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REVIEW OF INFORMATION RELATED TO ATLANTIC BLUEFIN TUNA EAST-WEST MOVEMENT

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SUMMARY

Information from recaptures of tagged fish is examined for indications of movement between areas; the sensitivity to one of several assumptions of a model of transfer rates is also examined.

RESUME

L'information sur les recaptures de poissons marqués est examinée à la recherche de signes de déplacement entre zones ; le degré de sensibilité à l'une de plusieurs hypothèses d'un modèle sur le taux de transfert est également étudié.

RESUMEN

Se examina información de recapturas de peces marcados, para obtener indicaciones del movimiento entre áreas y se examina la sensibilidad a uno de los varios supuestos de un modelo de tasas de transferencia.

Introduction

Mark and recapture data is being used in combination population models which incorporate mixing in assessments. The importance of the mixing rates to the assessments indicates that some exploration of that data with respect to release conditions and recapture distributions might be useful; thus the first part of this paper focuses on (1) aspects of the data and (2) the mixing assumption. In addition some exploration of sensitivity of an model for estimating transfer rates to underlying assumptions is presented.

Materials and Methods

Data on released bluefin tuna in U.S. and Spanish data bases were examined. The U.S. data (data file MRFISH.DAT) contains information from 1954 - 1990, while the Spanish data consists of information from 1976 - 1992 obtained from ICCAT.

Results and Discussion

Roughly 27,000 bluefin were released in the west Atlantic from 1954 through 1990 and about 17,100 of those fish were released after 1969. During the entire time period 3863 fish were recaptured with 1924 of those released from 1970 onwards for return rates of 14% and 11%, respectively. Spanish releases of bluefin have occurred in the Bay of Biscay and the Mediterranean Sea from 1976-1992. Approximately 5200 bluefin were released in the Bay of Biscay and about 3650 were released in the Mediterranean. From those releases about 225 Bay of Biscay releases and 44 Mediterranean releases have been reported recaptured for return rates of about 4% and 1% respectively. The majority of those tag returns occurred within 6 months of release; the returns rates for recoveries out more than 6 months were 1-2% for the Bay of Biscay releases and less than 1% for the Mediterranean releases. In contrast the bluefin tagged in the west and returned after at least 6 months at liberty represent about 8% of west Atlantic releases. The very low return rate after 6 months of the Spanish releases indicates that either fishing mortality rates are very low, or somehow tagged fish are being lost. Such loses could be due to tagging induced mortality, tag shedding and nonreporting of tags by fishermen.

The Mediterranean releases were primarily age 0 fish, while Bay of Biscay and west Atlantic releases have been dominated by 1-2 and 1-3 year olds respectively (Tables 1-3). Higher mortality rates of age 0 fish could be one explanation for the lower return rates of the Mediterranean releases.

Two of the of 44 recaptures of Mediterranean releases were caught in the east Atlantic. However most were recaptured within six months, all in the Mediterranean. Two of the four fish in this data base that were recaptured after at least 6 months at liberty were caught in the east Atlantic. Cort and de la Serna

(SCRS/93/81) included more recent data in their analyses and reported 20 recaptures out more than 6 months; 11 of those fish were recaptured in the east Atlantic. No bluefin tagged in the Mediterranean Sea have been recaptured in the west Atlantic.

Of the roughly 225 bluefin recaptured from Bay of Biscay releases about 90% were recaptured from that area, about 1% were caught in the Mediterranean and about 10% were caught in the west Atlantic (based both on data on recapture locations in the data file and in Cort and de la Serna). About 60% of the Bay of Biscay releases were recaptured within 5 months. Of the bluefin at liberty longer than 6 months about 20% were recaptured in the west Atlantic.

Of the roughly 3850 recaptures of west Atlantic releases from 1954-1990 which could be assigned a recapture location about 98% were recaptured in the west, about 2% in the east Atlantic, and 3 fish in the Mediterranean Sea (Table 4). Of the fish at liberty more than 5 months, about 3% were recaptured in the east. Two thirds of the transatlantic recaptures of bluefin tagged in the west and at liberty at least 6 months were released before 1970, while only about 43% of the tags out that long were released during 1954-1969. During 1954-1969 about 4% of recaptures out over 5 months were caught in the east Atlantic, and during 1970-1990 less than 2% were caught in the East Atlantic.

