WORKING PAPER ON SOUTHERN BLUEFIN TUNA POPULATION DYNAMICS

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This paper has been prepared for an ICCAT workshop on tuna to be held at Nantes in September 1974.

I. INTRODUCTION

The population dynamics of Southern Bluefin Tuna has been the subject of considerable research by Japanese and Australian scientists in the past 5 years. Papers by Hayashi et al (1969), Suda, (1971) and Hynd and Lucas (1974)* are relevant. There is also a considerable number of papers relating to various aspects of the biology of the species and the commercial fisheries. Most of these references appear in the bibliographies of the three papers cited.

At the IOFC meeting in Colombo, in October 1972, a decision was made that co-operative studies on southern bluefin tuna should be undertaken by Japanese and Australian scientists. As a result, a workshop was held at Cronulla, Australia, on 18-22/3/74 and the notes from this workshop are appended. These notes indicated clearly in which direction further analysis should progress.

The present paper is the result of such further analysis, both of data previously examined and new data that had become available subsequently.

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*This paper was read at the 15th meeting of IPFC in Wellington, New Zealand in November, 1972 just after the October 1972 meeting of IOFC in Sri Lanka. However, it was not published until 1974.

II. SIZE AND AGE COMPOSITION OF AUSTRALIAN CATCH

Commercial catch sampling has been carried out in the N.S.W. and S.A. fisheries since 1962 and the length frequencies are given Fig. 1. The number of fish caught each season is a count of the numbers processed and is therefore not an estimate whereas the tabulated number in each size group are estimates.

Hynd 1965, has identified three separate stocks in this distribution and derived a growth curve using the Petersen method. Yukinawa 1970, using scale readings of adults derived a growth curve. A growth curve based on tag releases in Australia and recaptures in the longline fishery was calculated using the method of least squares. The raw data contained 116 fish which had been recaptured and measured. However some of these has shown very little growth and 11 were considered to be incorrect, possibly the head off length was taken. The basis of selection was to reject any in which the expected length calculated from the growth curve of Yukinawa differed from the recorded length by more than 30 cm. The parameters and curves are given in Fig. 2. From this it is seen there is little difference between all methods for the 2-4 year old range. In the range above 5 years the tagged fish have a slower growth rate than that indicated by scale readings.

However since it is the age range 2-5 years with which we are concerned the discrepancy between the two methods above 5 years is of no consequence here.

Schaefer et al. (1961) have reported that tagged yellowfin have a slower growth than the untagged fish.

Assuming spawning occurs during the period October to March, Shingu (1967), then the ages of fish in the N.S.W. fishery, which operates from late August to early February, are $1\frac{1}{3}$-$2\frac{1}{3}$, $2\frac{1}{3}$-$3\frac{1}{3}$, etc., and the ages of fish in the S.A. fishery which operates from January to June are $1\frac{3}{4}$-$2\frac{3}{4}$, $2\frac{3}{4}$-$3\frac{3}{4}$, etc. Using the Petersen growth curve the length frequencies have been dissected into these age or spawning classes. They are given in Table 1.

Examination of this table shows (i) that 2 year old fish are obviously not fully recruited in either fishery and that 5 year old fish have almost entirely emigrated to the Japanese longline fishery, (ii) there is considerable variability in the migratory behaviour of different year classes. For the 61/62 year class, the dominant size class in S.A. was 87-102 and in N.S.W. 63-81. For the 62/63 year class, the dominant size class in S.A. was 69-86 and in N.S.W. 82-98. For the 66/67 and 67/68 year classes, the dominant size class in S.A. was 49-68.

III. FISHING EFFORT

While the S.A. boats are relatively uniform (and large) in size the N.S.W. fleet sometimes contains a large proportion of small boats which fish only part of the season on S.B.F. and have a very small carrying capacity. Hence their fishing power is much lower than that of the larger vessels and their inclusion in the numbers of boats operating gives an inflated impression of the fishing power of the N.S.W. fleet.

This problem may be overcome by introducing relative fishing power factors. Those boats which catch more than 50 tons each season are assumed to exert a unit of effort. The total effort f_{tot} is then given by

$$f_{tot} = \frac{C_{tot}}{C_s} \cdot s$$

where C_{tot} is the total catch, C_s is the catch of those boats with more than 50 ton of fish, and s is the number of such boats. Annual details are given in Table 2.

This process is considered reasonably accurate in S.A. where the numbers and type of vessels do not greatly vary. There are however two complications in the N.S.W. fishery. In 1967, isotherm maps indicating favourable areas for the appearance of S.B.F. were distributed to fishermen (Hynd 1969). Hence overall efficiency of the fleet may have abruptly increased in 1967. This would certainly be the case if a given group of fish only surfaced a small number of times in the season and if the probability of encountering these fish significantly increased by the use of the maps.

