INTEGRITY OF SCHOOLS OF SKIPJACK TUNA, *KATSUWONUS PELAMIS*, IN THE EASTERN PACIFIC OCEAN, AS DETERMINED FROM TAGGING DATA

WILLIAM H. BAYLIFF[1]

ABSTRACT

Little information concerning the integrity of schools is available for any species of fish. In this study the integrity of schools of skipjack tuna, *Katsuwonus pelamis*, was analyzed with data for returns of tagged fish which had been in the same schools when originally tagged. Two methods, the first using Chi-square contingency tests and the second using binomial homogeneity tests, were employed. From the results obtained with the first method it appears that after 1 month at liberty the tagged and untagged fish were randomly mixed with one another in some cases and after 3 to 5 months at liberty they were randomly mixed with one another in nearly all cases. The results obtained with the second method indicate somewhat less rapid mixing of the tagged and untagged fish.

Schooling occurs in many species of fish, and many studies have been made of the reasons for schooling and the behavior of the fish in the schools (e.g., Parr 1927; Shaw 1970; Pitcher 1986). Almost nothing has been written, however, about the integrity of schools over extended periods of time.

Parr (1927) stated that "apparently permanent" schools are formed by pelagic fishes such as mackerel, sprat, and herring, and Sharp (1978) reported that, "From the genetic sample data for the eastern Pacific yellowfin [(*Thunnus albacares*)] and the Pacific-wide skipjack [(*Katsuwonus pelamis*)] there is evidence for a cohesiveness of related fishes in schools.... What is observed is that where more than one very rare allele (overall expected occurrence <.01) is encountered in a large sample, the individuals exhibiting the rare alleles are often the same length or within 1 cm of each other. This is highly unlikely unless they are related."

On the other hand, Helfman (1981) reported "aggregations [of freshwater fish] that disbanded during twilight," and Moyle and Cech (1982) stated that "most schools break up at night." Observers on fishing vessels and aircraft have reported that the schools of tunas frequently break up and reform. Scott and Flittner (1972), for example, stated that "the relatively large nighttime schools [of bluefin tuna, *Thunnus thynnus*,] break down into several smaller foraging schools and begin their search for food.... The gradual increase in school size during the daylight hours may be due to regrouping of the smaller schools through random encounters." Such observations might lead to the conclusion that there is considerable mixing of fish from different schools and that fish of the same species and same approximate size in the same areas would mix thoroughly with one another within a period of a few days or weeks.

Anonymous (1960) stated that "Tag returns from individual schools [of skipjack tuna] suggest that, normally, the skipjack in Hawaiian waters remain within a school for one month or less, then at least some of the school break off, move into new areas, and regroup with other fish or schools. From the releases off Hilo and Mexico, however, it is evident that there are situations, possibly environmentally conditioned, where the schools remain intact...for at least 2 or 3 months." Lester et al. (1985) studied the occurrence of various parasites in skipjack tuna of the same and different schools and concluded that "school half-life is likely to be in terms of at least weeks rather than days." They stated, however, that their data did "not support the hypothesis [of Sharp (1978)] that fish stay in the same school for life."

Examination of data for fish tagged and released at the same location and time shows that some have been recaptured weeks or months later in the same purse seine set or baitboat stop, and others have been recaptured weeks or months later on the same date in widely separated locations (Hunter et al.

[1]Inter-American Tropical Tuna Commission, P.O. Box 271, La Jolla, CA 92038.

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1986). (Henceforth in this report, to save space, both sets and stops will be referred to as sets.) The former results might be due merely to chance. The latter results indicate that not all the fish remain together at all times, but this information is of limited value. A much more powerful method of analysis is needed. Turner (1986) employed statistical tests to show that tagged bluefin tuna caught during the calendar year after release had mixed considerably with the untagged population, but knowledge about shorter term mixing is necessary for short-lived species, such as skipjack tuna. The present report describes what are believed to be new and useful methods of analysis of the integrity of schools of fishes, using data for tagged skipjack tuna released and recaptured in the eastern Pacific Ocean.

MATERIALS AND METHODS

The methods of tagging the fish are described by Bayliff and Holland (1986).

Tagged fish, or tags unaccompanied by the fish to which they were attached, are recovered and returned by fishermen, unloaders, and cannery workers, accompanied by information which is used to assign them to specific sets. Additional details regarding this aspect of the study are discussed later in this report.

The methods of collecting and processing the catch statistics are discussed by Shimada and Schaefer (1956) and Joseph and Calkins (1969). Hennemuth (1957) and Shingu et al. (1974) described the methods of sampling the fish and the calculations employed to determine the size composition of tunas in the catches. The areas shown in Hennemuth's figure 1 have been changed several times since that report was published, however; the areas used currently are shown by Peterson (1982: fig. 30).

ANALYSES AND RESULTS

If tagged fish released at the same location on the same day mix thoroughly with the population of untagged fish in the same area, schools of fish caught in that area will have approximately equal ratios of tagged to total fish, whereas if they do not mix thoroughly some of the schools will have much higher ratios than the others. In this report the numbers of tagged fish recaptured in sets made at various intervals after release are compared with the numbers of tagged fish which would be expected in those sets if the tagged fish had mixed thoroughly with the rest of the population during the interval

TABLE 1.—Data used for analysis of integrity of schools of skipjack tuna. The ranges of values of sets and average weight in pounds are explained in the text.