Examination of west Atlantic recaptures at age (Table 5) suggests that the recovery rate of younger bluefin may be higher than that of older bluefin.

Given the larger catch at age of bluefin in the Mediterranean Sea compared to the east Atlantic (Table 6) during 1976-1992 when Spanish Bay of Biscay tagged fish were at liberty, especially for younger bluefin, if the Bay of Biscay fish were randomly mixing with bluefin in the Mediterranean Sea, higher numbers of tag returns from the Mediterranean would have been expected. This suggests that either tags are not being reported at the same rate in those areas or the Bay of Biscay fish are not randomly mixing with the Mediterranean fish. The similarity of numbers of recoveries of fish tagged off Mediterranean Spain and out several months indicates that at least some Mediterranean bluefin travel into the east Atlantic.

If reporting rates differ among fisheries, our perception of the randomness of the mixing and the transfer rates may be affected. Future programs designed to investigate mixing rates should include methods for estimating the reporting rates or should be designed to eliminate the problem of reporting by fisheries personnel through the use of tags which report <u>in situ</u> or through the use of biological tags.

Current analytical systems which calculate transfer rates from tagging data assume that a fish which transfers from area A to area B has the same probability of returning to area A as all other fish in area B (ie that movement to the other area is an actual transfer and not just mixing on the fishing grounds). Markers (archival tags or biological markers sensitive to identifiable environmental parameters) to record movement histories will be needed to address this question.

Transfer Rate Model Sensitivity

Another SCRS document presented at this meeting (SCRS number not yet available; title is "Report of the National Research Council review of Atlantic bluefin tuna"; referred to here as the "NRC report") presented estimation models using tagging data which estimate transfer across the Atlantic Ocean (Page 42 of NRC report). Here we explore these estimates by utilizing an alternative model which is quite similar to the NRC approach and the results will be compared so that one can infer the rigor of the estimates.

The NRC model equations for the catches when "t is sufficiently large" are:

$$C_{ww}/P_w = N_w\ F_w\ /(M+S+F_w+T_w) \quad (1)$$

$$C_{we}/P_e = N_w\ F_e\ T_w\ [\{1/(M+S+F_e)\} - \{1/(M+S+F_w+T_w)\}]/(F_w - F_e + T_w) \quad (2)$$

$$C_{ee}/P_e = N_e\ F_e\ /(M+S+F_e+T_e) \quad (3)$$

$$C_{ew}/P_w = N_e\ F_w\ T_e\ [\{1/(M+S+F_w)\} - \{1/(M+S+F_e+T_e)\}]/(F_e - F_w + T_e) \quad (4)$$

where

M	=	Natural Mortality rate
S	=	Shedding rate
C_{ww}	=	catch of fish tagged in the west and recaptured in the west
C_{we}	=	catch of fish tagged in the west and recaptured in the east
C_{ee}	=	catch of fish tagged in the east and recaptured in the east
C_{ew}	=	catch of fish tagged in the east and recaptured in the west
F_e, F_w	=	fishing mortality rates in the east and west, respectively
T_w	=	transfer rate west to east
T_e	=	transfer rate east to west
N_w	=	initial number of fished tagged in the west
N_e	=	initial number of fished tagged in the east
P_w	=	reporting rate in the west
P_e	=	reporting rate in the east

The NRC uses ratios of equations (2)/(1) and (4)/(3). Their "estimation models are then:

solve for T_w from $$C_{ew}/C_{ww} = P_e T_w F_e/[P_w F_w(F_e + S + M)] \quad (6)$$

where F_w is found from a VPA function of N_w, P_w, M, S, and C_w's (NRC Table 3-23 and page 67). Note, in this function F_w does NOT depend on T_w

and

where F_e is found from a VPA function of N_e, P_e, M, S, and C_e's (NRC Table 3-22 and page 67). Note, in this function F_e does NOT depend on T_e

solve for T_e from $$C_{we}/C_{ee} = P_w T_e F_w/[P_e F_e(F_w + S + M)] \quad (7)$$

where F_e and F_w are found from the same functions above

Note that the NRC approach in their Tables 3-22 and 3-23 used terminal F and terminal N assumptions with backward calculation to get the P's and F's. They then call the P's estimates. An equivalent procedure is to assume the P's and forward calculate to get the F's and terminal conditions. Results are the same either way for equivalent assumptions. I will use the latter approach (assume P's) for ease of comparison with the alternative model.

