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A PRELIMINARY ANALYSIS OF MORTALITY OF BLUEFIN TUNA (THUNNUS THYNNUS) TAGGED IN THE NORTHWESTERN ATLANTIC OCEAN

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SUMMARY

A summary of yearly releases and subsequent recaptures of U.S. tagged small bluefin tuna is presented. Initial unbiased estimates of annual survival rates and total instantaneous mortality were calculated. Estimates of rates of exploitation, instantaneous rates of fishing mortality and the instantaneous rates of other mortality were derived. These estimates were further refined by correcting for tag shedding as determined from the results of a double tagging study on bluefin tuna. Natural mortality rates as determined by this study were higher than expected and reasons for this are discussed.

RESUME

On présente une récapitulation des marquages de thon rouge effectués chaque année par les Etats-Unis, et des récupérations qui s'ensuivent. De premières estimations non biaisées du taux annuel de survie et de mortalité instantanée totale ont été effectuées. On en a tiré des estimations du taux d'exploitation, du taux instantané de mortalité par pêche et du taux instantané de mortalité due à d'autres causes. Ces calculs ont ensuite été affinés par compensation pour rejet de marques; le degré de rejet a été estimé à partir des résultats obtenus au moyen d'une expérience de marquage de thon rouge avec marque double. Le taux de mortalité naturelle établi par cette étude s'est avéré plus élevé que ce à quoi l'on s'attendait; un exposé critique des causes est présenté.

RESUMEN

Se presenta un resumen de las liberaciones anuales y posterior recaptura de atún rojo pequeño, marcado por USA. Se calcularon estimaciones iniciales (sin sesgo) de las tasas anuales de supervivencia y total de la mortalidad instantánea. Asimismo, fueron obtenidas estimaciones de las tasas de explotación, tasas instantáneas de mortalidad por pesca y tasas instantáneas de otras mortalidades. Estas estimaciones fueron mucho más afinadas a través de correcciones de pérdida de marcas y determinadas conclusiones de un estudio sobre marcado-doble de atún rojo. Como se determina por este informe, las tasas de mortalidad natural fueron más altas de lo que se esperaba y se debaten actualmente las razones de esta mortalidad.

INTRODUCTION

This study is based upon releases of tagged bluefin tuna, Thunnus thynnus, made by a variety of organizations and individuals at various locations along the middle Atlantic bight of North America during 1954-1978 and recoveries of these tags through 1978. The purpose of this paper is to present the estimates of mortality rates and exploitation rates as determined by a tagging experiment. The fishing mortality rates can be used in a Virtual Population Analysis (VPA) as starting F's.

MATERIALS AND METHODS

The data used for this analysis were extracted from a master tagging file of the National Marine Fisheries Service (NMFS), Southeast Fisheries Center (SEFC). The file includes bluefin tuna tagged from U.S. vessels in the northwestern Atlantic Ocean, those tagged in Bahamian waters, and some other foreign releases from fishermen participating in the joint Cooperative Game Fish Tagging Program, sponsored by the NMFS and the Woods Hole Oceanographic Institution (WHOI). A summary table of all the releases and subsequent recaptures for 1954-1978 can be found in the ICCAT working document SCRS/79/ by M.I. Farber and T.W. Chewning.

A summary of yearly releases and subsequent recaptures of U.S. tagged small bluefin tuna through 1978 is presented in Table 1. Only small bluefin tagged in the general area defined as the Mid-Atlantic Bight were included in the releases, though a few records from the New England area were also counted. Multi-tagged specimens were counted as single releases, and similarly multi-tagged recaptures were counted as single recaptures. The total number of tags recovered from a given release year is separated into the number of returns from each subsequent year. The phraseology "subsequent year" is considered to be synonymous with "following season". For example, a tagged fish at liberty for six months would be considered as the same year recapture with the release/recapture months being May/November, or as a subsequent year recapture with the release/recapture months being October/April.