Tagging cruise	Dates of release	Month of recapture	Numbers of returns	Sets	Average weight in pounds
1042	2, 3, 4, 17, 18, 19, 23, 24 June 1962	June	439	60–228	5.86–6.84
		July	152	174	5.85
		August	44	333	4.96
1043	5, 9, 20, 27, 28 June; 1 July 1963	June	130	11–89	6.10–6.27
		July	248	265–282	6.08–6.10
		August	108	385	5.74
		September	39	388	6.99
		October	13	247	4.98
1070	12, 13, 14, 30 June 1973	June	7	118–129	5.21–5.22
		July	32	144	5.08
		August	15	120	4.59
		September	27	45	5.35
		October	33	205	5.26
		November	10	229	5.69
1075	26 June; 20, 21 (two releases) July 1975	July	13	42–215	5.56–6.12
		August	55	274	6.83
1079	9, 10, 17, 18, 19 June 1976	June	158	232–297	4.31–4.32
		July	261	386	4.29
		August	15	47	4.24
		September	118	542	4.88
		October	61	546	4.56
		November	6	262	4.12

between release and recapture. A description of how this was done is given below. The data used in the analyses are summarized in Table 1, and a more detailed summary of the data for tagging cruise 1079, which will be discussed in more detail than the other cruises, is given in Table 2.

First, the units of time to be employed were selected. Tagged skipjack tuna have been recaptured after as long as 3 years at liberty, but the great majority of recaptures have been made within 6 months after release. It was decided to examine the data by monthly intervals because, for the experiments with sufficient total numbers of returns, that would produce several intervals with sufficient numbers of returns of tagged fish for each interval. Also, the statistical and size-frequency data of the Inter-American Tropical Tuna Commission (IATTC) are routinely calculated by month (and quarter and year), so no special calculations are required.

TABLE 2.—Data from cruise 1079 used for analysis of integrity of schools of skipjack tuna.

Date of release	Month of recapture	Numbers of returns	Sets	Average weight in pounds
9 June 1976	June	13	297	4.32
	July	13	386	4.29
	August	1	47	4.24
	September	5	542	4.88
	October	3	546	4.56
	November	0	262	4.12
10 June 1976	June	26	294	4.32
	July	17	386	4.29
	August	0	47	4.24
	September	8	542	4.88
	October	5	546	4.56
	November	1	262	4.12
17 June 1976	June	80	252	4.32
	July	120	386	4.29
	August	9	47	4.24
	September	48	542	4.88
	October	31	546	4.56
	November	1	262	4.12
18 June 1976	June	33	240	4.32
	July	88	386	4.29
	August	4	47	4.24
	September	43	542	4.88
	October	18	546	4.56
	November	2	262	4.12
19 June 1976	June	6	232	4.31
	July	23	386	4.29
	August	1	47	4.24
	September	14	542	4.88
	October	4	546	4.56
	November	2	262	4.12
Total	June	158	297	4.32
	July	261	386	4.29
	August	15	47	4.24
	September	118	542	4.88
	October	61	546	4.56
	November	6	262	4.12

Second, the areas of study were selected. If the tagged fish are released at a particular location, the vessels fishing near that location would catch more tagged fish, at least during the first few months after release, than would vessels fishing several hundred or more miles away. Thus only data for the vessels fishing near the location of release should be considered. The areas of study were selected by examining charts of the distributions of fishing effort and recaptures of tagged fish, by 1-degree areas and by months, and arbitrarily excluding those with lower recaptures per unit of fishing effort. This was quite simple, as during the periods in question practically no tagged fish were recaptured south of lat. 20°N, and there was little fishing effort north of lat. 20°N outside the area-time strata selected. The areas of study for the data for tagging cruise 1079 are shown in Figure 1.

Third, a list of sets for each area-time stratum was prepared. This included the weights of skipjack tuna caught (Table 3, column 2) and the numbers of tagged fish returned (Table 3, column 4). (Throughout this report the weights are expressed in short tons [0.907 metric tons] and pounds [0.454 kg]. The IATTC uses this system because the fishermen estimate the weights of the fish caught in individual sets in short tons, and these estimates are an important component of its data base.) In a few cases the catches were recorded only as weights of mixed skipjack tuna and some other species, and in those cases the weights were divided by 2, assuming that they consisted of equal weights of skipjack tuna and the other species. (The rest of this table will be discussed later.)

It can be seen in Table 1 that ranges instead of individual values are given for "Sets" for cases when the month of recapture is the same as the month of release. This is because sets made before the date of release were not considered for the analyses, and it was also decided not to use data for tagged fish recaptured on the date of release because these could not have mixed with the rest of the fish in the area to any appreciable extent. Therefore for cruise 1079, for example, there were 297 June sets after 9 June, 294 after 10 June, 252 after 17 June, 240 after 18 June, and 232 after 19 June (Table 2).

Fourth, an average weight for each month of recapture for each experiment was selected. Monthly average weight data for purse seine- and baitboat-caught fish from area 1 in Peterson (1982: fig. 30) were used for this purpose because they closely correspond to the strata selected for study. The aver-

