups, but eliminates roughly 10 percent of the recovered tags from our analysis. Table I-1 summarizes these release groups and Figure I-1 shows the locality of the release groups. Figure I-1 shows the general location of release for the release groups tabulated in Table I-1. It should be mentioned at this point that the sample size in these homogeneous groups were not sufficiently large for reliable mortality estimates, so for the purposes of mortality estimation, different groupings were also used and will be explained in the pertinent section of this report. In addition to showing the magnitude of the release groups, we can see from Table I-1 that during the study period 1954-1970, tagging

operations tended to move from the New Jersey coast, to the New York coast, to the Rhode Island coast, as well as the tendency for releases in July to be south of those made in August or September reflecting the apparent movement of the fish.

MIGRATIONS

Tagging data have been used to obtain a reasonable appreciation of the longer migrations of thebluefin tuna. The shorter migrations have also been charted, but not analytically. In this section we examine the shorter term recoveries from an analytic point of view. In order to do this, we make use of a method developed by Rothschild and Bayliff (in preparation). Basically the method stratifies each release group into intervals of time at liberty. For each release group the release vectors (latitude and longitude) are used to compute an average release vector. Each recapture vector is then standardized to the common release vector. The standardized vectors are then used to find (1) an average recapture vector, (2) recapture variance-covariance matrix, (3) recapture generalized variance and other statistics.

The reader should be cautioned that the vectors computed by this method are not on a per-unit-of-effort basis so that "migration patterns" reflect only the apparent movement of the fish and the distribution of effort. In order to more fully understand the nature of short-term movements, it will be necessary to study in some detail the complex problem of the distribution of bluefin tuna effort in the Northwest Atlantic.

These are all given in the computer output as an appendix to this report. The computer output also includes for each release group a map showing the standardized origin of release and the head of the mean recovery vector. Each individual recapture is recorded by a digit that reflects the size at tagging enabling rapid inspection of the

effect of tagging size on recovery location. Preliminary to the required detailed analysis of these statistics, we will survey some of the main features of the data, some of which are tabulated in Table III-1.

First let us consider the direction of movement. Figure II-1 contains a synthesis of these data and shows the direction of movement by tagging location and time at liberty. It is implicit that we are treating any symbol as reflecting the behavior of a sample of fish from the same statistical population. The main features of Figure II-1 are that fish tagged off New Jersey in July tend to disperse in an offshore direction both north and south during the first two weeks at liberty, but after the first two weeks, dispersal is strongly directed to the northeast until the winter lull in recoveries; when the fish return the following year, they tend to be recovered along the coast as indicated by the northeast and southeast recoveries for the 181-440 day interval. As we move into the Long Island area, there is initially some dispersal toward the north, but after the first 15 days, movement appears to be concentrated to the west and south. The same conclusion may be obtained from the Rhode Island taggings and for these fish, after the midwinter lull all recoveries are made to the southwest indicating, like the New Jersey longer term recoveries, that the fish are distributing along the coast.

An examination of the mean distance moved by each group is also of interest. Off New Jersey fish tend to be recovered at a slightly greater distance to the north than the south. The fish are moving very roughly 7 or 8 miles per day. By the second 15-day period, the

fish have dispersed in the northeast direction roughly 60-100 miles. What is of particular interest is that the New Jersey releases after 181-440 days at liberty exhibit a distance moved which more closely approximates the 1-15 day interval rather than the intermediate intervals. This implies that when the fish return to the fishery, they tend to enter in the New Jersey area rather than in the Long Island or Rhode Island area. The Long Island pattern, based on only a few observations, shows that dispersal distance of these fish during 0-15 days is approximately the same as that for the New Jersey releases, but the southeast returns for the 181-440 day interval exhibit greater distances than those released in New Jersey. It should be mentioned that the short-term recoveries of Rhode Island tagged fish reflect even less average distances than New Jersey short-term releases suggesting that either the fish off Rhode Island move less than off New Jersey or that the intensity of the Rhode Island fishery is greater than that off New Jersey. While the latter may be apparently true, in actuality there may be alternative interpretations so additional careful analysis is required. The relatively great recovery distance for the long-term recoveries of Rhode Island tagged fish after the winter lull then confirm the movement pattern hypothesized in the literature, viz., fish enter the fishery in July off New Jersey; the fish then migrate along the coast; some moving as far northeast so as to enter the August fishery off Rhode Island; the surviving fish become unavailable during the winter and in July enter the fisheries that are roughly 130 miles southeast of Rhode Island with a higher probability, given that the fish is recaptured, than of the fish tagged off of New Jersey in July entering the Rhode Island fishery in August.

MORTALITY ESTIMATION

The number of recoveries per year from releases by year, months within years, and various groupings of years, months and release locations were employed to estimate survival rates for young bluefin in coastal waters between Cape Hatteras, North Carolina and Cape Ann, Massachusetts. The first analyses were run using data assembled from the basic data cards supplied to the project. Unfortunately, there are some discrepancies between the recovery tables derived from the card set and the various summary tables previously developed. Most of these discrepancies result from using a subset of the recapture cards. Only the cards employed to form the basic groups as defined in the migration analysis were used for this first study, thus eliminating some releases which were substantially different with respect to their location or time than for most of the fish tagged. Only cards which had both release and recovery dates on them were used in this first analysis. Although these restrictions reduce the numbers of recoveries available, they would not be expected to greatly affect the estimates of mortality rates. Recall that estimates of total mortality rate do not depend upon the initial number of tags released.

Method of Release

In all years since 1961, with the exception of 1963, tuna were captured for tagging by both sport gear and by commercial gear (purse seine). In Table IV-1 the proportions of tags recaptured are compared for the two methods of original capture. Four of the nine chi-square

tests of the hypotheses of homogeneity indicate highly significant differences in the recovery percentages between the types of gear used to capture the tuna for tagging. The recovery proportions did not exhibit any consistent pattern. Restricting our attention to the four years with significant numbers released and subsequently recaptured for both types of gear, i.e., 1965, 1966, 1968, and 1969, we find sport tagged tuna had higher recapture percentages in three of the four. The data cannot be pooled over years to increase numbers in individual cells in the chi-square tables since the recovery percentages and numbers tagged vary so greatly from year to year; the cause of the year-to-year variations in recapture percentages is not known.

A t-test of the differences between the unweighted recapture percentages of sport and commercial gear releases for the years 1964-69 showed an average 15.2 percent higher recapture percentage for sport gear. This difference was not statistically significant ($t = .397$, d.f. = 5); however, the degrees of freedom are so small that the usual precautions must be applied in interpreting the meaning of this test. For the years 1965, 1966, 1968 and 1969 in which at least 10 recaptures were made in each type of gear, the average discrepancy rose to 20.8 percent in favor of sport gear releases but, again, this average difference was not statistically significant ($t = .558$, d.f. = 3). Since, for most years when large numbers of recoveries were made, the vast majority were tagged from commercial gear and since clear-cut differences between the two gear types

cannot be demonstrated, the data were pooled over the method of original capture in the various analyses that follow.

