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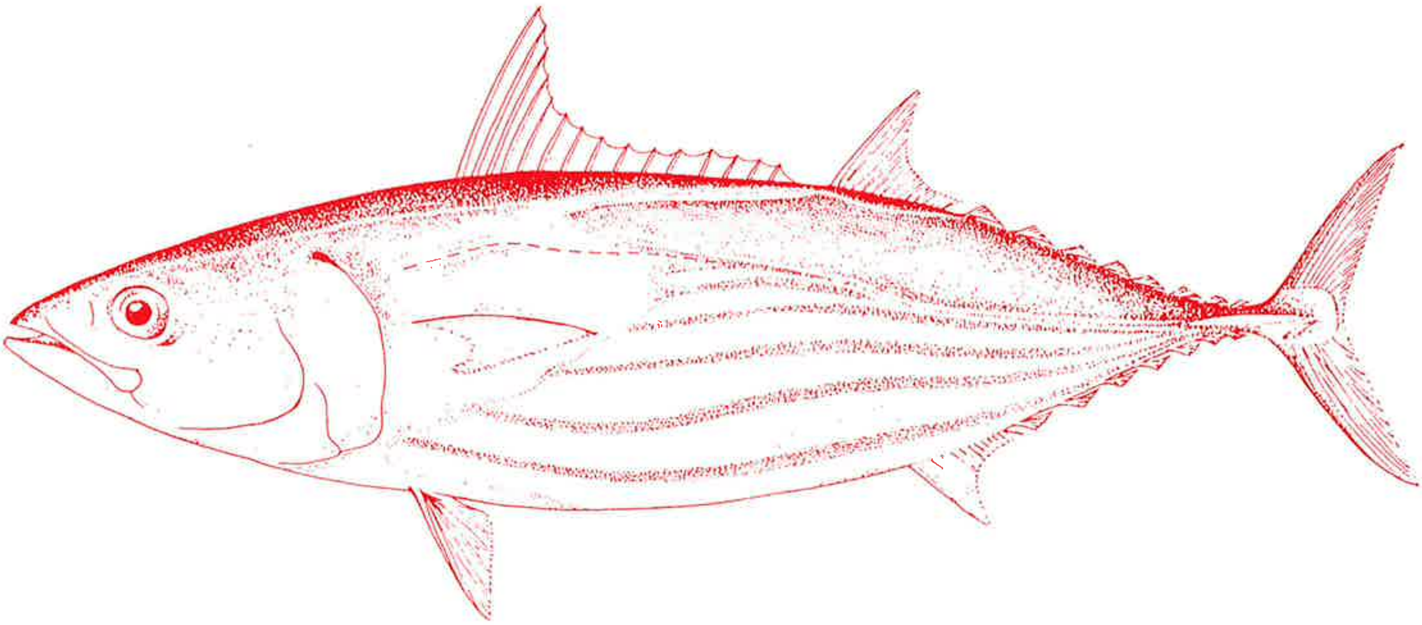

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Contents

Abstract

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The purseseine fishery in New Zealand for skipjack tuna, *Katsuwonus pelamis*, began in 1974-75. Catch, effort, and location details for the fishing seasons from 1975-76 until 1985-86 are presented. The fishery peaked at 19 vessels in 1980-81. Annual catches between 1977-78 and 1980-81 were between 8000 and 10 000 t. From 1983-84 only four vessels fished, all below 38 m overall length, and catches dropped to between 2000 and 4000 t per year. Catch per day fishing or searching stayed at just under 30 t per day.

Tagging and aerial sightings studies on the fishery are reviewed and it is concluded there has been a regular reduction in surface-schooling fish available to the fishery. If this is caused by some cyclic phenomenon, then the decline appears near to its lowest point and improvement may be expected. However, if the decline is not caused by natural cyclic phenomena, then the trend in the decline is approaching an asymptote, and the amount of surface-schooling skipjack available to the purseseine fishery around New Zealand may stabilise at about 10 000 t per season. A catch at that level is likely to result in increased vessel competition and lower catch per unit of effort (CPUE) and involve fishing on the west coast.