What is the alternative model?
The alternative model is simply this: given N's, P's, C's, M and S, equations (1)-(4) can be solved for the four unknowns of T_w, T_e, F_w and F_e.

What are the differences between the two approaches? The following table will help illustrate this.

		NRC model	Alternative model
Inputs:			
		M=0.14; S=0.26	same
		N_w=20951; N_e=5663	same
		C_{ww}=3037; C_{we}=65; C_{ee}=339; C_{ew}=17	same
		P_w, P_e various values	same various values
Assumptions:			
	(1)	Basic catch equations (1)-(4)	same
	(2)	Equilibrium	same
	(3)	F_w, F_e, T_w, T_e constant over ages (1-10+), years (1960-91)	same
	(4)	No "Type I" (initial) tag loss	same
	(5)	No round trips of transatlantic transfers	same
	(6)	F_e does not depend on T_e and T_w and F_w does not depend on T_e and T_w	F's and T's are allowed to be interrelated

The NRC asserts on page 77 that their model is robust to tag loss as long as it is the same on the east and west, due to ratios used [ratios of (2)/(1) and (4)/(3)]. However, with the NRC approach, the solutions of the F estimation models (NRC Tables 3-22 and 3-23) will change with Type I tag loss whether the loss is the same from the east and west or not. Hence, the ratio used to estimate the T's will NOT be the same if there is tag loss.

As can be seen by the above table the differences between the two approaches are essentially a relaxation of assumption (6) in the alternative model. The NRC makes the assumption that tag recaptures and the fishing mortality rates that cause them are linked to transfer rates on one hand (equations (1)-(4)) and then assume that they are not on the other (Tables 3-22,23). This appears to be an inconsistency in logic. Indeed the ADAPT results with mixing (NRC Table 4-10, page 101) show that F's and T's do appear to be sensitive to one another. Hence, the alternative model should be "better" in that it makes fewer assumptions. We do

not argue that the estimates themselves are better, because several of the assumptions of both approaches have probably been violated.

However, the alternative model does make fewer assumptions.

How do the two approaches perform? The following table explores that. [Note: the simultaneous solution of equations (1)-(4) was done by first analytically solving equations (1)-(3) as a function of F_w; and then numerically solving (4) for F_w, constraining solutions to include only those in which the F's were positive and the T's non-negative].

Also, the NRC report did not include the tagging from the Mediterranean from Cort and de la Serna (SCRS/93/81: Table 3 in their paper). When these data are included through 1991, then 3187 fish are added to N_e and 61 fish are added to C_{ee} (C_{ew} remains the same). This option (including Mediterranean data) was also tested with the alternative model.

		NRC model				Alternative model: without Mediterranean				Alternative model: with Mediterranean			
		T_w	T_e	F_w	F_e	T_w	T_e	F_w	F_e	T_w	T_e	F_w	F_e
P_w=.9147	P_e=.1330	0.0099	0.0316	0.0256	0.2606	0.0257	0.0148	0.0802	0.3395	0.0351	0.0076	0.0819	0.2095
P_w=.4400	P_e=.1330	0.0127	0.0262	0.0710	0.2606	0.0328	0.0148	0.2126	0.3395	0.0451	0.0076	0.2187	0.2095
P_w=.4400	P_e=.3616	0.0130	0.0179	0.0710	0.0656	0.0328	0.0097	0.2126	0.0813	0.0451	0.0057	0.2187	0.0579
P_w=.9147	P_e=.3616	0.0099	0.0216	0.0256	0.0656	0.0257	0.0096	0.0802	0.0813	0.0351	0.0057	0.0819	0.0579
P_w=.2659	P_e=.1330	0.0347	0.0147	0.3202	0.2606	0.0503	0.0148	0.5397	0.3395	0.0702	0.0076	0.5635	0.2095
P_w= 1	P_e=.1	---- not tested ----------				0.0253	0.0206	0.0721	0.6273	0.0345	0.0092	0.0737	0.3368
P_w= 1	P_e=.08	---- not tested ----------				0.0253	0.0339	0.0721	1.2898	0.0345	0.0116	0.0737	0.5332
P_w= 1	P_e=.05	---- not tested ----------				--- no positive solution --				0.0345	0.0582	0.0737	4.2619

The above table shows that using the same data and the same basic equations, but with a relaxation of assumption (6), an opposite conclusion is reached, i.e. that tranfer rates west to east are higher than those east to west, except at extremely high eastern fishing mortality rates; rates at which sustainability in the east comes into question. It is also interesting to point out that the NRC solutions are generally unable to predict the observed recapture values. Again, likely violation of assumptions may alter these estimates from either method.