Hynd and Robins 1967, indicate that the number of times fish surface in a season is probably not less than ten and possibly significantly more times than this. This suggests that while the isotherm mapping reduces steaming time and costs of the fleet, it may not increase fishing effort.

The other complication in N.S.W. is the possibility of a saturation effect. If all available schools are in fact sighted then an increased number of boats may not result in an increase in fishing effort. Hynd (personal communication) indicates that there is a tendency for the small boats to interfere with the larger boats and thus reducing the fishing effort of the larger boats. If this is the case then the fishing effort is approximately constant each year.

IV. RECRUITMENT

The basic assumption is that the strength of a year class is proportional to the subsequent catch in N.S.W. and S.A. Because of the different migratory behaviour of different year classes the best estimate is considered to be that obtained by adding the total numbers per unit effort of a given year class. Two effort measures are chosen: one is the relative numbers of standard boats given in Table 2, and the other is that effort is constant. The relative year class strengths are given in Fig. 3. This suggests poor recruitment in 62/63 and 63/64 and again in 69/70 and 70/71. The 71/72 recruitment is already almost as high as 69/70 and 70/71 recruitment and only the length class a is taken. The 70/71 year class numbers were down in 1973 N.S.W. catch but this may be due to unusually high temperatures in the coastal area of N.S.W. such that young fish were not available for capture. Overall, there is no downward trend in spite of higher fishing effort in the longline fishery The trends are similar irrespective of the calculation of relative effort.

V. TAGGING EXPERIMENTS

Tagging of southern bluefin tuna was initiated in Australian waters in 1959 and was concluded in 1970. The experiments were intended to delineate stock boundaries, show migration paths, confirm growth rates obtained by other methods and hopefully, to be of assistance in a stock assessment. The operations have been carried out on a somewhat ad hoc basis, being limited in both time and area by the availability of fish. However, it was possible to repeat experiments in some places in consecutive years, notably those conducted at Albany, W.A. where 2-year old fish are nearly always available in large numbers in June. To date 46,926 fish have been released. The release areas were Albany, W.A. and various localities in the N.S.W. and S.A. commercial fishery. Recoveries have been made in the N.S.W. and S.A. fisheries and by Japanese longliners fishing in the Southern Ocean. Total recoveries to June 1974 were 6,864. The Japanese recoveries are shown in Fig. 4. It is clear from these that the southern bluefin constitutes a singly stock with a near circumpolar distribution in the southern ocean and that there must be interaction between the Australian and Japanese fisheries. Tag releases and recaptures have been published in a summarised form in the Annual Reports of the CSIRO, Division of Fisheries and Oceanography. More detailed information is given in the Fisheries Field Bulletins (mimeo.) of the same Organization. These bulletins have been released monthly or half-monthly since 1964.

The tags used were the standard Floy dart tags employed by most tuna research organizations. They were applied about 2 in. (5 cm) below the second dorsal fin. Since 1963 all fish were double tagged with a tag each side in order to measure the shedding rate. Fish for tagging were caught by both the live bait and pole fishing method and by trolling. Most tagging was done from chartered commercial fishing boats though some was done during commercial fishing operations. To minimise initial tagging mortality only fish in prime condition were used and they were usually released within 30 seconds of capture, often less. Hynd (1965) observed that 2 recaptures were made within 20 seconds of release and from this and other facts concluded that initial tagging mortality was slight or absent.

Tag shedding was estimated using the method developed by Gulland (1963). If the probability of a tag having come off at time t is p_t then we can write

$${}_2N = \text{number of fish with two tags} = (1-p_t)^2$$

$${}_oN = \text{number of fish with no tag} = p_t^2$$

$${}_1N = \text{number of fish with one tag} = 2p_t(1-p_t)$$

hence

$$\frac{{}_1N}{{}_1N+N_2} = \frac{2p_t}{1+p_t} \qquad (1)$$

This quantity is plotted in Fig. 5 and p_t^2 estimated. Tag loss for double tagged fish is thus not a very large component in the other loss coefficient.

VI. FISHING AND NATURAL MORTALITY RATES

The model assumed in these calculations is that of a single spawning area (Oki and Oka grounds) with the 1+ fish moving down the West Australia coast, the 2+ fish moving into the N.S.W. and S.A. fisheries and subjected to fishing mortality from age 2.5 to 5 years. At this time the fish leave the continental shelf and spread out through the Southern Ocean where they are subjected to a longline fishing mortality rate. Releases at Albany may approximate a representative sample of fish (assuming no tagging effect). If the further assumption is made that all fish are available for capture in N.S.W. and S.A. then all releases in N.S.W. and S.A. should also be a representative sample. A summary of release and recapture data is given in Table 3. A more detailed summary is given in CSIRO Annual reports.