An investigation of the relationships between sea-surface temperature patterns and the fishery is reported. Differences between coasts in correlations of sea-surface temperature patterns with catch, CPUE, and abundance are due to vessel preference for fishing the east coast.

Introduction

The New Zealand purseseine fishery for skipjack tuna, *Katsuwonus pelamis*, began in the 1974-75 season with catches by the purseseine vessel *Paramount* (Eggleston 1976). The fishery is seasonal and can run from late October until the following June. The fleet peaked in the 1980-81 season at 19 vessels, 13 of which were seiners over 52 m overall length, and 12 of which were not New Zealand owned. The number of vessels in the fishery then declined, and by the 1983-84 season there were only four, all less than 38 m overall length, and all were New Zealand owned.

The decline of foreign vessel participation in the New Zealand fishery coincided with a decline in the price paid for skipjack on the U.S. market, and the development of a purseseine fishery for skipjack and yellowfin tunas north of Papua New Guinea and the Solomon Islands.

The fishing logbooks completed by masters of fishing vessels or by Ministry of Agriculture and Fisheries observers stationed on vessels are the basic source of information on the New Zealand fishery. Since the 1982-83 season, books are completed by masters as a condition of fishing licences, and observers are no longer regularly placed on vessels. The logbooks consist of a daily activity record, a record for each set made, and a landed-catch record, which is used to reconcile landed catch with the catch weights estimated at sea. The statistical areas used are shown in Figures 1 and 2.

During the purseseine observer programme, which ceased at the end of the 1982-83 season, observations were made on fish as they were caught. The main observations were length, sex, gonad state, blood samples, stomach contents, and parasites. Blood samples were analysed electrophoretically, and results were reported by Argue (1981), Argue and Kearney (1983), Richardson (1983), and Richardson and Habib (1987). Feeding studies were reported by Bailey and Habib (1982) and Bailey (1983), and gill and gut parasites by Lester (1981) and Lester *et al.* (1985). The year-by-year status of the fishery for the seasons 1975–76 to 1981–82 was analysed by Vooren (1976), Habib (1976), Clement (1976), Habib (1978), Habib *et al.* (1980a, 1980b, 1980c, 1981, [1982]). Hydrology and plankton of fishing grounds were described by Habib *et al.* (1982). An exhaustive bibliography of tuna fisheries and research in New Zealand has been compiled by Bailey (1988).

In the New Zealand purseseine skipjack fishery, shore-based fixed-wing aircraft search coastal waters for fishable surface aggregations of skipjack and guide vessels to them. Bell (1976) described the aerial sightings procedure, and summaries compiled from pilots' logbooks were published by Habib (1978), Habib *et al.* (1980a, 1980b, 1980c, [1982]), Wood and Fisher (1983, 1984), and Swanson and Wood (1986a, 1986b). These summaries detail areas and times of fish sightings and statistical descriptions of pilots' estimates of fish abundance.

The South Pacific Commission (SPC) Skipjack Survey and Assessment Programme tagged skipjack in New Zealand waters in February and March 1979 and March 1980. The results of this tagging were reported by Argue and Kearney (1983). Skipjack tagging from RV *Kaio Maru No. 52* in 1981 and 1982 was reported by Ichikawa (1981) and Iwasa *et al.* (1982).