Total Mortality Estimates

In the first analysis minimum variance unbiased estimates of the total annual survival rates were computed by the method developed by Chapman and Robson (1960) for the recovery data by year pooled in a variety of different ways over release categories. These data are restricted to those used for basic migration pattern estimation and include only those with definite recovery and release dates. Confidence intervals for both s, the fraction surviving per year, and Z, the associated instantaneous mortality rate, were computed. A chi-square test was used to determine if the number of recaptures in the first recovery period was compatible with the survival pattern exhibited by the rest of the data; this test was applied sequentially--if the first year's recaptures were not in accord with the remainder of the data, the second year was defined as the first recapture category and the test repeated until either all recapture years were eliminated or a survival rate was obtained from some subset of the data. For all releases the tagging year was taken as the first recapture category at the start of the analysis. The results of the survival rate computations are shown in Table IV-2 for the following data groupings:

1) Over all years
2) Over three adjacent release years
3) Individual years
4) July releases for three adjacent release years
5) Individual months within years
6) Release groups as defined in Table I-1

An obvious feature of this analysis is the considerable number of discrepancies between the actual recaptures in either the first year or two after release and the expected recaptures as computed from the entire recapture series. Even though it might be expected that the number recaptured the first year would be underrepresented because of less exposure to the fishery, this was not always the case. In many of the recapture series, the numbers recovered the first year or two were higher than expected. Three possible factors that could have caused the higher than expected recaptures in the first year or two after release are:

1) Tagged fish were released into an area where fishing activity was concentrated.
2) The proportion of the population migrating into the fishing area decreases as the fish get older; thus the availability of the tagged fish in the fishing area may fall off rapidly enough in later years to cause a disproportionate number of recaptures in the first and second years after release.
3) The method of estimation assumes constant fishing mortality rates and other loss rates; variability in recovery effort could cause the number of recaptures per year to deviate from a simple exponential decline with time.

Several patterns emerge from Table IV-1. The survival rates are low but highly erratic; restricting the releases to finer time-location grids does not improve the stability of the estimates as might be expected. No time trend in survival is evident; pooling over years is a useful device to average out some of the fluctuations in the data. In one

sense this is a substitute for use of recapture effort statistics and working with the number of recoveries per unit of recovery effort. The recaptures per year were combined over years using various weighting factors to develop adjusted numbers recaptured per year. None of these weighting schemes offered an improvement in the use of the simple unweighted average percent recaptured per year at liberty for the years 1964-68. The proportion disappearing per year as estimated from the simple average of the percentages was 0.188. This value is well within the confidence interval of the s-value of 0.231 estimated from the actual numbers pooled over all years. The latter estimate, however, discarded the recoveries made during the first two years at liberty.

Inclusion of the first recapture periods in the Chapman-Robson analysis, particularly for the last set of release groups which are fairly homogeneous, had the general effect of reducing the survival estimates. The numbers of recaptures drop off so rapidly, however, after the first two recapture periods that little reliability can actually be placed on estimates using only data from the tail end of the time series.

This first examination of the recaptures by time at liberty was followed by a revised analysis of the July releases each year and all releases each year for 1964 through 1968. An attempt to include all tags in the analysis was made by assigning tags without recorded release dates to most likely release dates by means of the accompanying information on the card, e.g., by cruise number. For the most part this revision produced minor changes in the estimates of total survival

rates. Raw exploitation rates were estimated from the total number of recaptures per release using all cards whether or not any information was available on date of recapture. It will be noted that there are a few differences between this table and that employed by the W.H.O.I. Cooperative Tuna Tagging Program. These differences are minor and do not have any meaningful effect on the estimates of population parameters.

The following formulae estimate the single season exploitation rate:

$$\hat{u}_1 = (\hat{u}_{Total}) / \sum_{i=0}^{n} \hat{s}^i$$

where $\hat{u}_1$ is the single season exploitation rate, $\hat{u}_{Total}$ is the total exploitation rate over n years, and s is the survival rate estimated from the revised data by the Chapman-Robson method.

These estimates for July releases are shown in Part A of Table IV-3 and in Part B of the same table estimates of the same set of parameters are given with the exception of the single season exploitation rates. We felt that distributing the releases during the entire fishing season rather than restricting them to the first part of the season--July--made it impossible to estimate a single season exploitation rate. It will be noted that the actual observed exploitation rates are high, especially in view of the fact that no corrections were made for either immediate tagging mortality or nonreporting. The total recapture percentages ranged from 21.3 percent to 49.2 percent.

The natural logarithm of the number of recoveries per unit-of-effort (Table IV-4) taking the number of boat-days recorded per season as a legitimate measure of effort was regressed on time as measured to the center of each year following the release. An exact analytical formulation of this mortality model has two independent variates--cumulative time and cumulative effort--however, not only are these two variables so highly correlated it is virtually impossible to obtain useful estimates of the two regression coefficients but too few data points are available to run a multiple regression analysis. The regression coefficient of the simple cumulative time regression is a crude measure of the total mortality rate. The regression lines fitted are shown in Figure III-1 for July releases and in Figure III-2 for all releases for each year. The values of the coefficients are given in Table IV-5.

With the exception of 1966 when the recaptures per boat-day increased during the year following release (and were eliminated from the regression), the logarithms of the recaptures per unit effort decrease in a linear fashion and it is clear the regressions provide reasonable fits to the data points. Seven of the eight estimated survival rates shown in Table IV-5 are lower than their counterparts in Table IV-3. Both of these analyses provide at best only crude approximations of the true survival rates; however, they do show fair general agreement. The catch-per-effort estimates indicate the loss rates are tending to increase with time.

Exactly what these "survivals" are measuring is of prime interest. They are properly thought of as disappearance rates which are composed of mortalities, tag shedding, and changing migratory patterns with age. Fewer of the older fish enter the surface fishery in the Western North Atlantic and the decreasing proportion of the population entering the fishery is a primary factor lowering the apparent survival. In 1966 when the fish tagged were significantly younger than in the other years--having an average age of 1.4 years as opposed to average ages of at least a year older in other tagging years--the greatest return of tags occurred during the year after release. For these younger bluefin, a higher proportion returned to the fishing area the year after they were released than for the older tagged fish.

The exploitation rate on these fish is exceedingly high when they are in the fishery. The high fishing mortality rates in Table IV-3 quite likely underestimate the true rates; most of the various sources of error that may bias these estimates act to decrease the estimate of the fishing rate relative to its true value.

REFERENCE

Chapman, D. G. and D. S. Robson. 1960. The analysis of a catch curve. Biometrics, 16:354-368.