The number of 2.5 year old recruits is given by

$$N_{2.5} = \frac{C_a}{n_a} \cdot N_a \qquad (2)$$

where C_a is the Australian catch in numbers (mean = 0.7×10^6) and n_a and N_a are the numbers of tagged fish recaptured and released respectively. The mean fishing mortality rate F_a is found by solving the equation

$$\frac{n_a}{N_a} = \frac{F_a}{F_a+M} \left(1 - e^{-(F_a+M)T}\right) \qquad (3)$$

where T is the length of time spent in the fishery (= 2.5 years). The number of 5 year old recruits to the longline fishery is given by

$$N_5 = N_{2.5}\, e^{-(F_a+M)T} \qquad (4)$$

The mean value of F_e, the fishing mortality rate in the longline fishery is then obtained by

$$C_e = N_5 \frac{F_e}{F_e + M} \qquad (5)$$

The mean observed longline catch, C_e is 1.2×10^6 (Hayashi). Hence the expected number of recaptures in the longline fishery is

$$n_e = N_a \cdot \frac{C_e}{N_{2.5}} \qquad (6)$$

The expected recaptures and actual recaptures, given in Table 4, indicate that the tagged data is not consistent with the observed catches. The expected number of recaptures in the longline fishery are much higher than the actual recaptures. There are three possible reasons for this. One is non-detection or non-reporting of tags. However this seems unlikely as each fish is individually handled. Secondly, tagged fish may not behave or migrate in the same way as untagged fish. Since tagged fish have been located in most fishing grounds (the exception being the spawning area) this seems unlikely to cause such a large discrepancy. Thirdly, tagged fish may suffer an addition tag mortality. Fink 1965, indicates yellowfin tuna may suffer an additional tag mortality rate of the order of M_t =1.0 year^{-1}

The mortality rate required to explain this discrepancy may be calculated as follows. Hayashi lists the estimates of F_e and M obtained from an analysis of the catch in the longline fishery (Table 5). The catch in numbers in this fishery is then given by

$$C_e = N_5 \int_5^{\infty} F\, e^{-(F_e+M)(t-5)}\, dt$$

$$= 0.71\, N_5 \qquad (7)$$

using Hayashi's values and a piece-wise integration. This is equivalent to a constant M = 0.2 and F_e = 0.5

Hence the number of 5 year old recruits is 1.7×10^6. The Australian catch is given by

$$C_a = N_{2.5} \frac{F_a}{F_a+M} \left(1-e^{-(F_a+M)T}\right) \qquad (8)$$

Solving eqns (4) and (8) gives the value

$$F_a = 0.108 \qquad (9)$$

The number of 2.5 year olds is 3.7×10^6 and the percentage taken in the Australian fishery is 19%. Since the estimate of M is not very precise, the calculations are re-done assuming M = 0.15 and 0.25 and given in Table 6. The percentages taken in the Australian and Japanese fisheries are not sensitive to changes in M of this order. The expected and actual recaptures in the longline fishery when there is an additional tag mortality rate is given in Table 7. The value $M_t = 1.0$ best fits the data. A tag mortality of this order appears to be the most likely explanation.

If such a tag mortality is operating on the fish, then the percentage of untagged fish taken is higher than that of tagged fish taken. This difference may be estimated as follows. Few of the Albany releases are recaptured within the first year of liberty in N.S.W. or S.A., during which time the numbers have been reduced to e^{-M_t+M} of the initial numbers. The number recaptured subsequently as a percentage of the initial number released is then given by

$$\text{\% recaptured} = e^{-M_t+M} \cdot \frac{F_a}{F_a+M_t+M} \left(1-e^{-(F_a+M_t+M)(T-1)}\right) \qquad (10)$$

Using the previously given values of the parameters this gives approximately 3%, which is the observed percentage. Thus there is internal consistency in postulating such an additional tag mortality rate.

This analysis tends to support Hayashi's general conclusions that the longline fishery is heavily exploiting the adult southern bluefin stock.

A possible alternative explanation is that there is no tag mortality and that the longline fishery operates on only a small part of the total adult bluefin stock (approximately one-seventh). This explanation would indicate there is considerable room for expansion of both the Australian and Japanese fisheries. However, since the longline fishery has expanded fishing effort on bluefin considerably since the early sixties, for little or no increased catch, this explanation seems unlikely.

VII. INTERACTION OF AUSTRALIAN AND LONGLINE FISHERIES

Any change in the Australian fishery will affect the numbers of 5 year old fish and hence affect the longline fishery. Any change in the longline fishery may effect spawning and hence the recruitment of young fish to both fisheries.