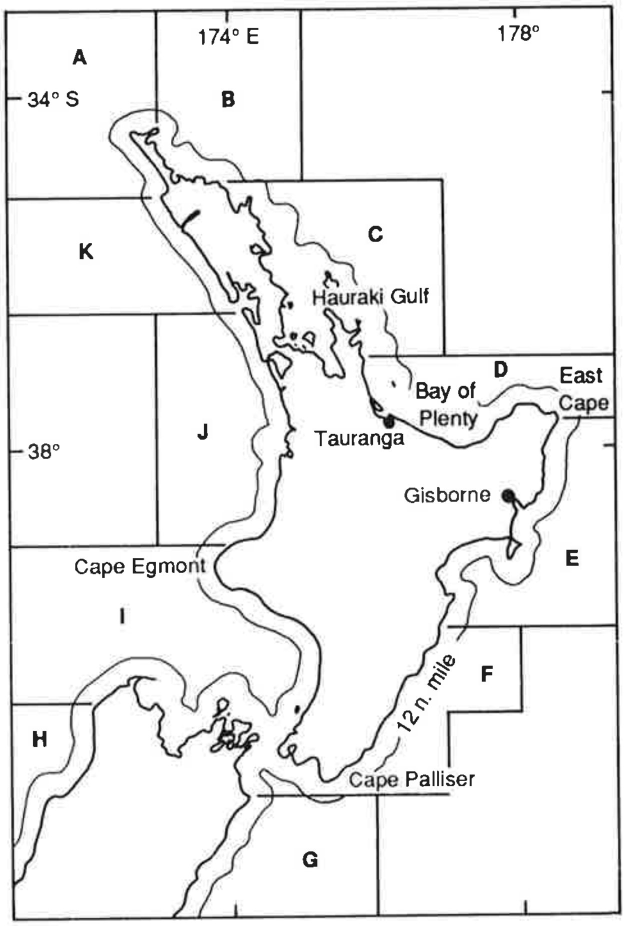


Figure 1: The statistical areas used from the 1975–76 season until the end of the 1981–82 season.

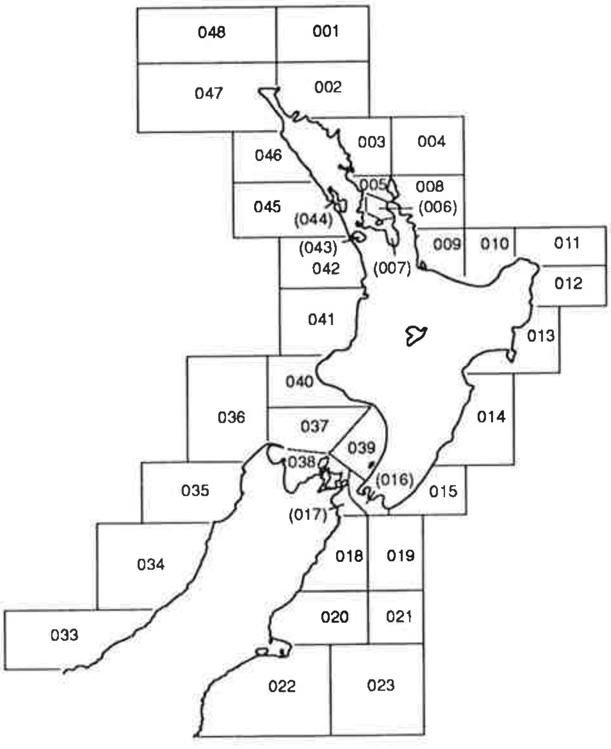


Figure 2: The statistical areas used from the 1982–83 season.

The fishery

Location

Most of the purseseining for skipjack around New Zealand is within 20 km of land, usually near the edge of the continental shelf and inside the 200 m depth contour. Habib *et al.* (1980a, 1980b, 1980c, 1981, [1982]) reported that most of the fishing occurs where the surface water temperature is 19–22 °C and the salinity is 35.0–35.5. Fishing has occurred off the east and west coasts of the North Island and off the west coast of the South Island down to 42° S. However, most skipjack purseseining has been off the east coast of the North Island north of East Cape (37° 40′ S). There is a significant fishery off the west coast, generally north of Cape Egmont (39° 20′ S). This is usually late in the season (February or later) and its importance varies widely from year to year. The positions of all sets for the seasons 1975–76 to 1985–86 are shown in Figure 3.