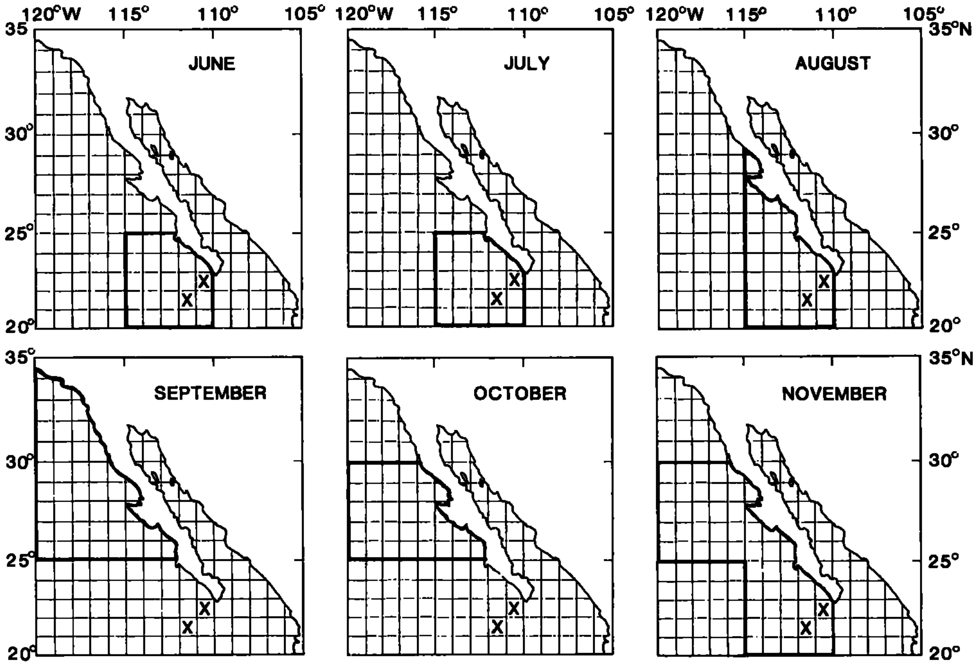

FIGURE 1.—Locations of release (X's) and areas of recapture selected for tagging cruise 1079 (areas delineated by heavy lines).

age weights were estimated by

$$\bar{w}_j = \frac{\left(\sum_{i=1}^{n} W_{ijPS} \times \bar{w}_{jPS}\right) + \left(\sum_{i=1}^{n} W_{ijBB} \times \bar{w}_{jBB}\right)}{\sum_{i=1}^{n} W_{ijPS} + \sum_{i=1}^{n} W_{ijBB}}$$

where $\bar{w}_j$ = average weight of skipjack tuna in stratum j,

W_{ijPS} and W_{ijBB} = weights of skipjack tuna caught in purse seine set i and baitboat set i, respectively, made in stratum j,

n = number of purse seine or baitboat sets in stratum j, and

$\bar{w}_{jPS}$ and $\bar{w}_{jBB}$ = average weights of skipjack tuna caught in stratum j by purse seiners and baitboats, respectively.

These are listed in Tables 1 and 2.

The average weights usually differ within strata which correspond to the months of release (Tables 1, 2) because only the sets after the dates of release are considered, and the portions of the total catches which are from purse seines and baitboats differ in accordance with the dates considered.

The data were analyzed by 1) Chi-square contingency tests and 2) the binomial homogeneity test described by Kendall and Stuart (1961:578–579).

Chi-Square Contingency Tests

A computer program, SCHOOL, was written to analyze the data. For a given release date and month of recapture, this program estimates the number of fish caught in each set from the weight of fish caught and the average weight of the fish. It then sums the estimates of the numbers of fish caught and numbers of tagged fish returned for all sets and calculates the tagged to total ratio. This ratio is then used with the equation for the binomial distribution to estimate the probabilities of 0, 1, 2, 3,... tagged fish appearing in each set if the fish are randomly mixed. The sums of the probabilities for all the sets for 0, 1, 2, 3,... tagged fish are then calculated so that these can be compared with the observed data, as described in the next paragraph. A sample output from this program is shown in Table 3. It can be seen that the sum of 39.40 + 6.41 + 1.00 + 0.16 + 0.02 (last line) is equal to 47, the number of sets, and that the sum of (39.40 × 0) + (6.41 × 1) + (1.00 × 2) + (0.16 × 3) is equal to 9, the number of tagged fish returned. (The numbers of tagged fish returned for each set had been entered in Table 3, column 4, as explained above. If the total, 9, had been entered for the first set, or any other set, however, the result in the bottom line would have been the same.)

The bottom lines from all the outputs from SCHOOL for tagging cruise 1079 are listed in the "exp." (expected) lines of Table 4. Just below these are listed the observed ("obs.") numbers of sets with 0, 1, 2, 3,... tagged fish. At the bottom of each section of this table the sums of the expected and observed values are listed. Chi-square tests were run, using MINITAB (Ryan et al. 1985), on the expected

TABLE 3.—Probabilities of 0, 1, 2, 3,...10 tagged fish in sets made in August in the area shown in Figure 1 from fish released on 17 June 1976. This table is similar to the output from program SCHOOL except that (1) normally the lines for the individual sets are not printed and (2) the output does not include the numbers of fish.