For the first consideration it is useful to determine the magnitude of any change and five cases are considered - no N.S.W. and S.A. fishery, an increase in the N.S.W. and S.A. fisheries by 25%, 50%, 100%, and finally a W.A. fishery on 2 year olds. For the first four cases the calculations are simply based on eqns (5) and (8). The number of 2.5 year old recruits required for the calculations as listed in Table 6, and the value of F_e is 0.5. The estimated effects are given in Table 8. The values are quite insensitive to changes in the natural mortality rate. In Table 9 are the re-calculated estimates based on the assumption that the longline fishery operates on only half the stock. If this fishery does operate on one half of the stock then the recalculated value of N_5 is 3.4×10^6. The mean $F_e = 0.11$, $F_a = 0.06$ $N_{2.5} = 6.5 \times 10^6$ and the percentage taken in the Australian fishery is 11%.

The effect of the W.A. fishery is calculated firstly by obtaining the number of 2 year old fish from

$$N_{2.5} = N_2 e^{-0.5M} \quad (11)$$

and secondly by estimating the number of fish caught assuming that a 2 year old fish weighs 3.7 kg. These calculations are given in Table 10. The highest catch taken at Albany was in 1971, with a total catch of 0.8×10^6 kg but catches in other years are considerably less than this.

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TABLE 1

DISSECTION OF CATCH BY SPAWNING CLASS

Length Class*

	Short Tons	a	b	c	d	Total
N.S.W. '62	1,524	83	20,772	83,525	3,751	108,000
S.A. '63	3,956	1,115	98,279	106,873	26,830	233,000
Total	5,480	1,198	119,051	190,398	30,581	341,000
N.S.W. '63	2,877	2,127	95,430	75,969	24,984	199,000
S.A. '64	6,070	4,165	204,656	168,282	16,587	394,000
Total	8,947	6,292	300,086	244,251	41,571	592,000
N.S.W. '64	2,506	1,625	244,918	26,948	3,493	277,000
S.A. '65	5,254	2,202	84,495	166,055	37,948	290,000
Total	7,760	3,827	329,413	193,003	41,441	568,000
N.S.W. '65	2,595	5,121	33,831	116,004	32,168	187,000
S.A. '66	6,604	1,680	180,815	227,475	14,703	425,000
Total	9,199	6,801	214,646	343,479	46,871	612,000
N.S.W. '66	2,362	12,840	64,395	70,060	20,476	168,000
S.A. '67	3,776	8,641	121,683	102,369	11,456	244,000
Total	6,138	21,481	186,078	172,429	31,932	412,000
N.S.W. '67	4,108	35	323,870	50,028	15,510	389,000
S.A. '68	3,245	12,618	186,668	52,583	5,330	257,000
Total	7,353	12,653	510,538	102,611	20,840	646,000
N.S.W. '68	5,990	11,821	551,112	101,294	13,262	677,000
S.A. '69	3,439	265,337	189,791	44,598	89	500,000
Total	9,429	277,158	740,903	145,892	13,351	1,177,000
N.S.W. '69	6,338	34	558,844	78,768	28,322	666,000
S.A. '70	2,085	245,815	70,717	4,278	19	321,000
Total	8,409	245,849	629,561	83,046	28,341	987,000
N.S.W. '70	3,981	9,109	413,231	44,720	4,598	472,000
S.A. '71	3,105	139,943	154,124	32,030	707	327,000
Total	7,086	149,052	567,355	76,750	5,305	798,000
N.S.W. '71	5,548	222	257,783	161,958	26,471	446,000
S.A. '72	4,821	65,563	305,809	32,965	93	404,000
Total	10,369	65,785	563,592	194,923	26,564	851,000
N.S.W. '72	6,761	67	103,480	177,324	94,990	376,000
S.A. '73	7,534	60,541	189,505	246,884	4,165	501,000
Total	14,295	60,608	292,985	424,208	99,155	877,000
N.S.W. '73	1,996	59	5,529	4,506	65,465	76,000
S.A. '74	7,699	305,480	307,673	123,175	14,140	750,000
Total	9,695	305,539	313,202	127,681	79,605	826,000

*The length classes a, b, c, d, in N.S.W. are 41-61, 62-80, 81-97, 98-112, and in S.A. are 49-69, 70-87, 88-103, 104-118, respectively.

TABLE 2(a)

ANNUAL CATCHES BY BOATS EXCEEDING 50 SHORT TONS AND

TOTAL NUMBERS OF EQUIVALENT STANDARD BOATS IN S.A.