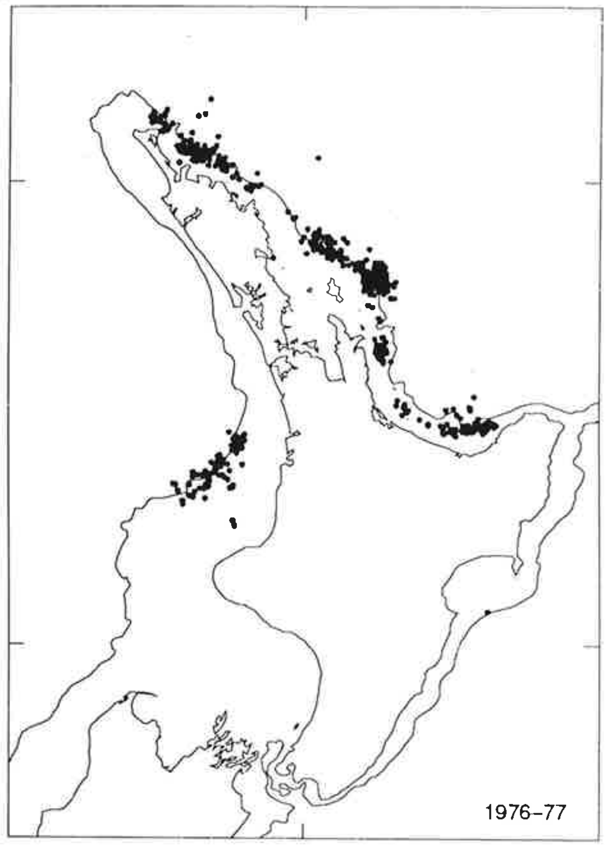
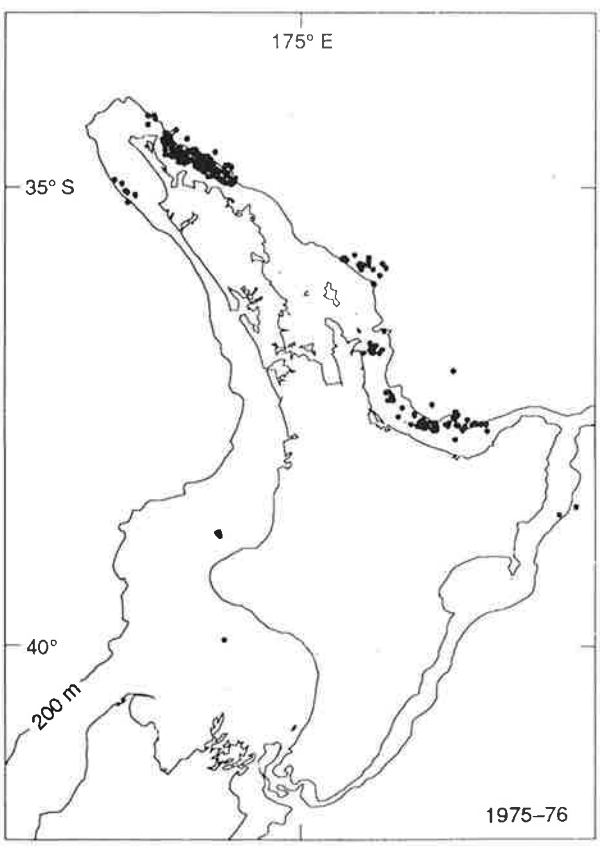
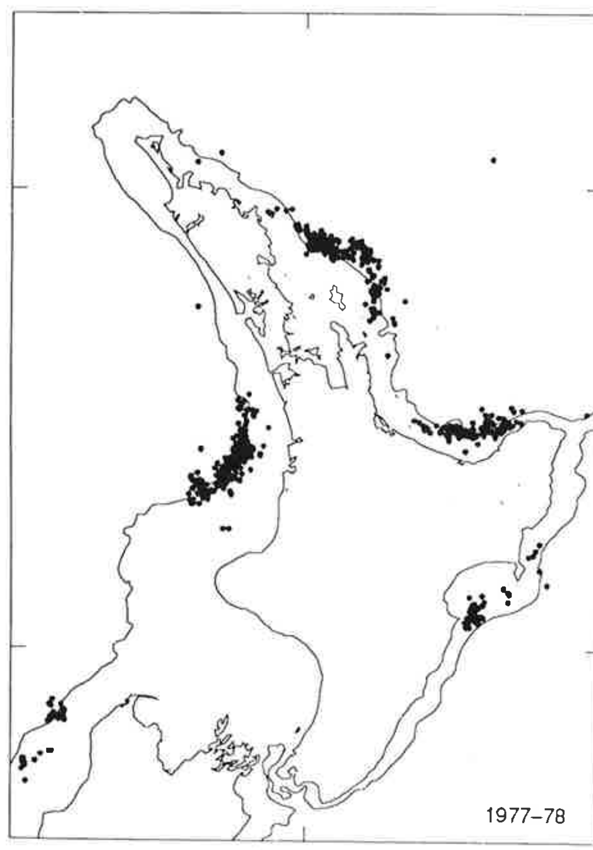


Figure 3: Locations of purseseine sets from 1975–76 to 1985–86.