My analysis is limited to include only small ("school-size") bluefin tuna. Chapman and Robson (1960) and Robson and Chapman (1961) derived techniques for determining the minimum variance unbiased estimate of the annual survival rate (S). These rates were calculated from the values in Table 1. The assumptions included constant annual survival rates at least over a limited range of age groups and that all fish beyond some minimum age are equally vulnerable to the sampling gear. To use as much of the available data as possible, I followed the procedure used by Mather et al. (1974) and combined the results from the sport and commercial gears to obtain the estimates of mortality rates. Though data have been compiled for 1954-1978 the actual analysis is carried out for 1964-1975. The period of 1954-1963 is excluded since the total number of returns from each year is small at best, ranging from 0 to 10. The period from 1975 to date is excluded because the number of possible recovery years is insufficient to allow any confidence in the estimated results. The analysis technique employed in this study is based on multi-year recovery periods. Therefore a minimum of three subsequent years for recoveries permits estimations through only 1975.

Estimates of total instantaneous mortality (Z1) were calculated from the annual survival rates (S) with a correction for bias applied as

outlined by Chapman and Robson (1960). Each value of S and Zl is tabulated in Table 2 for 1964-1975, along with their respective estimated variance, standard error and approximate lower and upper bounds for 95% confidence intervals.

From the values in Table 1 and the annual survival rates in Table 2, I applied the equations found in Lenarz et al. (1973). [In general, I followed the notations, techniques and equations used by Bayliff and Mobrand (1972), Lenarz et al. (1973) and then by Mather et al. (1974).] This yielded estimates of rates of exploitation of tagged bluefin tuna (UT and Ul), instantaneous fishing mortality rates (F) and total instantaneous other loss rates (X). Estimates of the instantaneous rate of tag shedding (EL) and the rate of immediate tag shedding (1-RHO) were determined by a bluefin tuna double tagging study (Baglin et al., In Press). By applying these tag shedding rates, I calculated the "corrected" estimates of total instantaneous mortality (ZC), annual survival rates (SC), rates of exploitation of tagged bluefin tuna (UTC and UlC), instantaneous fishing mortality rates (FC), total instantaneous other loss rates (XC), and rates of exploitation of all bluefin tuna (UTCC and UlCC). These values are all shown in Table 4 with a list of definition of terms found in Table 3.

Mather et al. (1974) determined hypothetical values for immediate tagging mortaltiy (1-PIE) in their study that included tag releases during 1964-1968. By applying this factor to the previously estimated values, refined "corrected" estimates were calculated for rates of exploitation (UTCCC and UlCCC), instantaneous fishing mortality rates (FCC) and total instantaneous other loss rates (XCC). These values are shown in the lower portion of Table 4.

RESULTS AND DISCUSSION

The estimate of the instantaneous rate of tag shedding is EL = 0.2045 and the estimate of the rate of immediate tag shedding is (1-RHO) = 0.040 as determined by Baglin et al. (In Press). Estimates of annual survival corrected for tag shedding (SC) range from 0.241 to 0.640 with the average being 0.499 (Table 4). The range of estimates for the instantaneous fishing mortality corrected for tag shedding (FC) is 0.114 to 0.653, with the average being 0.285. This value is roughly in agreement with the average F's for ages 1-4 ("school-size" bluefin tuna) for 1960-1974 determined by Parrack et al. (1979).

Estimates of other losses corrected for tag shedding (XC) range from 0.216 to 0.928 with the average being 0.447. This is higher than might be expected, assuming an instantaneous natural mortality rate of 0.2 as used by other previous investigators. One possible cause for the discrepancy considered in this study is the existence of immediate tagging mortality. By assuming hypothetically [as was done by Mather et al. (1974)] that the portion of bluefin which remain alive after immediate tagging mortality takes place is 80%, I calculated the average estimate for instantaneous other losses corrected for shedding and immediate tagging mortality (XCC) to be 0.376. This value is still higher than a natural mortality rate of 0.2. Therefore, there may be significant amounts of long-term tagging mortality, non-reporting of recaptured tagged fish or apparent mortality caused by emigration. The estimate of fishing mortality corrected for shedding and tagging mortality (FCC) may actually underestimate the true rates for tagged bluefin because the estimate of the fishing rate relative to its true value, as determined by tagging experiments, tends to be decreased by the various sources of error that may bias these estimates.