	Number of boats catching more than 50(S/T)	Weight of catch by these boats (S/T)	Annual catch (S/T)	Number of standard boats
1963	18	3826	3956	18.6
1964	20	6064	6070	20.0
1965	~~23~~ 22	5144 ~~5275~~	5254	~~22.9~~ 22.5
1966	~~27~~ 26	6081 ~~6144~~	6604	~~29.0~~ 28.2
1967	22	3395	3776	24.5
1968	~~22~~ 21	3064 ~~3338~~	3245	~~21.4~~ 20.2
1969	18	3462	3588 ~~3439~~	~~17.9~~ 18.7
1970	11	1965	2085	11.7
1971	20	2921	3105	21.3
1972	16	4477	4821	17.2
1973	28	6929	7534	30.4
1974	37	7492	7699	38.0

TABLE 2(b)

ANNUAL CATCHES BY BOATS EXCEEDING 50 SHORT TONS AND

TOTAL NUMBERS OF EQUIVALENT STANDARD BOATS IN N.S.W.

	Number of boats catching more than 50(S/T)	Weight of catch by these boats (S/T)	Annual catch (S/T)	Number of standard boats
1962	9	904	1524	15.2
1963	10	2629	2877	10.9
1964	16	1518	2506	26.4
1965	16	1890	2595	22.0
1966	19	2151	2362	20.9
1967	26	3734	4108	28.6
1968	39	4912	5990	47.6
1969	24	4785	6338	31.8
1970	24	2847	3981	33.6
1971	26	3248	5548	44.4
1972	25	3346	6761	50.5
1973	15	1448	1996	20.7

TABLE 3

NUMBERS OF FISH RELEASED AT ALBANY AND IN N.S.W. AND S.A. AND RECAPTURES IN N.S.W. AND S.A. AND IN THE LONGLINE FISHERY

Area Released	Dates Released	Numbers Released	Number of re-captures in NSW and SA	%	Number of re-captures by long-line	%
Albany	63,64,65	11989	325 (372)*	3.1%	60 (90)*	0.75%
Albany, NSW SA.	59-67	37005	3076 (3507)*	9.5%	270 (405)*	1.1%

* Corrected for tag shedding

TABLE 4

EXPECTED AND ACTUAL RECAPTURES IN LONGLINE FISHERY

The mean Australian catch is 0.7×10^6 fish and the mean longline catch is 1.2×10^6 fish.

% recaptures in NSW and SA	3.1%	9.5%
Calculated number of 2.5 year old fish	22.6×10^6	7.4×10^6
Expected longline recaptures	5.3%	16.2%
Actual % longline recaptures	0.75%	1.1%

TABLE 5

Estimates of F and M by age in the longline fishery given by Hayashi

Age	F	M
5	0.3	0.2
6	0.6	0.2
7	1.0	0.2
8	1.0	0.6
9	1.0	1.0

TABLE 6

Estimates of number of 2.5 year old recruits and fishing mortality in N.S.W. and S.A. for different natural mortality rates assuming Hayashi longline mortality rates

	M = 0.15	M = 0.20	M = 0.25
Number of 5 year old fish	1.7×10^6	1.7×10^6	1.7×10^6
Number of 2.5 year old fish	3.3×10^6	3.7×10^6	4.1×10^6
Fishing mortality rate in N.S.W. and S.A.	0.114	0.108	0.102
% captured in N.S.W. and S.A.	21%	19%	17%

TABLE 7

Expected and actual recaptures in longline fishery if there is a tag mortality rate M_t and assuming fishing mortality in the longline fishery has the mean value 0.5 $year^{-1}$.

Tag mortality rate	0.6	1.0	1.4
Number of 2.5 year old fish	3.7×10^6	3.7×10^6	3.7×10^6
Calculated number of 5 year old fish	0.38×10^6	0.14×10^6	0.05×10^6
Expected % longline recaptures	4.0%	1.1%	0.3%
Actual % longline recaptures	1.1%	1.1%	1.1%

TABLE 8

Table of relative yields in the N.S.W. and S.A. fishery and the longline fishery for changes in the fishing effort in N.S.W. and S.A. The mean annual N.S.W. and S.A. catch is 9×10^6 kg and the mean longline catch is 50×10^6 kg. The value of F_e is 0.5 $year^{-1}$.

	Present	No NSW or SA fishery	Increase in NSW and SA catch by		
			25%	50%	100%
		M = 0.15			
F_a	0.114	0.0	0.146	0.188	0.272
NSW and SA catch	9.0	0.0	11.3	13.5	18.0
Longline catch	50.0	66.5	46.2	41.6	33.7
Total catch	59.0	66.5	57.5	55.1	51.7
		M = 0.20			
F_a	0.108	0.0	0.139	0.175	0.252
NSW and SA catch	9.0	0.0	11.3	13.5	18.0
Longline catch	50.0	65.4	46.3	42.3	34.9
Total catch	59.0	65.4	57.6	55.8	52.9
		M = 0.25			
F_a	0.102	0.0	0.132	0.164	0.236
NSW and SA catch	9.0	0.0	11.3	13.5	18.0
Longline catch	50.0	64.5	46.4	42.8	35.7
Total catch	59.0	64.5	57.7	56.3	53.7

TABLE 9

Table of relative yields in the NSW and SA fishery and the longline fishery for changes in the fishing effort in NSW and SA. The mean annual NSW and SA catch is 9 x 10^6 kg and the mean longline catch is 50 x 10^6 kg. The value of F_e is o.11 $year^{-1}$ and M = 0.2 in the NSW and SA fisheries.