				Tags											
Set	Tons	Fish		*P*(0)	*P*(1)	*P*(2)	*P*(3)	*P*(4)	*P*(5)	*P*(6)	*P*(7)	*P*(8)	*P*(9)	*P*(10)	Total
1	12.0	5,660	0	0.6921	0.2546	0.0468	0.0057	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
2	15.5	7,311	1	0.6217	0.2954	0.0702	0.0111	0.0013	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
3	15.0	7,075	0	0.6313	0.2903	0.0667	0.0102	0.0012	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
4	5.0	2,358	0	0.8578	0.1314	0.0101	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
5	3.0	1,415	0	0.9121	0.0838	0.0038	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
6	1.0	472	1	0.9698	0.0296	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
7	2.0	943	0	0.9405	0.0575	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
8	1.0	472	0	0.9698	0.0296	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
9	25.0	11,792	0	0.4646	0.3561	0.1365	0.0349	0.0067	0.0010	0.0001	0.0000	0.0000	0.0000	0.0000	0.9998
10	25.0	11,792	0	0.4646	0.3561	0.1365	0.0349	0.0067	0.0010	0.0001	0.0000	0.0000	0.0000	0.0000	0.9998
11	1.0	472	0	0.9698	0.0296	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
12	1.0	472	3	0.9698	0.0296	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
13	1.0	472	0	0.9698	0.0296	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
14	2.0	943	0	0.9405	0.0575	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
15	5.0	2,358	0	0.8578	0.1314	0.0101	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
16	5.0	2,358	0	0.8578	0.1314	0.0101	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
17	9.0	4,245	0	0.7588	0.2093	0.0289	0.0027	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
18	5.0	2,358	0	0.8578	0.1314	0.0101	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
19	5.0	2,358	0	0.8578	0.1314	0.0101	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
20	22.0	10,377	1	0.5093	0.3436	0.1159	0.0260	0.0044	0.0006	0.0001	0.0000	0.0000	0.0000	0.0000	0.9998
21	2.0	943	0	0.9405	0.0575	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
22	1.5	708	0	0.9550	0.0438	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
23	2.5	1,179	0	0.9262	0.0709	0.0027	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
24	2.0	943	0	0.9405	0.0575	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
25	8.0	3,774	0	0.7824	0.1919	0.0235	0.0019	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
26	10.0	4,717	0	0.7359	0.2256	0.0346	0.0035	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
27	13.0	6,132	0	0.6712	0.2675	0.0533	0.0071	0.0007	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
28	4.5	2,123	0	0.8711	0.1201	0.0083	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
29	6.0	2,830	0	0.8319	0.1530	0.0141	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
30	4.0	1,887	0	0.8846	0.1084	0.0066	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
31	3.0	1,415	0	0.9121	0.0838	0.0038	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
32	6.5	3,066	0	0.8193	0.1632	0.0162	0.0011	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
33	7.0	3,302	0	0.8068	0.1731	0.0186	0.0013	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
34	10.0	4,717	0	0.7359	0.2256	0.0346	0.0035	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
35	4.0	1,887	0	0.8846	0.1084	0.0066	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
36	1.5	708	1	0.9550	0.0438	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
37	1.5	708	0	0.9550	0.0438	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
38	4.0	1,887	0	0.8846	0.1084	0.0066	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
39	4.0	1,887	0	0.8846	0.1084	0.0066	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
40	10.0	4,717	0	0.7359	0.2256	0.0346	0.0035	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
41	8.0	3,774	0	0.7824	0.1919	0.0235	0.0019	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
42	5.0	2,358	0	0.8578	0.1314	0.0101	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
43	2.5	1,179	0	0.9262	0.0709	0.0027	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
44	2.5	1,179	0	0.9262	0.0709	0.0027	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
45	7.5	3,538	2	0.7945	0.1827	0.0210	0.0016	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
46	2.0	943	0	0.9405	0.0575	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9998
47	0.5	236	0	0.9848	0.0150	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9999
Total	293.5	138,443	9	39.40	6.41	1.00	0.16	0.02	0.00	0.00	0.00	0.00	0.00	0.00	46.99

TABLE 4.—Data for analysis, by Chi-square contingency tests, of the integrity of schools of skipjack tuna released during tagging cruise 1079. [exp. = expected; obs. = observed.]

Date of release	Month of recapture	Tags		Occurrences of tagged fish 0	1	2	3	4	5	>5	Total	χ^2 value	df	Probability
9 June	June	13	exp.	284.87	11.38	0.63	0.09	0.02			297.00	0.001	1	>0.05
1976		13	obs.	285	11	1					297			
10 June		26	exp.	271.06	20.61	1.81	0.32	0.11	0.04	0.01	294.00	4.672	1	<0.05
1976		26	obs.	281	8	2	1		1	1	294			
17 June		80	exp.	194.53	44.10	9.32	2.23	0.68	0.31	0.76	252.00	16.032	2	<0.01
1976		80	obs.	218	20	6	4			4	252			
18 June		33	exp.	212.49	23.70	2.82	0.56	0.22	0.11	0.08	240.00	2.316	1	>0.05
1976		33	obs.	220	13	3	2	2			240			
19 June		6	exp.	226.26	5.50	0.21	0.02				232.00	0.012	1	>0.05
1976		6	obs.	226	6						232			
Total		158	exp.	1,189.21	105.29	14.79	3.22	1.03	0.46	0.85	1,315.00	38.280	3	<0.01
		158	obs.	1,230	58	12	7	2	1	5	1,315			
9 June	July	13	exp.	373.43	12.14	0.40	0.01				386.00	0.203	1	>0.05
1976		13	obs.	375	9	2					386			
10 June		17	exp.	369.73	15.56	0.66	0.03				386.00	0.686	1	>0.05
1976		17	obs.	373	10	2	1				386			
17 June		120	exp.	294.44	70.30	15.83	3.93	1.05	0.28	0.09	386.00	80.519	3	<0.01
1976		120	obs.	339	20	8	8	5	4	2	386			
18 June		88	exp.	314.41	58.43	10.48	2.08	0.43	0.09	0.02	386.00	31.073	2	<0.01
1976		88	obs.	342	22	9	8	2	2	1	386			
19 June		23	exp.	364.32	20.43	1.16	0.07				386.00	0.662	1	>0.05
1976		23	obs.	368	14	3	1				386			
Total		261	exp.	1,716.33	176.86	28.53	6.12	1.48	0.37	0.11	1,930.00	141.566	3	<0.01
		261	obs.	1,797	75	24	18	7	6	3	1,930			
9 June	August	1	exp.	46.02	0.96	0.02					47.00			
1976		1	obs.	46	1						47			
10 June		0	exp.	47.00							47.00			
1976		0	obs.	47							47			
17June		9	exp.	39.40	6.41	1.00	0.16	0.02			47.00	0.402	1	>0.05
1976		9	obs.	41	4	1	1				47			
18 June		4	exp.	43.30	3.42	0.26	0.02				47.00			
1976		4	obs.	44	2	1					47			
19 June		1	exp.	46.02	0.96	0.02					47.00			
1976		1	obs.	46	1						47			
Total		15	exp.	221.74	11.75	1.30	0.18	0.02			235.00	0.408	1	>0.05
		15	exp.	224	8	2	1				235			

and observed values, and the results are shown in the last four columns of Table 4. The categories were combined so that none had an expected value of less than 5. For the first test in Table 4 (releases on 9 June 1976, and recaptures during June), for example, the expected values are 284.87 and (11.38 + 0.63 + 0.09 + 0.02 = 12.12) and the observed values are 285 and (11 + 1 = 12). When only one category had an expected value of 5 or greater no test was run.