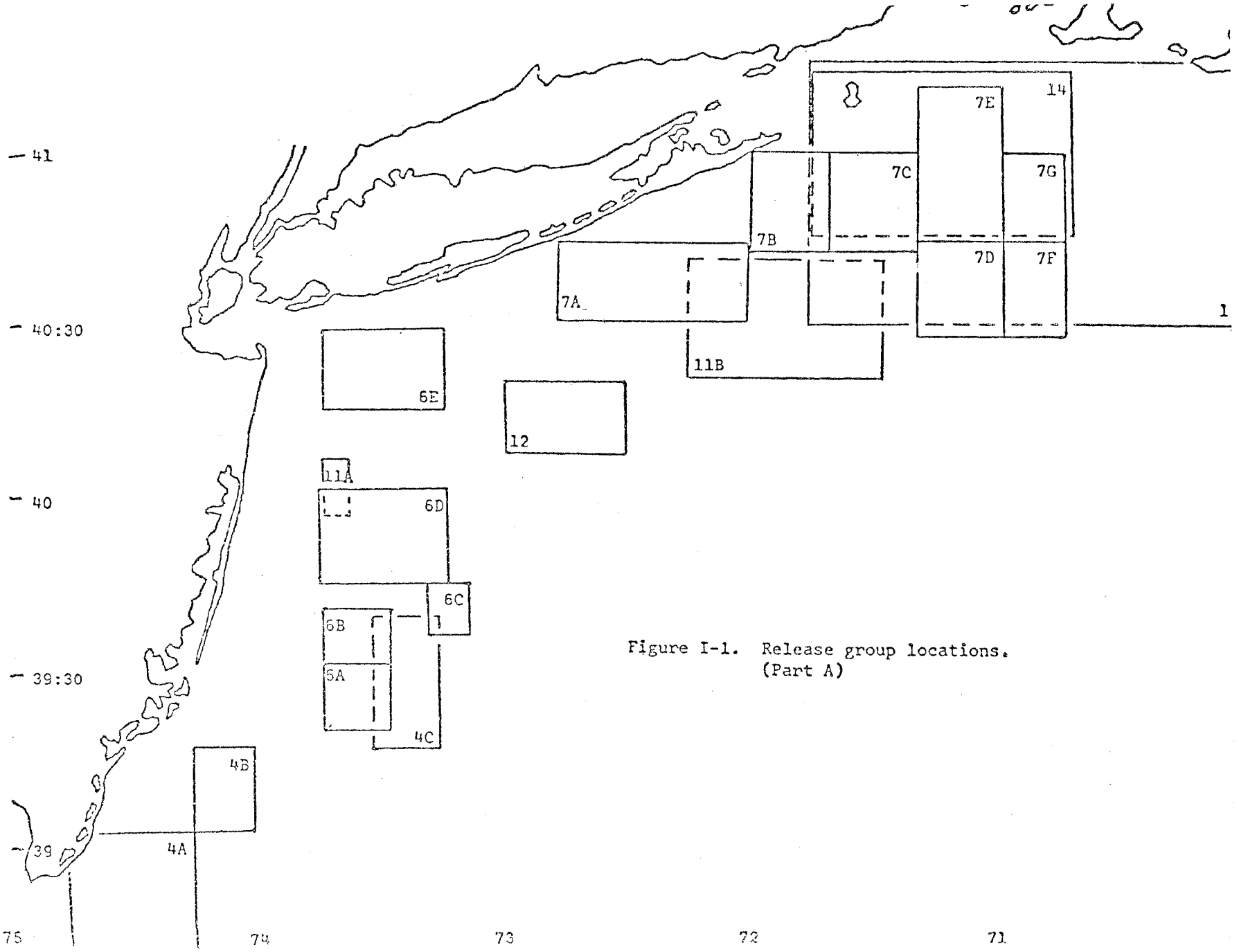


Figure I-1. Release group locations. (Part A)