	Present	No NSW or SA fishery	Increase in NSW and SA fishery by		
			25%	50%	100%
F_a	0.060	0.0	0.075	0.090	0.13
NSW and SA catch (kg x 10^6)	9.0	0.0	11.3	13.5	18.0
Longline catch (kg x 10^6)	50.0	58.0	48.1	46.3	41.9
Total catch	59.0	58.0	59.4	59.8	59.9

TABLE 10

Effect on the N.S.W., S.A. and longline catch for a fishery on 2 year olds in W.A.

	F_e = 0.5		
Numbers of 2 year old fish	4.3	4.3	4.3
W.A. catch (kg x 10^6)	0.0	1.0	5.0
W.A. catch (numbers) x 10^6	0.0	0.27	1.35
NSW and S.A. catch (kg)x 10^6	9.0	8.4	6.1
Longline catch (kg) x 10^6	50.0	46.8	34
Total (kg)	59.0	56.2	45.1
	F_e = 0.11		
Numbers of 2 year old fish	7.2	7.2	7.2
W.A. catch (x10^6kg)	0.0	1.0	5.0
W.A. catch (numbers x 10^6)	0.0	0.27	1.35
NSW and SA catch (x10^6kg)	9.0	8.7	7.3
Longline catch (x10^6kg)	50.0	48.1	40.6
Total catch	59.0	57.8	52.9