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Table 1. Preliminary summary of yearly releases and subsequent recaptures of U.S. tagged small bluefin tuna for 1964-1978 (revised Sept. 1979)

Year	Releases	N_0*	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	N_9	N_{10}	N_{11}	Total Recaptures	% Recaptures
1964	452	100	32	0	0	0	0	0	0	0	0	0	0	132	29
1965	1694	164	63	36	3	0	0	0	0	0	0	0	0	266	16
1966	3902	523	578	51	8	6	0	2	0	0	0	1	0	1169	30
1967	628	97	60	16	13	0	0	0	0	0	0	0	0	186	30
1968	259	87	19	9	0	0	0	0	0	0	0	0	-	115	44
1969	337	13	82	12	2	1	0	0	0	0	0	-	-	110	33
1970	461	51	119	9	7	1	0	0	0	0	-	-	-	187	41
1971	343	11	59	9	0	0	0	0	0	-	-	-	-	79	23
1972	194	9	54	6	0	0	0	0	-	-	-	-	-	69	36
1973	348	40	20	7	2	0	0	-	-	-	-	-	-	69	20
1974	1707	73	122	51	12	7	-	-	-	-	-	-	-	265	16
1975	321	22	27	3	2	-	-	-	-	-	-	-	-	54	17
1976	2386	184	62	74	-	-	-	-	-	-	-	-	-	320	13
1977	1887	34	194	-	-	-	-	-	-	-	-	-	-	228	12
1978	1360	16	-	-	-	-	-	-	-	-	-	-	-	16	1

*Note: N_0 are the same year recaptures.

N_i represents the number of recaptures in the i^{th} subsequent year.

Table 2. Preliminary initial estimates of annual survival and total instantaneous mortality, along with their respective estimated variance, standard error and approximate 95% confidence interval (Sept. 1979)

S	VARS	SES	LCBS	UCBS	Z1	VARZ1	SEZ1	LCBZ1	UCBZ1	IYR
0.196	0.001	0.031	0.134	0.259	1.603	0.025	0.158	1.287	1.919	1964
0.352	0.001	0.024	0.305	0.399	1.039	0.004	0.067	0.906	1.173	1965
0.391	0.000	0.011	0.369	0.413	0.938	0.001	0.028	0.881	0.995	1966
0.415	0.001	0.028	0.359	0.470	0.876	0.004	0.067	0.743	1.009	1967
0.245	0.001	0.035	0.175	0.315	1.386	0.020	0.142	1.102	1.671	1968
0.516	0.001	0.033	0.449	0.582	0.658	0.004	0.064	0.530	0.787	1969
0.466	0.001	0.027	0.412	0.519	0.761	0.003	0.057	0.647	0.876	1970
0.497	0.002	0.040	0.416	0.577	0.693	0.006	0.080	0.533	0.854	1971
0.493	0.002	0.043	0.406	0.579	0.701	0.008	0.087	0.527	0.875	1972
0.370	0.002	0.047	0.277	0.464	0.978	0.016	0.125	0.729	1.227	1973
0.522	0.000	0.021	0.479	0.564	0.649	0.002	0.041	0.568	0.730	1974
0.424	0.003	0.052	0.320	0.528	0.844	0.014	0.120	0.603	1.085	1975

AVERAGE S = 0.407

AVERAGE Z1 = 0.927

S = Estimate of annual survival rate calculated from Table 1

VARS = Variance of S

SES = Standard Error of S

LCBS/UCBS = Lower Confidence Bound on S and Upper Confidence Bound on S; i.e., approximate 95% confidence interval about S

Z1 = Estimate of total instantaneous mortality calculated from S

VARZ1 = Variance of Z1

SEZ1 = Standard Error of S

LCBZ1/UCBZ1 = Lower Confidence Bound on Z1 and Upper Confidence Bound on Z1; i.e., approximate 95% confidence interval about Z1.

Table 3. Definition of terms used in Table 4.

S = Estimate of annual survival rate calculated from Table 1

Z1 = Estimate of total instantaneous mortality calculated from S

UT = Estimate of total exploitation of tagged bluefin tuna over n years

U1 = Estimate of single season exploitation of tagged bluefin tuna

F = Instantaneous fishing mortality on an annual basis

X = Instantaneous other losses on an annual basis

Z = Instantaneous total losses on an annual basis, i.e. F + X.

ZC = Estimate of total instantaneous mortality corrected for tag shedding rate EL,
where EL = instantaneous Type-II tag shedding on an annual basis

SC = Estimate of annual survival corrected for shedding rate (1 - RHO),
where RHO = portion of tags which are retained after immediate Type-I shedding takes place

UTC = Estimate of total exploitation of tagged bluefin tuna corrected for immediate tag shedding

U1C = Estimate of seasonal exploitation corrected for immediate tag shedding.