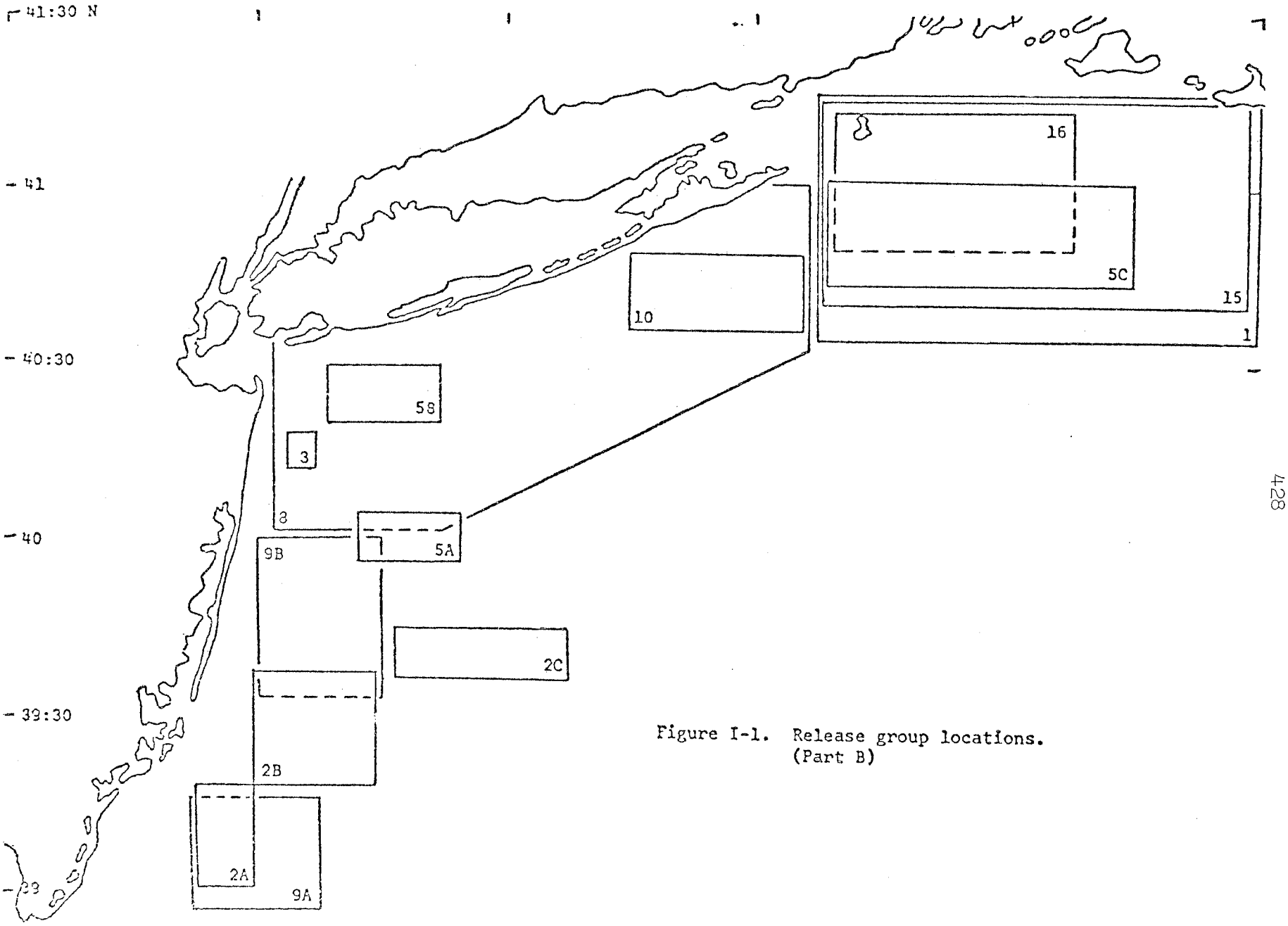
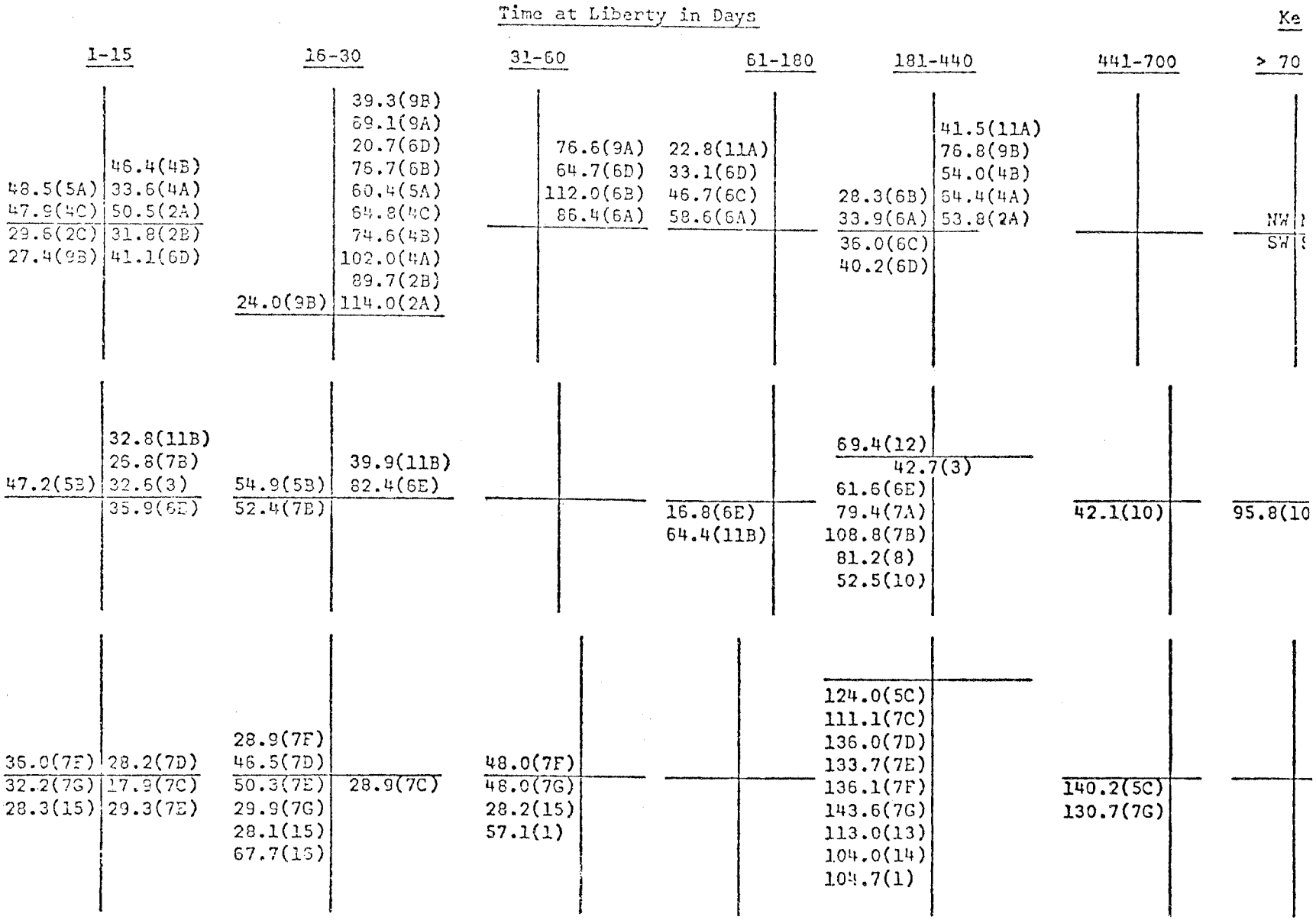


Figure I-1. Release group locations.
(Part B)

Figure II-1. stratified by time at liberty and by general area of release. Distances are in nautical miles. Release group numbers are given in parentheses.



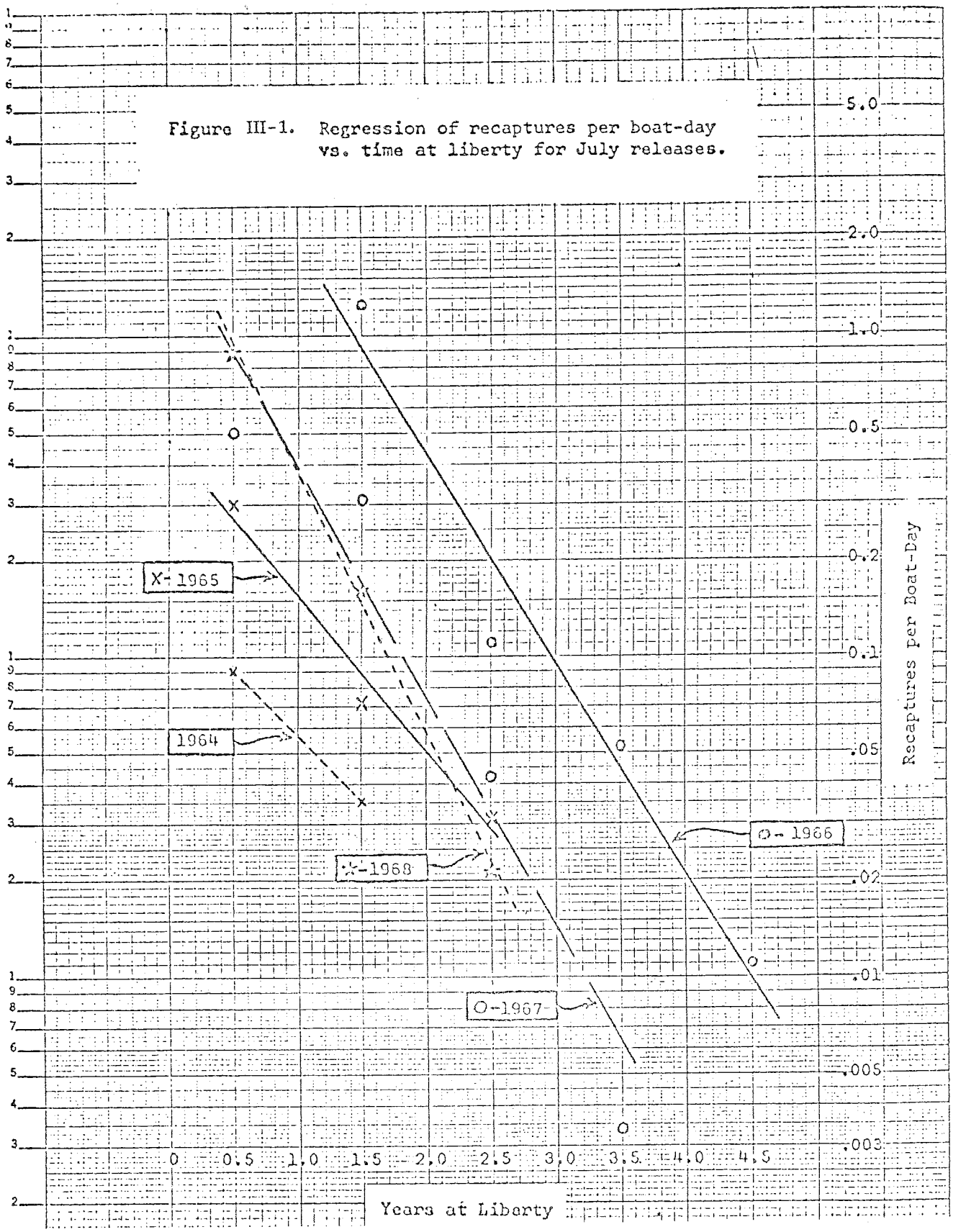


Figure III-1. Regression of recaptures per boat-day vs. time at liberty for July releases.