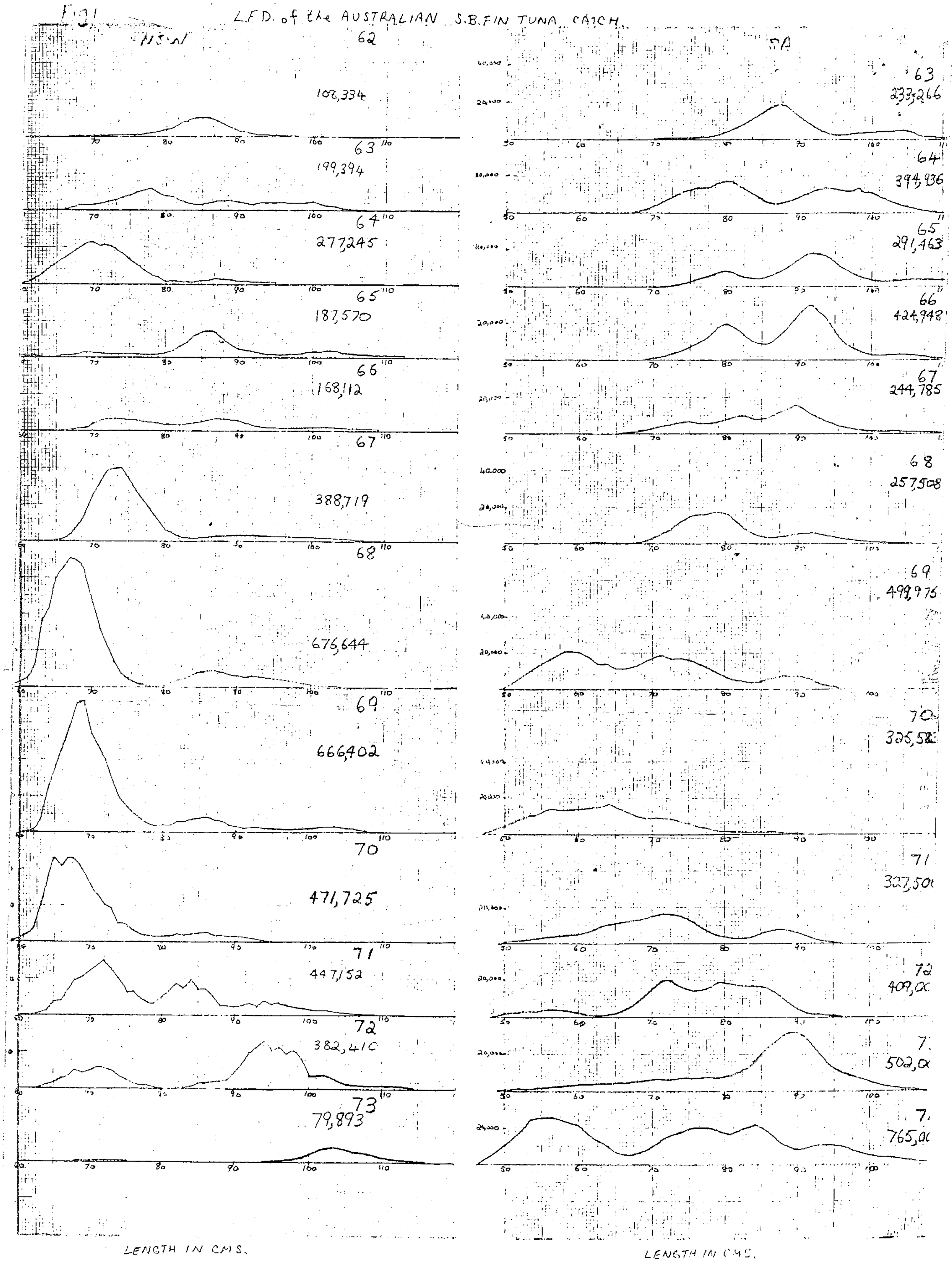

L.F.D. of the AUSTRALIAN S.B.FIN TUNA CATCH
NSW
SA
62
108,334
63
199,394
64
277,245
65
187,570
66
168,112
67
388,719
68
676,644
69
666,402
70
471,725
71
447,152
72
382,410
73
79,893
63
233,266
64
394,936
65
291,463
66
424,948
67
244,785
68
257,508
69
499,976
70
325,58
71
327,50
72
409,00
502,0
765,00
LENGTH IN CMS.
LENGTH IN CMS.

Fig 2. Plot of length versus age for tag data and scale data.

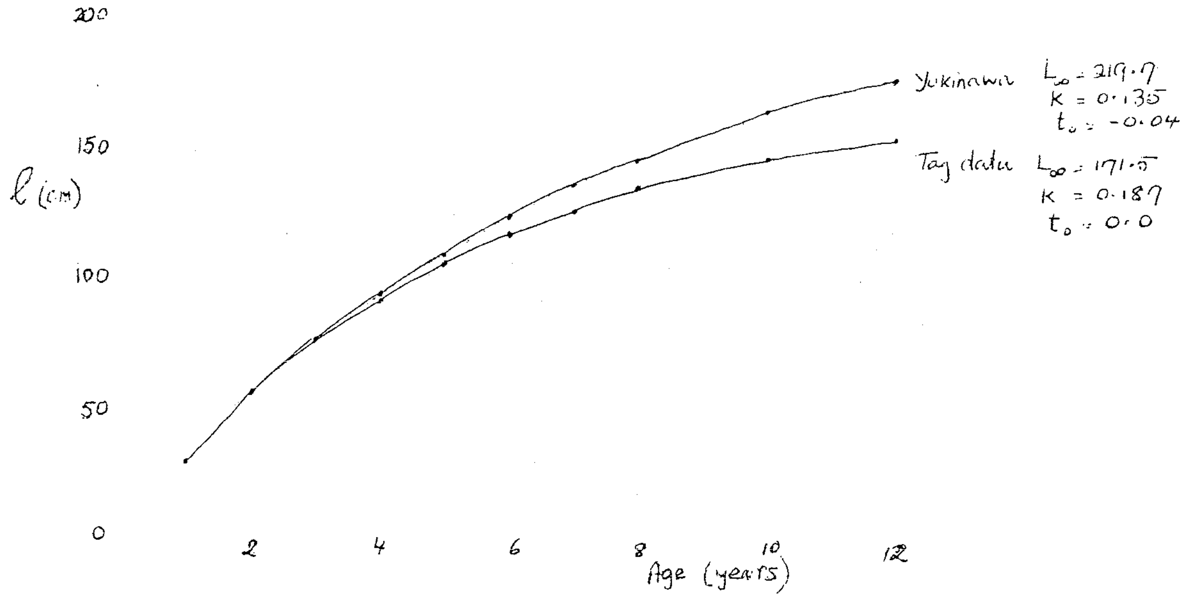
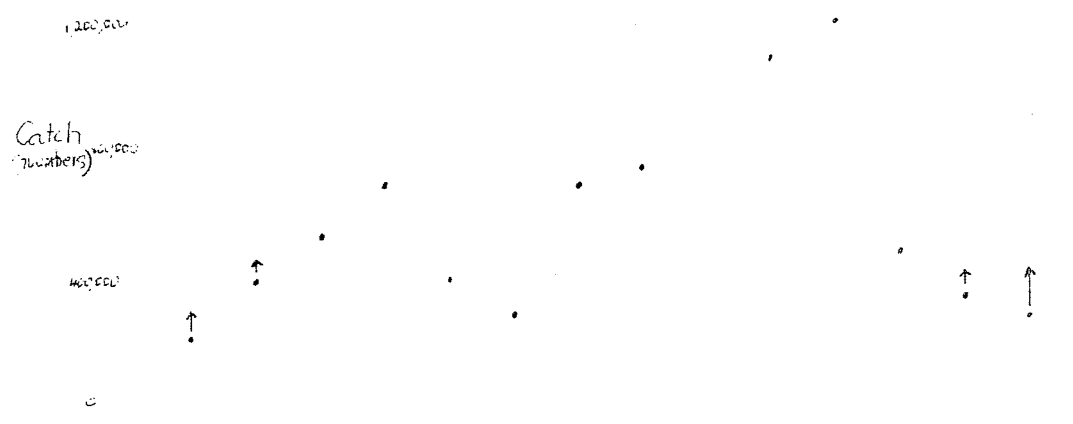
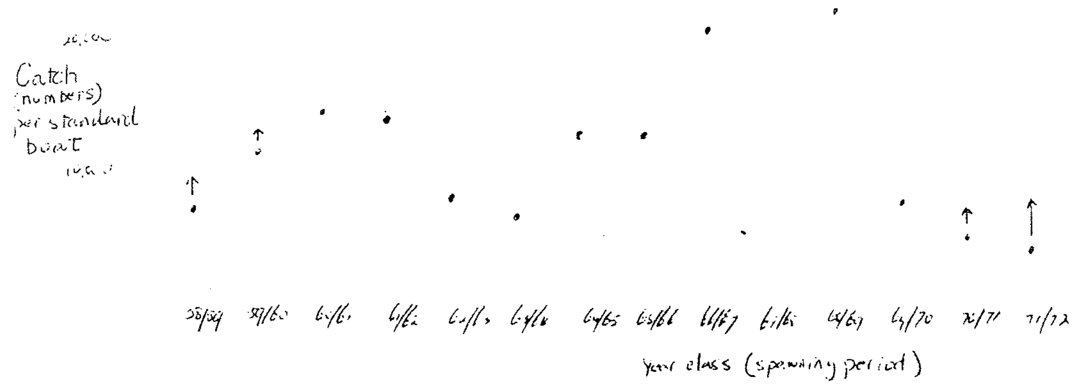