Additionally, in order to get an idea of the variation in these estimates a simple bootstrap example was constructed using our alternative method without the Mediterranean data. In this example an annual number of releases in the east was selected for each year (1976-91) from the observed releases per year (NRC page 44). Then a proportion of transatlantic returns was selected from the yearly observations for each year and a proportion of same-side returns selected for each year (also, from NRC page 44). The random selections were used to get numbers of recaptures of each type for each annual batch of releases. These were summed over years to get bootstrap samples of N_e, C_{ee} and C_{ew}. Similarly, bootstrap samples of N_w, C_{ww} and C_{we} were constructed for 22 years corresponding to 1960-81 on NRC pages 48, 64 and 66. Three combinations of P_w and P_e were run. Results are shown below in the table and in the scatterplots (Figures 1-3).

		T_w 10%tile	T_w median	T_w 90%tile	T_e 10%tile	T_e median	T_e 90%tile	n
P_w = 0.9147	P_e = 0.1330	0.0128	0.0273	0.0541	0.0047	0.0163	0.0515	2302
P_w = 0.2659	P_e = 0.1330	0.0218	0.0465	0.1020	0.0061	0.0192	0.0592	3630
P_w = 0.4400	P_e = 0.3616	0.0142	0.0295	0.0623	0.0046	0.0112	0.0251	1890

Based on these analyses it is difficult to isolate any particular set of transfer rates as being the most appropriate for inclusion into a vpa framework.

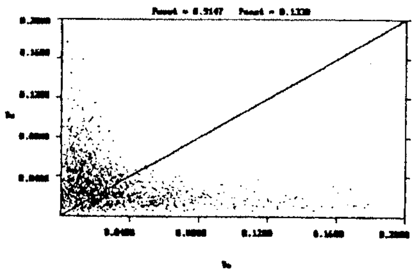

Figure 1. Bootstrapped pairs of transfer rates (T_w and T_e) with P_w = 0.9147 and P_e = 0.1330.

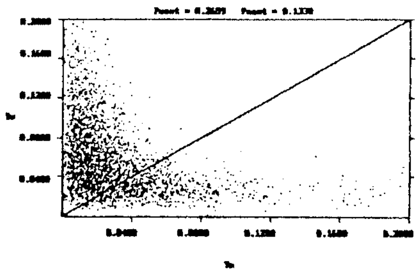

Figure 2. Bootstrapped pairs of transfer rates (T_w and T_e) with P_w = 0.2659 and P_e = 0.1330.

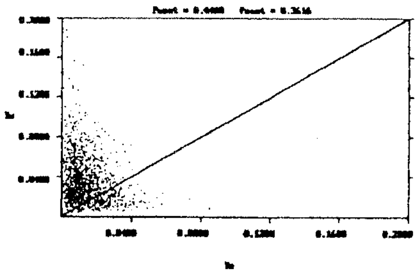

Figure 3. Bootstrapped pairs of transfer rates (T_w and T_e) with P_w = 0.4400 and P_e = 0.3616.

Table 1. Spanish releases at age of bluefin tuna in the Mediterranean Sea. The oldest observed age was 3.

release age	release year									
	83	84	85	86	87	88	89	90	91	92
0	331.	30.	0.	0.	0.	0.	0.	536.	2099.	468.
1	1.	0.	0.	1.	0.	0.	0.	0.	211.	0.
2	1.	0.	0.	0.	0.	0.	0.	0.	6.	0.
3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
total	333.	30.	0.	1.	0.	0.	0.	536.	2316.	468.

Table 2. Spanish releases at age of bluefin tuna in the Bay of Biscay. The oldest observed age was 7 years.

release age	release year																
	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.
1	0.	121.	123.	9.	28.	67.	216.	34.	1.	30.	800.	0.	1127.	117.	841.	29.	0.
2	1.	6.	41.	90.	7.	231.	70.	330.	390.	227.	26.	0.	26.	6.	6.	1.	0.
3	0.	0.	6.	1.	0.	1.	77.	1.	97.	50.	4.	0.	1.	0.	0.	0.	0.
4	0.	0.	1.	0.	1.	0.	27.	1.	8.	2.	1.	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	1.	0.	1.	2.	6.	0.	1.	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	1.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	0.	0.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.
total	1.	127.	171.	100.	38.	299.	392.	368.	504.	309.	832.	0.	1154.	123.	847.	30.	1.