Figure II-2. Regression of recaptures per boat-day vs. time for all releases, by year.

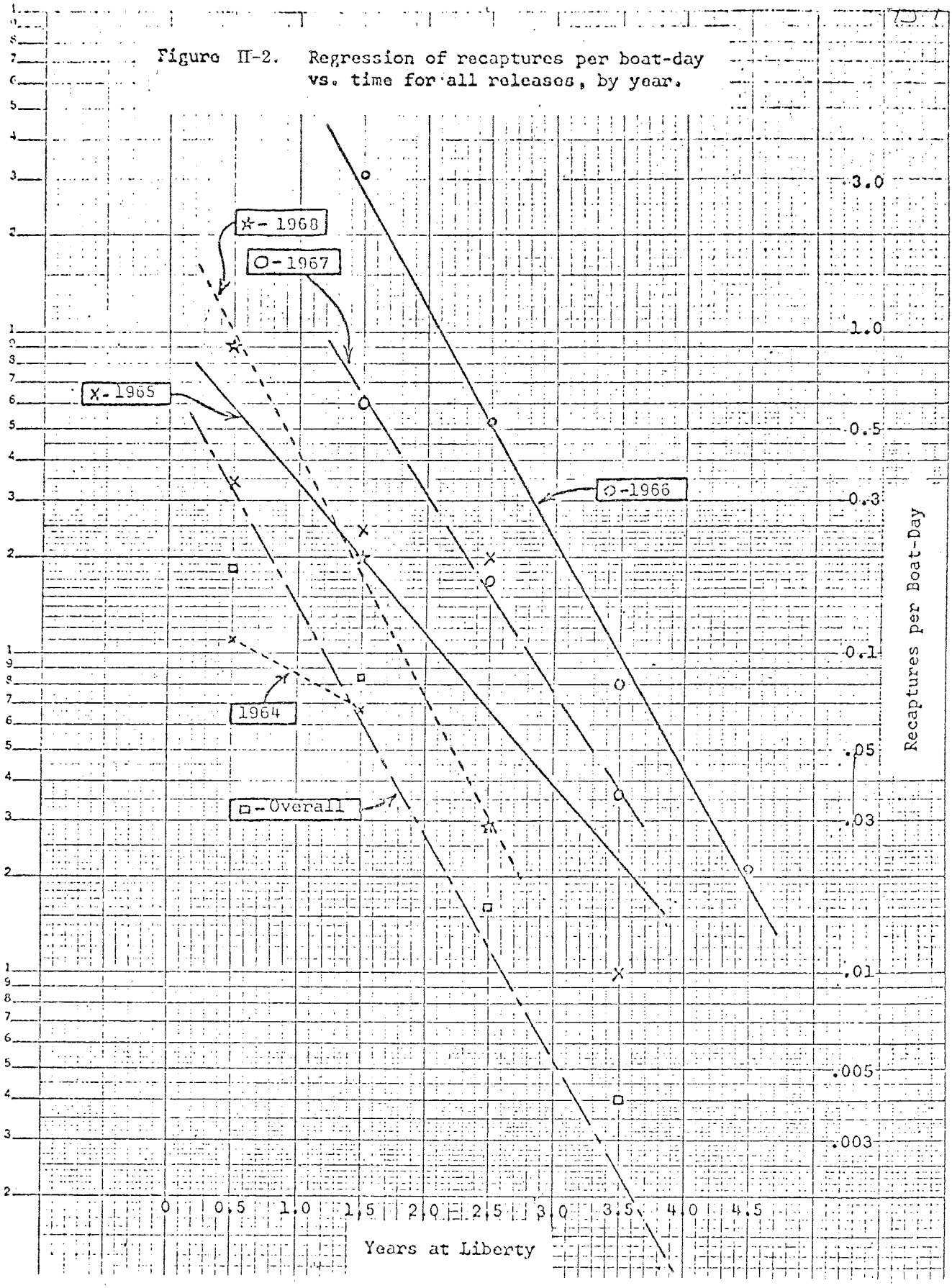


Table I-1. Release groups used for analysis of tagging data.

Release Date	GENERAL LOCATION OF RELEASE: New Jersey Coast Group No.	New Jersey Coast No. of recaptures	Long Island Coast Group No.	Long Island Coast No. of recaptures	Rhode Island Coast Group No.	Rhode Island Coast No. of recaptures
July 1954-Aug. 1963					1	24
July 1964	2A	33				
	2B	32				
	2C	27				
Aug. 1964			3	33		
July 1965	4A	36				
	4B	86				
	4C	38				
Aug. 1965	5A	22	5B	47	5C	24
July 1966	6A	114				
	6B	127				
	6C	45				
	6D	85	6E	62		
Aug. 1966			7A	20	7C	85
			7B	81	7D	36
					7E	55
					7F	203
					7G	177
Sept.-Oct. 1966			8	23		
July 1967	9A	23				
	9B	94				
Sept. 1967			10	27		
July 1968	11A	21	11B	39		
July 1969			12	24		
Aug. 1969					13	40
Sept. 1969					14	22
July 1970					15	17
Aug. 1970					16	25

Table II-1. Estimates of von Bertalanffy Growth Function paremeters. K is yearly. Fish at liberty less than 30 days are eliminated.