Fig 3 Relative year class strength

(a) assuming fishing constant.



(b) assuming fishing effort proportional to numbers of standard boats.



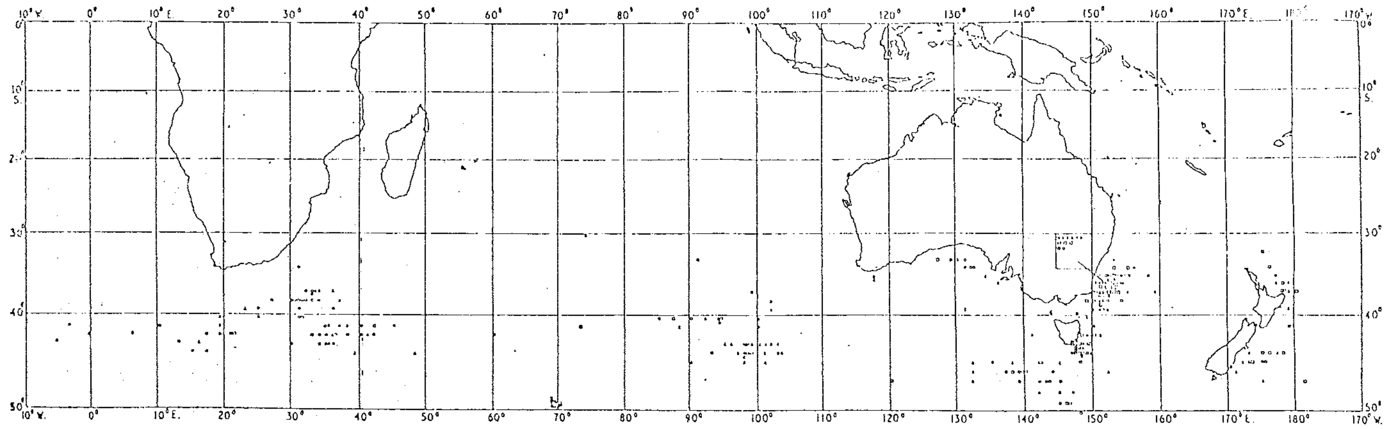


Fig. 4 - Recaptures by Japanese longliners of tagged southern bluefin tuna released in Australian coastal waters.

o Fish released at Albany, W.A.
Δ Fish released in South Australia.
□ Fish released in New South Wales.

Fig 5. Ratio of numbers of recaptures with one tag to recaptures with both tags for each time period.

Time period	N_1	N_2
0-6 mths	419	2507
6-12 mths	272	709
12-18 mths	277	406
18-24 mths	196	130
2-3 yrs	133	74
3-4 yrs	37	19
4-5 yrs	49	27
5-6 yrs	42	7
6-7 yrs	15	3
7-8 yrs	4	2
8-9 yrs	1	2
9-10 yrs	0	1
10-11 yrs	1	0