Table 3. West Atlantic releases at age of bluefin tuna.

release age	release year															
	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
0	0.	4.	0.	1.	4.	0.	0.	1.	2.	1.	0.	0.	1.	10.	13.	7.
1	20.	52.	5.	28.	5.	11.	3.	80.	23.	3.	184.	552.	2395.	2.	5.	75.
2	93.	82.	9.	1.	14.	5.	20.	17.	18.	16.	54.	535.	1110.	576.	175.	129.
3	55.	61.	29.	0.	9.	0.	3.	10.	5.	4.	69.	0.	7.	34.	60.	24.
4	0.	9.	14.	2.	0.	4.	30.	26.	19.	13.	90.	8.	0.	0.	0.	11.
5	0.	7.	1.	1.	0.	5.	10.	4.	0.	17.	3.	0.	0.	0.	0.	0.
6	0.	1.	0.	0.	0.	16.	13.	1.	2.	4.	3.	1.	1.	0.	0.	0.
7	0.	2.	0.	0.	0.	33.	97.	2.	0.	4.	3.	0.	5.	0.	1.	1.
8	0.	1.	1.	0.	0.	1.	0.	2.	4.	4.	3.	29.	57.	2.	1.	3.
9	0.	0.	0.	0.	0.	2.	2.	7.	13.	11.	8.	6.	12.	7.	2.	7.
10	0.	8.	17.	1.	0.	10.	10.	13.	18.	65.	26.	41.	32.	27.	26.	21.
11	0.	2.	16.	1.	0.	9.	2.	4.	11.	48.	32.	37.	42.	27.	107.	59.
12	0.	2.	1.	3.	0.	2.	1.	4.	5.	11.	23.	23.	28.	17.	92.	70.
13	0.	1.	0.	0.	0.	0.	3.	0.	0.	2.	5.	2.	13.	4.	16.	40.
14	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	1.	1.	3.	1.
15	0.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	2.	0.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
total	168.	232.	99.	38.	32.	100.	195.	171.	120.	203.	503.	1234.	3704.	707.	501.	448.

Table 3 continued.

release age	release year																				
	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
0	2.	1.	1.	42.	10.	6.	4.	46.	23.	4.	8.	5.	0.	15.	0.	1.	0.	0.	3.	1.	2.
1	210.	160.	110.	42.	1334.	131.	710.	175.	754.	87.	54.	137.	87.	50.	8.	35.	7.	18.	45.	13.	25.
2	29.	161.	76.	190.	204.	85.	963.	1622.	567.	72.	1938.	33.	34.	40.	55.	28.	9.	9.	29.	33.	50.
3	66.	11.	6.	24.	137.	17.	588.	15.	10.	104.	205.	15.	3.	3.	11.	34.	9.	7.	3.	19.	19.
4	1.	5.	0.	0.	10.	38.	0.	10.	1.	15.	68.	0.	1.	7.	4.	16.	8.	4.	0.	22.	17.
5	1.	0.	0.	0.	0.	7.	0.	1.	1.	75.	0.	0.	7.	0.	3.	2.	0.	4.	3.	8.	3.
6	1.	1.	1.	0.	0.	3.	0.	0.	40.	78.	0.	0.	0.	0.	2.	0.	0.	2.	3.	8.	4.
7	0.	0.	0.	0.	0.	1.	0.	1.	0.	98.	0.	0.	1.	0.	0.	1.	0.	0.	1.	1.	4.
8	2.	0.	1.	0.	0.	1.	0.	1.	25.	20.	1.	0.	5.	0.	0.	0.	0.	1.	1.	0.	0.
9	19.	5.	2.	2.	0.	2.	1.	0.	4.	1.	0.	0.	6.	1.	0.	1.	1.	1.	0.	1.	1.
10	45.	7.	7.	2.	7.	9.	0.	5.	5.	6.	1.	0.	12.	3.	1.	0.	1.	0.	1.	0.	0.
11	101.	25.	28.	16.	4.	5.	2.	9.	11.	10.	1.	0.	9.	5.	1.	3.	3.	1.	0.	1.	0.
12	47.	28.	32.	17.	11.	5.	8.	33.	32.	352.	1.	1.	9.	5.	1.	4.	3.	1.	2.	0.	1.
13	31.	16.	10.	4.	8.	6.	9.	63.	58.	18.	2.	1.	13.	5.	0.	2.	2.	0.	0.	0.	0.
14	4.	0.	4.	3.	2.	2.	10.	72.	95.	149.	0.	1.	14.	5.	0.	0.	3.	2.	2.	0.	0.
15	0.	0.	1.	0.	0.	2.	2.	17.	25.	19.	0.	1.	4.	1.	0.	1.	2.	7.	2.	1.	0.
16	0.	0.	0.	0.	0.	1.	1.	7.	9.	3.	0.	0.	0.	3.	0.	1.	1.	1.	0.	0.	0.
17	0.	1.	0.	1.	0.	0.	0.	0.	1.	0.	0.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	1.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.	1.	2.	5.	1.	0.	0.
21	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	1.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
total	559.	421.	279.	343.	1727.	322.	2298.	2079.	1661.	1111.	2279.	194.	209.	143.	86.	130.	51.	64.	96.	108.	126.