Group	Release Date	General Location	Sample Size	K	L_∞
1	7-54 to 8-63	R.I.	13	.285	172.7
2A	7-64	N.J.	7	.151	291.2
2B	"	"	3	-	-
2C	"	"	4	-	-
3	8-64	L.I.	13	-	-
4A	7-65	N.J.	7	-	-
4B	"	"	13	.187	187.6
4C	"	"	3	-	-
5A	8-65	N.J.	17	.571	110.3
5B	"	L.I.	24	-	-
5C	"	R.I.	23	.379	131.1
6A	7-66	N.J.	88	-	-
6B	"	"	106	-	-
6C	"	"	35	.033	759.5
6D	"	"	58	.057	452.7
6E	"	L.I.	34	.604	123.3
7A	8-66	L.I.	14	-	-
7B	"	"	57	-	-
7C	"	R.I.	50	.142	237.2
7D	"	"	16	-	-
7E	"	"	23	.350	128.1
7F	"	"	72	-	-
7G	"	"	79	.329	137.0
8	9 & 10-66	L.I.	18	.093	277.0
9A	7-67	N.J.	12	.295	155.5
9B	"	"	52	-	-
10	9-67	L.I.	26	.252	170.3
11A	7-68	N.J.	17	.527	141.7
11B	"	L.I.	13	.003	6940.5
12	7-69	L.I.	16	.104	262.1
13	8-69	R.I.	24	.753	106.8
14	9-69	R.I.	19	.429	123.9
15	7-70	R.I.	3	-	-
16	8-70	R.I.	3	-	-
All			957	.098	295.8

Table III-1. Summary of statistics on movements of tagged bluefin tuna. All distance measures are nautical miles. North and east are positive.

ase ap	Time at Liberty (days)	Mean Miles N-S	Mean Miles E-W	Deter-minant ($x10^4$)	r^2	Mean Square Distance	Mean Distance	No. of Fish	Release Month	General Release Location
	1-15	26.5	34.1	2.3	.79	2,549	50.5	13	7-64	N.J.
	16-30	74.2	74.9	26.0	.60	12,985	114.0	9		
	31-60							1		
	61-180							0		
	181-440	31.2	5.2	15.8	.80	2,889	53.8	5		
	441-700							0		
	> 700							0		
	1-15	-9.2	11.4	2.9	.84	1,012	31.8	18	7-64	N.J.
	16-30	25.1	58.5	1.4	.99	8,038	89.7	7		
	31-60							2		
	61-180							0		
	181-440							1		
	441-700							0		
	> 700							0		
	1-15	-7.2	-15.0	1.3	.86	875	29.6	14	7-64	N.J.
	16-30							1		
	31-60							1		
	61-180							0		
	181-440							4		
	441-700							0		
	> 700							0		
	1-15	8.0	12.2	0.3	.92	1,064	32.6	12	8-64	L.I.
	16-30							1		
	31-60							0		
	61-180							0		
	181-440	-33.9	0.1	4.4	.43	1,826	42.7	14		
	441-700							0		
	> 700							0		
	1-15	12.0	18.3	3.8	.65	1,126	33.6	18	7-65	N.J.
	16-30	83.6	52.8	11.7	.03	10,412	102.0	8		
	31-60							1		
	61-180							1		
	181-440	42.8	46.3	0.8	.07	4,145	64.4	5		
	441-700							1		
	> 700							0		
	1-15	20.9	7.4	8.7	.81	2,149	46.4	39	7-65	N.J.
	16-30	70.8	21.2	0.2	.00	5,562	74.6	28		
	31-60							3		
	61-180							0		
	181-440	45.7	20.7	0.7	.27	2,915	54.0	7		
	441-700							4		
	> 700							0		

lease roup	Time at Liberty (days)	Mean Miles N-S	Mean Miles E-W	Deter-minant ($x10^4$)	r^2	Mean Square Distance	Mean Distance	No. of Fish	Release Month	General Release Location
4C	1-15	25.3	-16.6	13.4	.69	2,291	47.9	17	7-65	N.J.
	16-30	62.3	3.1	1.1	.12	4,201	64.8	13		
	31-60							0		
	61-180							0		
	181-440							2		
	441-700							0		
	> 700							0		
5A	1-15	25.8	-15.4	19.4	.62	2,348	48.5	9	8-65	N.J.
	16-30	53.5	5.4	17.2	.00	3,654	60.4	12		
	31-60							0		
	61-180							0		
	181-440							0		
	441-700							0		
	> 700							0		
5B	1-15	24.8	-17.9	9.5	.80	2,227	47.2	8	8-65	L.I.
	16-30	44.8	-1.8	36.0	.02	3,018	54.9	5		
	31-60							0		
	61-180							0		
	181-440							2		
	441-700							0		
	> 700							0		
5C	1-15							0	8-65	R.I.
	16-30							0		
	31-60							0		
	61-180							0		
	181-440	-46.4	-97.0	166.0	.40	15,370	124.0	11		
	441-700	-71.3	-116.1	33.1	.02	19,659	140.2	6		
	> 700							0		
6A	1-15							2	7-66	N.J.
	16-30							3		
	31-60	59.1	25.9	18.7	.82	7,470	86.4	11		
	61-180	57.0	-11.1	0.01	.05	3,433	58.6	23		
	181-440	15.9	-6.2	5.0	.14	1,147	33.9	66		
	441-700							1		
	> 700							2		
6B	1-15							4	7-66	N.J.
	16-30	52.8	39.6	0.2	.99	5,878	76.7	5		
	31-60	62.2	70.0	90.9	.30	12,552	112.0	20		
	61-180							4		
	181-440	11.9	-4.5	4.5	.00	801	28.3	84		
	441-700							1		
	> 700							4		

Time at Liberty (days)	Mean Miles N-S	Mean Miles E-W	Determinant ($x10^4$)	r^2	Mean Square Distance	Mean Distance	No. of Fish	Release Month	General Release Location
1-15							0	7-66	N.J.
16-30							2		
31-60							1		
61-180	39.9	-23.7	0.002	.82	2,180	46.7	9		
181-440	-2.0	-18.0	12.5	.002	1,296	36.0	30		
441-700							0		
> 700							0		
1-15	-5.5	5.6	62.3	.15	1,687	41.1	10	7-66	N.J.
16-30	4.0	3.3	1.7	.71	429	20.7	6		
31-60	30.6	15.6	51.9	.47	4,186	64.7	9		
61-180	30.0	-13.2	0.006	.06	1,094	33.1	14		
181-440	-19.0	-12.0	8.0	.36	1,619	40.2	41		
441-700							1		
> 700							0		
1-15	-28.2	3.0	1.8	.01	1,290	35.9	14	7-66	L.I.
16-30	5.0	58.1	36.0	.80	6,794	82.4	6		
31-60							3		
61-180	-3.8	-3.6	1.2	.01	284	16.8	10		
181-440	-51.6	-12.8	8.9	.05	3,798	61.6	22		
441-700							0		
> 700							0		
1-15							1	8-66	L.I.
16-30							2		
31-60							1		
61-180							0		
181-440	-44.7	-60.2	6.0	.19	6,310	79.4	14		
441-700							2		
> 700							0		
1-15	0.6	22.1	0.8	.02	717	26.8	11	8-66	L.I.
16-30	-11.4	-15.5	8.8	.75	2,747	52.4	7		
31-60							1		
61-180							0		
181-440	-61.9	-83.4	19.3	.06	11,825	108.8	54		
441-700							4		
> 700							2		
1-15	-2.0	6.0	1.3	.35	321	17.9	9	8-66	R.I.
16-30	-3.6	6.0	1.0	.06	836	28.9	8		
31-60							1		
61-180							0		
181-440	-55.3	-83.0	124.4	.05	12,338	111.1	50		
441-700							3		
> 700							1		