The two total lines for each section of Table 4 are listed in Table 5, with the equivalent values for the other four experiments. These were summed for each cruise and month of recapture, and Chi-square tests were run with these sums. Those results are shown in the last four columns of Table 5.

The results of the tests are summarized as follows:

Category	*df*	*Months of recapture* *6*	*7*	*8*	*9*	*10*	*11*
releases made on	1	3/11	2/17	0/12	0/10	0/6	
individual dates	2	1/1	3/4	0/1			
	3	1/1	2/2				
	4	2/2					
totals for cruises	1	0/1	0/2	0/4	0/2	0/3	0/2
	2		1/1	0/1	1/1		
	3	1/2	2/2				
	4	1/1					
overall totals	1					0/1	0/1
	2			1/1	1/1		
	3		1/1				
	4	1/1					

TABLE 4.—*Continued.*

Date of release	Month of recapture	Tags		Occurrences of tagged fish 0	1	2	3	4	5	>5	Total	χ^2 value	df	Probability
9 June 1976	September	5	exp.	537.05	4.90	0.05					542.00			
		5	obs.	537	5						542			
10 June 1976		8	exp.	534.12	7.75	0.12					542.00	0.002	1	>0.05
		8	obs.	534	8						542			
17 June 1976		48	exp.	498.05	40.23	3.35	0.30	0.03			542.00	2.969	1	>0.05
		48	obs.	509	20	12		1			542			
18 June 1976		43	exp.	502.28	36.68	2.77	0.22	0.02			542.00	0.889	1	>0.05
		43	obs.	508	26	7	1				542			
19 June 1976		14	exp.	528.37	13.26	0.35	0.01				542.00	0.030	1	>0.05
		14	obs.	529	12	1					542			
Total		118	exp.	2,599.87	102.82	6.64	0.53	0.05			2,710.00	39.481	2	<0.01
		118	obs.	2,617	71	20	1	1			2,710			
9 June 1976	October	3	exp.	543.02	2.96	0.02					546.00			
		3	obs.	544	1	1					546			
10 June 1976		5	exp.	541.06	4.88	0.06					546.00			
		5	obs.	541	5						546			
17 June 1976		31	exp.	517.04	27.07	1.74	0.13	0.01			546.00	1.766	1	>0.05
		31	obs.	524	15	5	2				546			
18 June 1976		18	exp.	528.71	16.60	0.65	0.03				546.00	0.099	1	>0.05
		18	obs.	530	14	2					546			
19 June 1976		4	exp.	542.04	3.93	0.04					546.00			
		4	obs.	542	4						546			
Total		61	exp.	2,671.87	55.44	2.51	0.16	0.01			2,730.00	1.465	1	>0.05
		61	obs.	2,681	39	8	2				2,730			
9 June 1976	November	0	exp.	262.00							262.00			
		0	obs.	262							262			
10 June 1976		1	exp.	261.00	0.99						262.00			
		1	obs.	261	1						262			
17 June 1976		1	exp.	261.00	0.99						262.00			
		1	obs.	261	1						262			
18 June 1976		2	exp.	260.02	1.96	0.02					262.00			
		2	obs.	260	2						262			
19 June 1976		2	exp.	260.02	1.96	0.02					262.00			
		2	obs.	260	2						262			
Total		6	exp.	1,304.04	5.90	0.04					1,310.00	0.000	1	>0.05
		6	obs.	1,304	6						1,310			

This means that for individual dates for recaptures during June (i.e., during the month of release), 3 of 11 tests equivalent to those in Table 4 with 1 degree of freedom were significant at the 5% level; for recaptures during July, 2 of 17 tests equivalent to those in Table 4 with 1 degree of freedom were significant; and so on. From these tests it appears that after 1 month at liberty the tagged and untagged fish are randomly mixed with one another in some cases, and after 3 to 5 months at liberty they are randomly mixed with one another in nearly all cases.

Binomial Homogeneity Tests

For the binomial homogeneity test the formula

$$\chi^2 = \sum_{i=1}^{n} \frac{(T_i - F_i\hat{P})^2}{F_i\hat{P}\,(1 - \hat{P})}$$

where T_i = number of tagged fish in set i,
F_i = number of tagged and untagged fish in set i,
n = number of sets, and
$\hat{P}$ = probability of a fish being tagged = $\sum_{i=1}^{n} (T_i)/\sum_{i=1}^{n} (F_i)$

is used. Computer program SCHOOLA was used for this purpose.

The results are given in Table 6. In general, the

TABLE 5.—Data for analysis, by Chi-square contingency tests, of the integrity of schools of skipjack tuna released during all cruises. [exp. = expected; obs. = observed.]