Table 4. Recapture locations of west Atlantic releases and recaptures 1954-1990 for fish caught in less than 6 months and fish at liberty more than 6 months. Recapture locations are Mediterranean Sea (med), east Atlantic (east) and west Atlantic (west). Prop is the proportion of the total recaptures for one of the periods of time a liberty.

release year	n releases	recaptures: time out < 6 months: total	med		east		west		time out 6 months or more: total	med		east		west	
			n	prop	n	prop	n	prop		n	prop	n	prop	n	prop
1954	193	1	0	0.00	0	0.00	1	1.00	2	0	0.00	2	1.00	0	0.00
1955	232	0	0	0.00	0	0.00	0	0.00	0	0	0.00	0	0.00	0	0.00
1956	99	0	0	0.00	0	0.00	0	0.00	0	0	0.00	0	0.00	0	0.00
1957	39	0	0	0.00	0	0.00	0	0.00	1	0	0.00	0	0.00	1	1.00
1958	38	0	0	0.00	0	0.00	0	0.00	0	0	0.00	0	0.00	0	0.00
1959	147	1	0	0.00	0	0.00	1	1.00	0	0	0.00	0	0.00	0	0.00
1960	237	0	0	0.00	0	0.00	0	0.00	5	0	0.00	2	0.40	3	0.60
1961	188	2	0	0.00	2	1.00	0	0.00	7	0	0.00	0	0.00	7	1.00
1962	128	1	0	0.00	1	1.00	0	0.00	4	0	0.00	0	0.00	4	1.00
1963	221	11	0	0.00	0	0.00	11	1.00	4	0	0.00	0	0.00	4	1.00
1964	551	91	0	0.00	0	0.00	91	1.00	25	0	0.00	0	0.00	25	1.00
1965	1811	159	0	0.00	0	0.00	159	1.00	97	0	0.00	18	0.19	79	0.81
1966	4128	487	0	0.00	1	0.00	486	1.00	639	0	0.00	17	0.03	622	0.97
1967	718	97	0	0.00	1	0.01	96	0.99	87	0	0.00	2	0.02	85	0.98
1968	520	88	0	0.00	0	0.00	88	1.00	24	0	0.00	0	0.00	24	1.00
1969	547	14	0	0.00	0	0.00	14	1.00	90	0	0.00	2	0.02	88	0.98
1970	729	53	0	0.00	2	0.04	51	0.96	118	0	0.00	7	0.06	111	0.94
1971	432	11	0	0.00	0	0.00	11	1.00	67	0	0.00	0	0.00	67	1.00
1972	284	10	0	0.00	0	0.00	10	1.00	63	0	0.00	1	0.02	62	0.98
1973	393	41	0	0.00	0	0.00	41	1.00	28	0	0.00	1	0.04	27	0.96
1974	1748	72	0	0.00	0	0.00	72	1.00	201	0	0.00	0	0.00	201	1.00
1975	349	22	0	0.00	0	0.00	22	1.00	36	0	0.00	0	0.00	36	1.00
1976	2459	118	0	0.00	0	0.00	118	1.00	144	0	0.00	1	0.01	143	0.99
1977	2115	51	0	0.00	0	0.00	51	1.00	285	0	0.00	4	0.01	281	0.99
1978	1671	23	0	0.00	0	0.00	23	1.00	166	1	0.01	5	0.03	160	0.96
1979	1124	9	0	0.00	0	0.00	9	1.00	41	0	0.00	1	0.02	40	0.98
1980	3074	141	0	0.00	0	0.00	141	1.00	127	1	0.01	1	0.01	125	0.98
1981	1797	55	0	0.00	0	0.00	55	1.00	13	1	0.08	0	0.00	12	0.92
1982	210	1	0	0.00	0	0.00	1	1.00	4	0	0.00	0	0.00	4	1.00
1983	149	1	0	0.00	0	0.00	1	1.00	11	0	0.00	0	0.00	11	1.00
1984	86	2	0	0.00	0	0.00	2	1.00	1	0	0.00	0	0.00	1	1.00
1985	130	0	0	0.00	0	0.00	0	0.00	3	0	0.00	0	0.00	3	1.00
1986	51	0	0	0.00	0	0.00	0	0.00	2	0	0.00	0	0.00	2	1.00
1987	66	1	0	0.00	0	0.00	1	1.00	1	0	0.00	0	0.00	1	1.00
1988	96	0	0	0.00	0	0.00	0	0.00	2	0	0.00	0	0.00	2	1.00
1989	108	0	0	0.00	0	0.00	0	0.00	0	0	0.00	0	0.00	0	0.00
1990	126	0	0	0.00	0	0.00	0	0.00	0	0	0.00	0	0.00	0	0.00