se p	Time at Liberty (days)	Mean Miles N-S	Mean Miles E-W	Determinant ($x10^4$)	r^2	Mean Square Distance	Mean Distance	No. of Fish	Release Month	General Release Location
	1-15	13.2	2.5	6.2	.02	794	28.2	10	8-66	R.I.
	16-30	7.2	-14.9	12.0	.56	2,166	46.5	8		
	31-60							1		
	61-180							0		
	181-440	-56.8	-118.8	5.0	.01	18,485	136.0	15		
	441-700							1		
	> 700							0		
	1-15	-17.3	2.6	8.8	.002	859	29.3	15	8-66	R.I.
	16-30	-8.8	-21.7	30.3	.04	2,526	50.3	5		
	31-60							1		
	61-180							0		
	181-440	-64.2	-113.8	8.8	.03	17,871	133.7	23		
	441-700							3		
	> 700							0		
	1-15	7.5	-20.0	4.5	.002	1,292	36.0	39	8-66	R.I.
	16-30	7.5	-17.4	3.3	.001	839	28.9	65		
	31-60	1.3	-26.2	15.6	.68	2,376	48.0	14		
	61-180							1		
	181-440	-53.1	-122.8	5.2	.02	18,516	136.1	58		
	441-700							3		
	> 700							0		
	1-15	-3.8	-19.1	3.0	.04	1,038	32.2	37	8-66	R.I.
	16-30	-0.7	-15.9	3.1	.00	893	29.9	50		
	31-60	-4.6	-24.6	12.8	.64	2,304	48.0	14		
	61-180							1		
	181-440	-63.0	-124.9	15.8	.24	20,617	143.6	66		
	441-700	-53.6	-92.3	414.7	.64	17,058	130.7	5		
	> 700							0		
	1-15							1	9/10-66	L.I.
	16-30							0		
	31-60							0		
	61-180							0		
	181-440	-59.9	-36.3	65.8	.13	6,601	81.2	19		
	441-700							1		
	> 700							1		
	1-15							2	7-67	N.J.
	16-30	67.7	12.7	0.003	.17	4,775	69.1	9		
	31-60	66.8	26.8	9.4	.32	5,867	76.6	8		
	61-180							0		
	181-440							4		
	441-700							0		
	> 700							0		

ase up	Time at Liberty (days)	Mean Miles N-S	Mean Miles E-W	Determinant ($x10^4$)	r^2	Mean Square Distance	Mean Distance	No. of Fish	Release Month	General Release Location
	1-15	-18.4	-7.1	1.0	.47	753	27.4	14	7-67	N.J.
	16-30	13.1	-3.6	1.7	.34	575	24.0	12		
	31-60	27.0	7.1	13.5	.11	1,544	39.3	47		
	61-180							2		
	181-440	28.2	35.1	109.7	.75	5,893	76.8	12		
	441-700							3		
	> 700							1		
	1-15							0	9-67	L.I.
	16-30							0		
	31-60							2		
	61-180							0		
	181-440	-11.0	-10.6	7.5	.91	2,755	52.5	5		
	441-700	-25.0	-17.7	5.1	.49	1,772	42.1	12		
	> 700	-42.2	-82.8	5.7	.23	9,175	95.8	8		
	1-15							0	7-68	N.J.
	16-30							2		
	31-60							0		
	61-180	21.9	-4.0	0.008	.31	517	22.8	9		
	181-440	4.0	35.1	3.8	.42	1,721	41.5	6		
	441-700							2		
	> 700							0		
	1-15	.5.8	22.4	4.2	.03	1,077	32.8	13	7-68	L.I.
	16-30	10.4	35.8	0.3	.58	1,589	39.9	11		
	31-60							1		
	61-180							4		
	181-440	-16.2	-12.6	25.2	.69	4,147	64.4	8		
	441-700							2		
	> 700							0		
	1-15							4	7-69	L.I.
	16-30							0		
	31-60							4		
	61-180							0		
	181-440	6.8	-19.5	97.6	.49	4,820	69.4	14		
	441-700							0		
	> 700							0		
	1-15							1	8-69	R.I.
	16-30							1		
	31-60							1		
	61-180							0		
	181-440	-48.0	-81.6	180.2	.45	12,845	113.0	34		
	441-700							0		
	> 700							0		

ease oup	Time at Liberty (days)	Mean Miles N-S	Mean Miles E-W	Determinant ($x10^4$)	r^2	Mean Square Distance	Mean Distance	No. of Fish	Release Month	General Release Location
	1-15							0	9-69	R.I.
	16-30							0		
	31-60							0		
	61-180							0		
	181-440	-48.2	-60.3	206.2	.54	10,828	104.0	21		
	441-700							0		
	> 700							0		
	1-15							3	7-70	R.I.
	16-30	-1.7	-20.6	3.5	.06	787	28.1	9		
	31-60	-24.4	-6.8	0.5	.25	797	28.2	5		
	61-180							0		
	181-440							0		
	441-700							0		
	> 700							0		
	1-15	-13.1	-14.7	2.0	.25	799	28.3	9	8-70	R.I.
	16-30	-33.0	-11.6	69.6	.49	4,583	67.7	7		
	31-60							3		
	61-180							1		
	181-440							0		
	441-700							0		
	> 700							0		
	1-15							0	1954-63	R.I.
	16-30							3		
	31-60	-.2	-10.4	222.9	.40	3,263	57.1	5		
	61-180							0		
	181-440	-31.9	-26.8	464.0	.83	10,959	104.7	8		
	441-700							4		
	> 700							4		

Table IV-1. Chi-square tests of equality of recapture probabilities between sport gear and commercial gear releases.

Year	Chi-Square Value		Highest Recapture From:
1961	1.23	N.S.	Sport Releases
1962	1.39	N.S.	Sport Releases
1964	0.01	N.S.	Sport Releases
1965	17.53	**	Sport Releases
1966	14.51	**	Sport Releases
1967	0.36	N.S.	Commercial Releases
1968	7.53	**	Commercial Releases
1969	9.27	**	Sport Releases
1970	3.55	N.S.	Sport Releases

N.S. Not Significant.