FC = Estimate of F corrected for immediate tag shedding

XC = Estimate of X corrected for immediate tag shedding

U1CC = Estimate of single season exploitation of tagged and untagged bluefin corrected for all tag shedding

UTCC = Estimate of total exploitation of tagged and untagged bluefin corrected for all tag shedding

UTCCC = Estimate of total exploitation corrected for shedding and Type-I tagging mortality (1 - PIE),
where PIE = portion of bluefin which remain alive after Type-I, immediate, tagging mortality takes place

U1CCC = Estimate of seasonal exploitation corrected for shedding and Type-I tagging mortality

FCC = Estimate of F corrected for shedding and Type-I tagging mortality

XCC = Estimate of X corrected for shedding and Type-I tagging mortality

Table 4. Preliminary initial estimates of annual survival, rates of exploitation, fishing mortality rates and total other loss rates; and estimates corrected for tag shedding and a hypothetical value of immediate tagging mortality (Sept. 1979). (See Table 3 for definitions.)

YEAR	S	Z1	UT	U1	F	X	Z	ZC	SC	UTC	U1C	FC	XC	U1CC	UTCC
1964	0.196	1.603	0.292	0.235	0.476	1.152	1.628	1.424	0.241	0.304	0.245	0.496	0.928	0.264	0.347
1965	0.352	1.039	0.157	0.103	0.166	0.877	1.044	0.839	0.432	0.164	0.108	0.173	0.666	0.117	0.199
1966	0.391	0.938	0.300	0.187	0.288	0.651	0.939	0.734	0.480	0.312	0.195	0.300	0.434	0.213	0.387
1967	0.415	0.876	0.296	0.179	0.269	0.612	0.881	0.676	0.509	0.309	0.186	0.280	0.396	0.203	0.386
1968	0.245	1.386	0.444	0.336	0.627	0.780	1.406	1.202	0.301	0.463	0.350	0.653	0.549	0.380	0.539
1969	0.516	0.658	0.326	0.170	0.233	0.430	0.663	0.458	0.633	0.340	0.177	0.242	0.216	0.194	0.444
1970	0.466	0.761	0.406	0.227	0.325	0.439	0.765	0.560	0.571	0.423	0.237	0.339	0.221	0.260	0.541
1971	0.497	0.693	0.230	0.123	0.172	0.528	0.700	0.495	0.609	0.240	0.129	0.179	0.316	0.141	0.311
1972	0.493	0.701	0.356	0.192	0.268	0.441	0.708	0.504	0.604	0.370	0.200	0.279	0.225	0.219	0.480
1973	0.370	0.978	0.198	0.127	0.201	0.793	0.993	0.789	0.454	0.207	0.133	0.209	0.580	0.145	0.254
1974	0.522	0.649	0.155	0.080	0.109	0.542	0.651	0.446	0.640	0.162	0.084	0.114	0.332	0.092	0.212
1975	0.424	0.844	0.168	0.100	0.149	0.709	0.858	0.654	0.520	0.175	0.104	0.155	0.498	0.114	0.220
		AVERAGE VALUES ARE:													
	0.407	0.927	0.277	0.172	0.274	0.663	0.936	0.732	0.499	0.289	0.179	0.285	0.447	0.195	0.360

UTCCC	U1CCC	FCC	XCC	YEAR
0.434	0.331	0.620	0.804	1964
0.249	0.147	0.217	0.623	1965
0.484	0.266	0.375	0.359	1966
0.483	0.254	0.350	0.326	1967
0.673	0.475	0.816	0.386	1968
0.556	0.243	0.303	0.155	1969
0.676	0.324	0.424	0.136	1970
0.389	0.176	0.223	0.272	1971
0.600	0.274	0.348	0.155	1972
0.317	0.181	0.261	0.527	1973
0.265	0.115	0.142	0.304	1974
0.275	0.143	0.194	0.459	1975
	AVERAGE VALUES ARE:			
0.450	0.244	0.356	0.376	

** TAGGING PARAMETERS USED ARE : EL = 0.2045 RHO = 0.960 PIE = 0.80 **