Table 5. Age and year at recapture of bluefin tuna released in the west Atlantic between 1954 and 1990.

recapture age	recapture year: 54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	40.	38.	338.	0.	2.	1.
2	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.	10.	134.	163.	484.	74.	9.
3	1.	0.	0.	0.	0.	0.	0.	0.	1.	7.	22.	3.	8.	168.	114.	15.
4	0.	0.	0.	0.	0.	0.	0.	0.	1.	2.	16.	1.	0.	7.	4.	20.
5	0.	0.	0.	0.	0.	0.	0.	0.	0.	2.	1.	1.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.
12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.
13	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.
14	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
total	1.	0.	0.	0.	0.	0.	0.	0.	2.	17.	90.	177.	509.	660.	196.	46.

Table 5 continued.

recapture age	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
	recapture year																				
0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	2.	2.	8.	0.	61.	8.	22.	4.	4.	1.	1.	17.	1.	1.	0.	0.	0.	1.	0.	0.	0.
2	7.	18.	37.	71.	8.	125.	83.	66.	23.	58.	139.	8.	2.	0.	2.	1.	1.	0.	0.	1.	0.
3	15.	5.	22.	22.	18.	9.	87.	5.	218.	58.	28.	97.	0.	1.	0.	1.	0.	0.	1.	0.	0.
4	4.	4.	4.	11.	3.	6.	1.	35.	23.	66.	11.	5.	5.	0.	1.	4.	2.	2.	0.	1.	0.
5	13.	0.	2.	0.	1.	0.	3.	1.	16.	3.	1.	3.	3.	2.	0.	2.	1.	1.	0.	0.	0.
6	2.	0.	0.	4.	0.	0.	0.	0.	0.	1.	3.	0.	0.	3.	4.	1.	0.	0.	1.	0.	0.
7	0.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	2.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.	1.	0.	0.	1.	1.	0.	1.	1.	0.	0.	0.
9	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	1.	2.	0.	1.	0.
10	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	1.	0.	1.	4.	0.	0.
11	1.	0.	0.	0.	0.	1.	1.	0.	1.	1.	0.	1.	0.	0.	2.	0.	1.	1.	1.	1.	0.
12	0.	0.	0.	1.	2.	0.	0.	1.	1.	1.	0.	0.	0.	0.	1.	0.	0.	0.	0.	1.	0.
13	0.	0.	0.	2.	1.	0.	0.	6.	2.	0.	5.	0.	0.	0.	1.	1.	1.	0.	2.	0.	0.
14	0.	0.	0.	2.	0.	2.	0.	7.	4.	4.	3.	1.	0.	1.	0.	1.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	1.	0.	1.	2.	3.	3.	2.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	2.	1.	1.	4.	1.	2.	3.	0.	0.	0.	0.	0.	1.	0.
17	0.	0.	0.	0.	1.	1.	0.	0.	1.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	1.	1.	0.	0.	1.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.	0.	2.	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
total	44.	29.	76.	113.	96.	154.	198.	130.	299.	197.	198.	135.	15.	14.	14.	16.	8.	9.	9.	6.	0.