Tagging cruise	Month of recapture	Tags		Occurrences of tagged fish								χ^2 value	df	Probability
				0	1	2	3	4	5	>5	Total			
1042	June	439	exp.	971.84	193.13	53.10	19.75	8.53	3.89	4.76	1,255.00	121.553	4	<0.01
		439	obs.	1,114	74	26	11	4	7	19	1,255			
1043		130	exp.	203.70	39.03	11.32	4.42	2.08	1.16	4.29	266.00	5.428	3	>0.05
		130	obs.	212	27	11	8	3	3	2	266			
1070		7	exp.	345.25	6.51	0.23	0.01				352.00	0.009	1	>0.05
		7	obs.	345	7						352			
1079		158	exp.	1,189.21	105.29	14.79	3.22	1.03	0.46	0.85	1,315.00	38.280	3	<0.01
		158	obs.	1,230	58	12	7	2	1	5	1,315			
Total		734	exp.	2,710.00	343.96	79.44	27.40	11.64	5.51	9.90	3,188.00	149.523	6	<0.01
		734	obs.	2,901	166	49	26	9	11	26	3,188			
1042	July	152	exp.	1,265.04	107.21	15.36	3.20	0.75	0.17	0.27	1,392.00	32.137	2	<0.01
		152	obs.	1,307	55	22	4	0	1	3	1,392			
1043		248	exp.	1,479.32	158.72	26.60	6.72	2.19	0.79	0.44	1,675.00	50.425	3	<0.01
		248	obs.	1,536	96	18	12	6	2	5	1,675			
1070		32	exp.	545.75	28.57	1.54	0.09				576.00	0.002	1	>0.05
		32	obs.	546	28	2					576			
1075		13	exp.	338.04	11.01	0.84	0.09				350.00	2.130	1	>0.05
		13	obs.	343	6					1	350			
1079		261	exp.	1,716.33	176.86	28.53	6.12	1.48	0.37	0.11	1,930.00	141.566	3	<0.01
		261	obs.	1,797	75	24	18	7	6	3	1,930			
Total		706	exp.	5,344.48	482.37	72.87	16.22	4.42	1.33	0.82	5.923.00	231.819	4	<0.01
		706	obs.	5,529	260	66	34	13	9	12	5,923			
1042	August	44	exp.	2,613.04	41.88	0.98	0.03				2,656.00	0.582	1	>0.05
		44	obs.	2,618	33	4	1				2,656			
1043		108	exp.	2,211.08	90.80	7.13	0.78	0.10	0.01		2,310.00	2.334	2	>0.05
		108	obs.	2,219	80	7	3		1		2,310			
1070		15	exp.	465.42	14.16	0.39					480.00	0.012	1	>0.05
		15	obs.	465	15						480			
1075		55	exp.	1,044.57	48.13	2.92	0.26	0.03			1,096.00	0.602	1	>0.05
		55	obs.	1,050	39	5	2				1,096			
1079		15	exp.	221.74	11.75	1.30	0.18	0.02			235.00	0.408	1	>0.05
		15	obs.	224	8	2	1				235			
Total		237	exp.	6,555.85	206.72	12.72	1.25	0.15	0.01		6,777.00	14.206	2	<0.01
		237	exp.	6,576	175	18	7		1		6,777			
1043	September	39	exp.	2,290.28	36.42	1.18	0.05				2,328.00	0.014	1	>0.05
		39	obs.	2,291	35	2					2,328			
1070		27	exp.	156.88	19.77	2.88	0.41	0.05			180.00	0.483	1	>0.05
		27	obs.	160	14	5	1				180			
1079		118	exp.	2,599.87	102.82	6.64	0.53	0.05			2,710.00	39.481	2	<0.01
		118	obs.	2,617	71	20	1	1			2,710			
Total		184	exp.	5,047.03	159.01	10.70	0.99	0.10			5,218.00	36.868	2	<0.01
		184	obs.	5,068	120	27	2	1			5,218			
1043	October	13	exp.	1,481.38	12.26	0.35	0.01				1,494.00	0.031	1	>0.05
		13	obs.	1,482	11	1					1,494			
1070		33	exp.	788.27	30.49	1.17	0.04				820.00	0.017	1	>0.05
		33	obs.	789	29	2					820			
1079		61	exp.	2,671.87	55.44	2.51	0.16	0.01			2,730.00	1.465	1	>0.05
		61	obs.	2,681	39	8	2				2,730			
Total		107	exp.	4,941.52	98.19	4.03	0.21	0.01			5,044.00	1.094	1	>0.05
		107	obs.	4,952	79	11	2				5,044			
1070	November	10	exp.	906.14	9.69	0.14					916.00	0.002	1	>0.05
		10	obs.	906	10						916			
1079		6	exp.	1,304.04	5.90	0.04					1,310.00	0.000	1	>0.05
		6	obs.	1,304	6						1,310			
Total		16	exp.	2,210.18	15.59	0.18					2,226.00	0.002	1	>0.05
		16	obs.	2,210	16						2,226			

χ^2/df values do not appear to decrease consistently with time, as would be expected if the fish tend to mix gradually with time. If, however, only the values corresponding to date of release-month of recapture strata with more than 10 tag returns are considered the χ^2/df values tend to decrease with time. The χ^2 values corresponding to these strata are summed at the bottoms of the first five sections of Table 6, and these sums are divided by the sums of the degrees of freedom to obtain total χ^2/df values. It can be seen that these also tend to decrease with time. In addition, the χ^2 values and degrees of freedom for the strata with more than 10 tag returns for all the experiments are summed in the last section of Table 6; the χ^2/df values again tend to decrease with time. It thus appears that the fish were gradually mixing as time passed.

One thousand Monte Carlo simulations were run for each stratum with more than 10 tags, using computer program MONTCARL, to determine the probability of obtaining an equal or greater value of χ^2/df, if the tagged and untagged fish were randomly mixed with one another. The results are shown in the last column of Table 6. In most cases these indicated that the tagged and untagged fish were not randomly mixed. These data tend to indicate less rapid mixing with time than do the data for the Chi-square contingency tests.

DISCUSSION

There is a fundamental difference between the two methods. The Chi-square contingency tests test whether the tagged fish occurred in many or few of the schools, whereas the binomial tests test whether the ratios of tagged to total fish are consistent among schools. For example, if there was a total of 15 returns of tagged fish obtained from 15 different sets from a total of 20 25-ton sets and 20 1-ton sets, it would make no difference for the Chi-square contingency tests which sets the tagged fish occurred in. For the binomial homogeneity tests, however, the χ^2/df value would be much greater if the tagged fish occurred in 15 of the 20 1-ton sets than if they occurred in 15 of the 20 25-ton sets.