** Significant at the .01 level.

Table IV-2. Survival rate estimates for various release group categories

	Grouping Code	Recapture Years Used in s & Z computation*	s(95% confidence interval)	Z(95% confidence interval)
	All	(1, 2)*, 3, 4, 5	.231 (.16, .30)	1.44 (1.14, 1.75)
	RY-345	-	Not Constant	
	RY-456	(1, 2)*, 3, 4, 5	.174 (.09, .26)	1.70 (1.23, 2.16)
1	RY-567	(1)*, 2, 3, 4, 5	.118 (.10, .14)	2.13 (1.93, 2.32)
	RY-678	(1, 2)*, 3, 4, 5	.254 (.14, .37)	1.32 (0.88, 1.77)
	RY-789	(1)*, 2, 3, 4	.103 (.04, .17)	2.19 (1.60, 2.79)
	RY-890	-	NC	
	1964	-	NC	
	1965	1, 2, 3, 4	.343 (.29, .39)	1.07 (.93, 1.21)
2[1/,2/]	1966	(1, 2)*, 3, 4, 5	.233 (.14, .32)	1.42 (1.03, 1.81)
	1967	(1)*, 2, 3, 4	.323 (.24, .41)	1.11 (0.86, 1.37)
	1968	1, 2, 3	.243 (.17, .31)	1.39 (1.11, 1.68)
	1969		NC	
	July RY-345	1, 2, 3	.146 (.10, .19)	1.90 (1.61, 2.19)
	July RY-456	(1, 2)*, 3, 4, 5	.400 (.20, .60)	0.87 (0.39, 1.34)
3	July RY-567	(1, 2)*, 3, 4, 5	.355 (.18, .53)	0.99 (0.51, 1.46)
	July RY-678	(1, 2)*, 3, 4, 5	.367 (.19, .55)	0.96 (0.49, 1.42)
	July RY-789	1, 2, 3, 4	.246 (.19, .30)	1.39 (1.17, 1.61)
	July RY-890	-	NC	
	July 1964	1, 2	.128 (.06, .19)	2.00 (1.50, 2.49)
	Aug. 1964	-	NC	
	July 1965	1, 2, 3	.160 (.11, .21)	1.81 (1.48, 2.13)
	Aug. 1965	-	NC	
4[1/,3/]	July 1966	(1, 2)*, 3, 4, 5	.407 (.21, .60)	0.85 (0.40, 1.30)
	Aug. 1966	(1, 2)*, 3, 4, 5	.085 (.05, .12)	2.43 (2.08, 2.79)
	July 1967	1, 2, 3, 4	.244 (.18, .31)	1.39 (1.13, 1.66)
	Aug. 1967	-	NC	
	July 1968	1, 2, 3	.201 (.13, .27)	1.57 (1.23, 1.92)
	July 1969	-	NC	
	Aug. 1969	-	NC	
	G1	1, 2, 3, 4	.582 (.45, .72)	0.53 (0.31, 0.75)
	G2A	1, 2	.189 (.06, .32)	1.57 (0.90, 2.24)
	G2B	1, 2	.065 (.00, .15)	2.45 (1.10, 3.79)
	G2C	1, 2	.160 (.01, .31)	1.68 (0.78, 2.58)
	3	-	NC	
	4A	1, 2, 3	.190 (.07, .31)	1.57 (0.95, 2.20)
	4B	1, 2, 3	.165 (.09, .24)	1.75 (1.30, 2.21)
	4C	1, 2	.083 (.00, .18)	2.27 (1.18, 3.36)
	5A	-	NC	
	5B	-	NC	
	5C	-	NC	
	6A	-	NC	
	6B	-	NC	
	6C	-	NC	
	6D	-	NC	
5	6E	-	NC	
	7A	-	NC	
	7B	(1, 2)*, 3, 4, 5	.375 (.01, .74)	0.88 (0.04, 1.71)
	7C	(1)*, 2, 3, 4	.083 (.01, .16)	2.34 (1.49, 3.19)
	7D	-	NC	
	7E	-	NC	
	7F	-	NC	
	7G	-	NC	
	8	(1)*, 2, 3, 4	.125 (.00, .26)	1.88 (0.83, 2.94)
	9A	1, 2	.154 (.01, .30)	1.72 (0.82, 2.62)
	9B	1, 2, 3, 4	.205 (.13, .28)	1.55 (1.19, 1.92)
	10	-	NC	
	11A	1, 2, 3	.357 (.17, .54)	0.98 (0.48, 1.47)
	11B	1, 2, 3	.240 (.12, .36)	1.37 (0.87, 1.87)
	12	-	NC	
	13	-	NC	
	14	-	NC	

*Recapture years eliminated by chi-square test of full recruitment to tagged population are shown in parentheses.

[1] Grouping codes are explained in text.

[2] Includes tags assigned by cruise number.

[3] July results include tags assigned by cruise number.

Table IV-3. Estimates of total survival, rate of exploitation, fishing mortality rate and total "other-loss" rate for July releases and for all releases by year

Part A. July releases only	1964	1965	1966	1967	1968
(N) Numbers released	397	951	2,047	448	226
(R) Numbers recovered	96	169	461	131	108
$\hat{s}$	0.128	0.160	0.407	0.244	0.201
$\hat{u}_1$	0.211	0.150	0.143	0.224	0.385
$\hat{u}_T$	0.242	0.178	0.225	0.292	0.478
$\hat{F}$	0.497	0.326	0.202	0.412	0.767
$\hat{X}$	1.558	1.506	0.697	0.999	0.838
$(\hat{F+X})$	2.056	1.833	0.899	1.411	1.604

Part B. All releases by year	1964	1965	1966	1967	1968
(N) Numbers released	465	1,672	3,959	628	260
(R) Numbers recovered	132	262	1,177	187	116
$\hat{s}$	0.196	0.343	0.233	0.323	0.243
$\hat{u}_T$	0.284	0.157	0.297	0.298	0.446
$\hat{F}$	0.463	0.168	0.433	0.337	0.631
$\hat{X}$	1.167	0.902	1.024	0.793	0.784
$(\hat{F+X})$	1.630	1.070	1.457	1.130	1.415

Formulae:

$\hat{u}_1 = (R/N)/(1+s+s^2+\ldots)$ = single season exploitation rate

$\hat{F}_1 = u_1(-\ln s)/(1-s)$ = instantaneous fishing mortality rate

$\hat{X}_1 = (-\ln s) - F$ = instantaneous "other-loss" rate

$\hat{u}_T = (R/N)$ = total rate of exploitation after tagging

$(\hat{F+X}) = -\ln s$ = total instantaneous rate of decline

$\hat{F}_T = u_T(-\ln s) =$ } instantaneous rates computed from total rates of exploitation

$\hat{X}_T = (F+X) - F =$ }

Tables IV-4. Recaptures per boat day by years at liberty

Part A. July releases only	0	1	2	3	4
1964	0.0902	0.0344			
1965	0.3538	0.0968	0.0374		
1966	0.9839	1.3957	0.1059	0.0526	0.0111
1967	0.5080	0.3647	0.0421	0.0037	
1968	1.0235	0.1579	0.0222		

Part B. All releases	0	1	2	3	4
1964	0.1100	0.0786			
1965	0.4029	0.3280	0.1925	0.0718	
1966	2.8495	3.1016	0.6235	0.0842	0.0222
1967	0.5241	0.7059	0.1684	0.0481	
1968	1.0353	0.2000	0.0333		

Table IV-5. Estimates of total survival or disappearance rates from regression analysis of recapture per unit-of-effort data

	July releases only		All releases	
	Z	s	Z	s
1965	1.12	0.33	1.08	0.34
1966*	1.51	0.22	1.68	0.19
1967	1.70	0.18	1.41	0.24
1968	1.87	0.15	1.73	0.18
Average	1.55	0.21**	1.48	0.23**

Regression estimates using average unweighted percentage recoveries for 1964-68 are: $Z = 1.67$ and $s = 0.19$. This estimate happens to be exactly the same as the estimate of $Z = 1.67 = (\text{average time at liberty})^{-1}$ where average time at liberty is 0.60 year.

* Recaptures in release year not included in 1966 regression analysis

** Survival rate computed from average Z value