Table 6. Catch at age of bluefin tuna caught in the east Atlantic and in the Mediterranean Sea.

east Atlantic

AGE	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
1	130475	9739	113780	135097	139586	626783	79425	165197	139495	74633	101227	119546
2	65919	54737	58280	48282	57547	129120	54843	97198	68789	17447	34397	41437
3	20359	21374	7707	15784	36934	11291	11720	20581	11255	17133	13361	4012
4	14239	11773	4331	3053	9289	6783	1978	6666	14453	14213	2653	1594
5	6940	11888	7733	1971	4396	1873	1506	630	3698	3826	3332	1032
6	3057	3061	6493	2310	3439	969	769	557	1122	2223	2760	1506
7	1388	780	3208	3639	367	471	122	690	440	1892	2406	1957
8	1004	282	1415	3685	618	377	145	1030	323	3012	1027	2548
9	1946	332	659	2893	481	540	273	1711	350	3170	981	1122
10	12024	8919	7477	7583	14102	30565	18004	17796	13946	9594	8255	7171
total	257352	122884	211084	224297	266758	808772	168786	312056	253871	147143	170401	181925

AGE	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	170604	425235	54009	48024	242375	68927	380595	271438	87486	78397
2	33874	50039	181698	105385	79734	127386	68940	105880	41558	72338
3	6263	4684	23753	40606	7301	3369	8818	11481	21938	5418
4	2671	1833	3265	7575	5244	3766	2128	2910	4030	5307
5	1790	1073	2403	2178	1274	2063	1659	1434	6127	3117
6	1164	1115	1026	1552	940	1895	1379	1717	2180	2572
7	3173	1612	1493	466	887	1179	1515	2684	2538	2119
8	6804	2308	2812	457	665	933	1440	2467	4109	2605
9	2402	2082	5684	614	936	880	1362	1582	4955	4057
10	20228	18865	13848	9184	6854	7834	13674	6834	9979	11046
total	248974	508847	289992	216041	346209	218232	481509	408427	184899	186976

Table 6 continued.

Mediterranean Sea

AGE	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
1	1243	781	2801	7837	47530	69988	17453	52348	12220	999	10183	30224
2	10316	33904	90321	18602	72571	160154	133394	192259	125315	16522	130099	298060
3	6522	31809	69528	67937	20109	23552	269303	24806	141357	84781	110657	107200
4	2102	2914	7029	3214	53785	13118	37715	57385	4729	35820	27945	11415
5	2905	511	549	1343	2929	4174	18918	1703	1468	3187	5786	13831
6	5160	590	592	1004	1373	3401	4290	4704	425	191	1880	4151
7	3153	3690	1031	3107	2527	2735	3054	3294	2434	401	669	1876
8	2546	9407	878	4221	3771	2958	1885	1431	1476	927	1249	2010
9	3629	5300	2631	5623	10095	4830	3520	788	874	488	1395	2287
10	12741	9303	8019	9024	25344	23561	21127	18399	12825	13200	16203	10481
total	50317	98209	183378	121912	240035	308470	510658	357116	303123	156516	306067	481533

AGE	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	529852	281667	118834	168786	382027	190647	436499	190487	441297	229069
2	192189	119863	461321	253535	194035	317958	101102	315373	326450	343587
3	185233	116587	25078	275903	160105	106144	240865	77813	187275	141181
4	20885	23121	33183	24245	69737	26569	27311	61459	53071	33061
5	3552	11445	17156	11128	7007	7710	7809	36327	21141	15557
6	2118	2244	9150	7461	4740	5828	8713	4968	5744	3743
7	2038	8248	4728	3659	1864	7113	9362	9107	4020	1805
8	2154	3557	3816	3163	1361	3090	4552	4233	5009	2502
9	2770	2417	4623	3240	2080	2585	3793	2994	5254	6256
10	18676	20883	32801	24392	19932	15858	21210	16632	11978	20476
total	959467	590052	710689	775513	842888	683501	861215	719393	1061240	797236