The Chi-square contingency tests are adversely affected by the small numbers of tag returns, which makes them rather low powered. For example, for the releases of 19 June 1962, and 28 June 1963,

TABLE 6.—Results of binomial homogeneity tests with skipjack tuna tag return data.

Year	Date of release	Month of recapture	Sets	Tags	χ^2	χ^2/df	Probability
1962	2 June	June	228	33	714.44	3.15	<0.01
		July	174	15	236.33	1.37	>0.05
		August	333	10	1,467.22	4.42	
	3 June	June	223	26	880.38	3.97	<0.01
		July	174	18	272.03	1.57	<0.05
		August	333	10	304.10	0.92	
	4 June	June	212	32	4,395.24	20.83	<0.01
		July	174	15	327.12	1.89	<0.05
		August	333	9	666.62	2.01	
	17 June	June	162	129	7,862.99	48.84	<0.01
		July	174	6	333.26	1.93	
		August	333	1	81.91	0.25	
	18 June	June	152	15	435.92	2.89	<0.01
		July	174	2	466.73	2.70	
		August	333	0	—	—	
	19 June	June	141	95	543.94	3.89	<0.01
		July	174	28	575.73	3.33	<0.01
		August	333	5	236.97	0.71	
	23 June	June	77	95	392.78	5.17	<0.01
		July	174	40	744.76	4.30	<0.01
		August	333	7	533.24	1.61	
	24 June	June	60	14	99.18	1.68	<0.05
		July	174	28	1,592.40	9.20	<0.01
		August	333	2	299.98	0.90	
	Total	June	1,255	439	15,324.87	12.29	
		July	1,044	144	3,748.37	3.61	

TABLE 6.—*Continued.*

Year	Date of release	Month of recapture	Sets	Tags	χ^2	χ^2/df	Probability
1963	5 June	June	89	26	141.07	1.60	>0.05
		July	282	25	702.74	2.50	<0.01
		August	385	16	1,250.94	3.26	<0.01
		September	388	6	645.62	1.67	
		October	249	1	2,110.73	8.51	
	9 June	June	89	28	293.56	3.34	<0.01
		July	282	50	1,036.42	3.69	<0.01
		August	385	24	514.06	1.34	>0.05
		September	388	6	779.54	2.01	
		October	249	2	314.69	1.28	
	20 June	June	53	12	56.66	1.09	>0.05
		July	282	15	532.52	1.90	<0.05
		August	385	10	681.99	1.78	
		September	388	6	1,105.22	2.86	
		October	249	2	192.00	0.78	
	27 June	June	24	33	197.47	8.59	<0.01
		July	282	101	1,683.31	5.99	<0.01
		August	385	48	1,019.23	2.65	<0.01
		September	388	19	843,91	2.18	<0.01
		October	249	8	258.17	1.05	
	28 June	June	11	31	401.40	40.14	<0.01
		July	282	43	1,071.63	3.81	<0.01
		August	385	5	85.27	0.22	
		September	388	1	268.06	0.69	
		October	249	0	—	—	
	1 July	July	265	14	1,272.38	4.82	<0.01
		August	385	5	1,000.85	2.61	
		September	388	1	447.33	1.16	
		October	249	0	—	—	
	Total	June	266	130	1,090.16	4.16	
		July	1,675	248	6,299.00	3.77	
		August	1,155	88	2,784.23	2.42	
		September	388	19	843.91	2.18	
1973	12 June	June	129	4	125.55	0.98	
		July	144	9	190.46	1.33	
		August	120	4	90.50	0.76	
		September	45	5	77.04	1.75	
		October	205	7	289.43	1.42	
		November	229	1	78.43	0.34	
	13 June	June	118	3	156.86	1.34	
		July	144	8	118.45	0.83	
		August	120	4	256.57	2.16	
		September	45	4	24.50	0.56	
		October	205	13	214.15	1.05	>0.05
		November	229	3	116.14	0.51	
	14 June	June	105	0	—	—	
		July	144	6	333.14	2.33	
		August	120	2	78.99	0.66	
		September	45	8	41.23	0.94	
		October	205	10	387.81	1.90	
		November	229	5	477.96	2.10	
	30 June	July	144	9	344.95	2.41	
		August	120	5	50.35	0.42	
		September	45	10	21.62	0.49	
		October	205	3	324.07	1.59	
		November	229	1	197.57	0.87	
	Total	October	205	13	214.15	1.05	

TABLE 6.—*Continued.*

Year	Date of release	Month of recapture	Sets	Tags	χ^2	χ^2/df	Probability
1975	26 June	July	215	5	192.62	0.90	
		August	274	15	536.17	1.96	<0.01
	20 July	July	51	1	13.23	0.26	
		August	274	8	246.67	0.90	
	21 July	July	42	7	64.87	1.58	
		August	274	10	1,255.33	4.60	
	21 July	July	42	0	—	—	
		August	274	22	1,036.53	3.80	<0.01
	Total	August	548	37	1,572.70	2.88	
1976	9 June	June	297	13	468.83	1.58	>0.05
		July	386	13	874.92	2.27	<0.01
		August	47	1	38.13	0.83	
		September	542	5	628.52	1.16	
		October	546	3	1,830.07	3.36	
		November	262	0	—	—	
	10 June	June	294	26	664.08	2.27	<0.01
		July	386	17	744.88	1.93	<0.01
		August	47	0	—	—	
		September	542	8	578.70	1.07	
		October	546	5	354.91	0.65	
		November	262	1	410.61	1.57	
	17 June	June	252	80	977.05	3.89	<0.01
		July	386	120	1,283.42	3.33	<0.01
		August	47	9	359.63	7.82	
		September	542	48	1,448.02	2.68	<0.01
		October	546	31	1,002.48	1.84	<0.01
		November	262	1	153.34	0.59	
	18 June	June	240	33	1,749.76	7.32	<0.01
		July	386	88	947.11	2.46	<0.01
		August	47	4	399.34	8.68	
		September	542	43	2,018.78	3.73	<0.01
		October	546	18	704.02	1.29	>0.05
		November	262	2	105.17	0.40	
	19 June	June	232	6	249.12	1.08	
		July	386	23	611.28	1.59	<0.05
		August	47	1	292.31	6.35	
		September	542	14	594.33	1.10	>0.05
		October	546	4	771.34	1.42	
		November	262	2	242.38	0.93	
	Total	June	1,083	152	3,859.72	3.58	
		July	1,930	261	4,461.61	2.32	
		September	1,626	105	4,061.13	2.50	
		October	1,092	49	1,706.50	1.57	
all		June	2,604	721	20,274.75	7.84	
		July	4,649	653	14,508.98	3.13	
		August	1,703	125	4,356.93	2.56	
		September	2,014	124	4,905.04	2.44	
		October	1,297	62	1,920.65	1.48	

there were sets with more than five tagged fish in them, and yet the results of the Chi-square tests were not significant. This is caused by the requirement that each category have an expected value of 5 or greater. Accordingly, it is likely that if there had been more tag returns, there would have been more categories for many of the tests and significant results for more of them. The practice of combining the results for fish of the same experiment released on different days ("Total" lines in Table 4) and for fish of different experiments ("Total" lines of Table 5) helps to overcome this weakness. It can be seen in the text table above that the ratios increased with the degrees of freedom. If there were more tag returns, there would be fewer tests with one degree of freedom and more with three or more degrees of freedom, and the ratios of significant tests would almost certainly increase.

On the other hand, the way that the tag return data are handled causes it to appear that there were more sets with more than one tagged fish than was actually the case. Ideally, all tagged fish would be recovered by fishermen as soon as they are caught, and then set aside for later examination by an IATTC employee, and the tag numbers, locations, and dates of recapture would be recorded so that each fish could be assigned to the proper set. In reality, however, less than half the tagged fish recaptured are recovered by the fishermen, and since the fish from different sets are mixed in the wells of the vessels, the chance of assigning tagged fish to specific sets is lost, except when enough fish are caught in one set to fill an entire well. Virtually all of the tagged fish which are not recovered by fishermen are recovered later by unloaders and cannery workers. The unloaders and cannery workers usually inform the IATTC employee to whom they return the tagged fish (or the tag without the fish attached to it) that the fish was found in or had come from a particular well or pair of wells of a particular boat. The IATTC employee who receives the tagged fish or tag records this information, and later another IATTC employee compares this information with an abstract of the vessel's logbook and assigns the fish to the set which contributed the greatest weight of fish of the species in question to that well or pair of wells. For example, if a particular well contained fish from sets with 12, 15, 20, and 13 tons made on 1, 2, 3, and 4 June, respectively, and each included one tagged fish, all recovered by unloaders and cannery workers, all four would be assigned to the 3 June set. This would make it appear that the tagged fish tend to remain together more than is actually the case. Another way to handle a situation such as this would be to allocate the four fish among the four sets in proportion to the weights of fish in them, in this case one to each set. This is not done, however, because tagged fish from the same trip of the same vessel are often returned to the IATTC over a considerable period of time, and it is not feasible to keep the tags for long periods waiting for all of them to be returned before processing them. Furthermore, allocation of tagged fish in the way just described would tend to make it appear that the tagged fish remain together less than they actually do if they are not randomly mixed with the untagged ones.

In addition to the problems created by failure to recover all the tagged fish as soon as they are caught, there are probably problems created by false data. Sometimes the persons recovering tagged fish keep the tags they have recovered over a period of several days, weeks, or even longer, and then return them to an IATTC employee, telling him that they were all recovered that day in the well or pair of wells that was unloaded that day. The likelihood that the data are false can often, but not always, be detected by an alert IATTC employee. When the likelihood that the data are false is not detected, it will appear that the tagged fish remain together more than is actually the case. It is believed that, in spite of attempts to detect data which are likely to be false, some false data are included in the analyses and make it appear that the tagged fish remain together more than is actually the case.

The fact that the numbers of tag returns were small, coupled with the requirement for the Chi-square contingency tests that the categories for the expected numbers of tagged fish be equal to or greater than 5, tends to make it appear that the tagged fish mix more rapidly with the untagged ones than is actually the case. The biases resulting from the mixing of the fish caught in different sets in the same wells and from false data tend to make it appear that the tagged and untagged fish mix less rapidly than is actually the case. Thus the two factors tend to cancel each other out, at least partially, although the first bias may be stronger than the second. If so, the tentative conclusion made above that the tagged and untagged fish mix thoroughly within about 3 to 5 months may be incorrect; that time could be somewhat longer. For the binomial homogeneity tests only the second bias exists, so the rate of mixing of the tagged and untagged fish indicated by these tests is probably somewhat slower than is actually the case.

Sharp (1978) stated that it is likely that skipjack tuna in the same school are "related," but it seems unlikely that tunas could school together for their entire lives, an implication attributed to Sharp (1978) by Lester et al. (1985). During the egg and larval stages, the fish are at the mercy of their environment, and individuals which were together at one time would often be separated by the currents. Furthermore, large tunas of the genus *Thunnus* occur mostly in subsurface waters at depths to nearly 300 m (Suzuki et al. 1977). Although there are areas of greater and lesser concentrations of large, subsurface-dwelling fish, there is no evidence that they form concentrated schools such as those which occur at the surface. The present study indicates that skipjack tuna in the size range of about 3.4 to 7.0 pounds (about 43 to 53 cm in length) of the same school mix randomly with those of other schools within about 3 to 5 months, or possibly somewhat longer. This is in agreement with the findings of Anonymous (1960) and Lester et al. (1985), but not those of Sharp (1978), discussed at the beginning of this report.

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