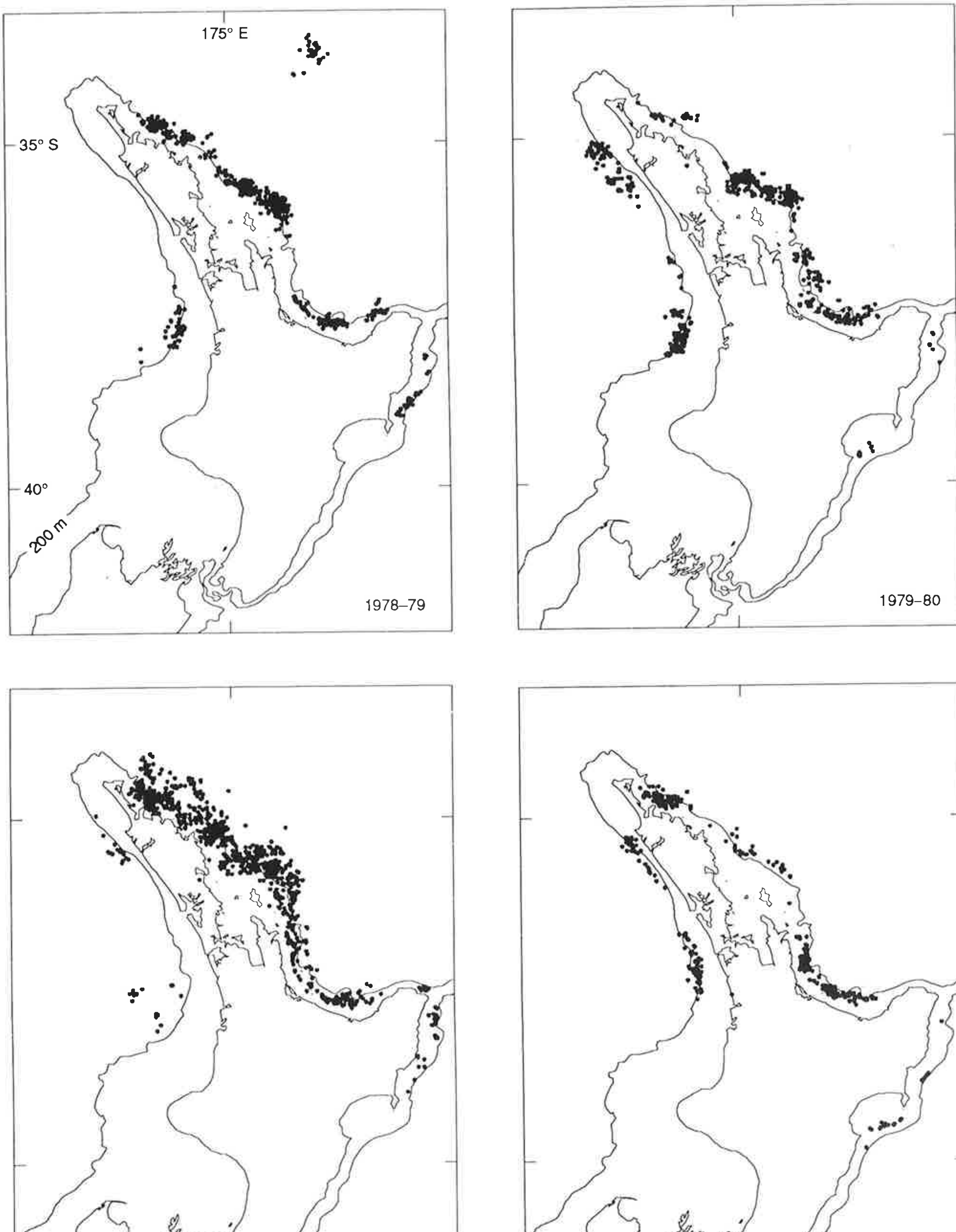


Figure 3—*continued.*

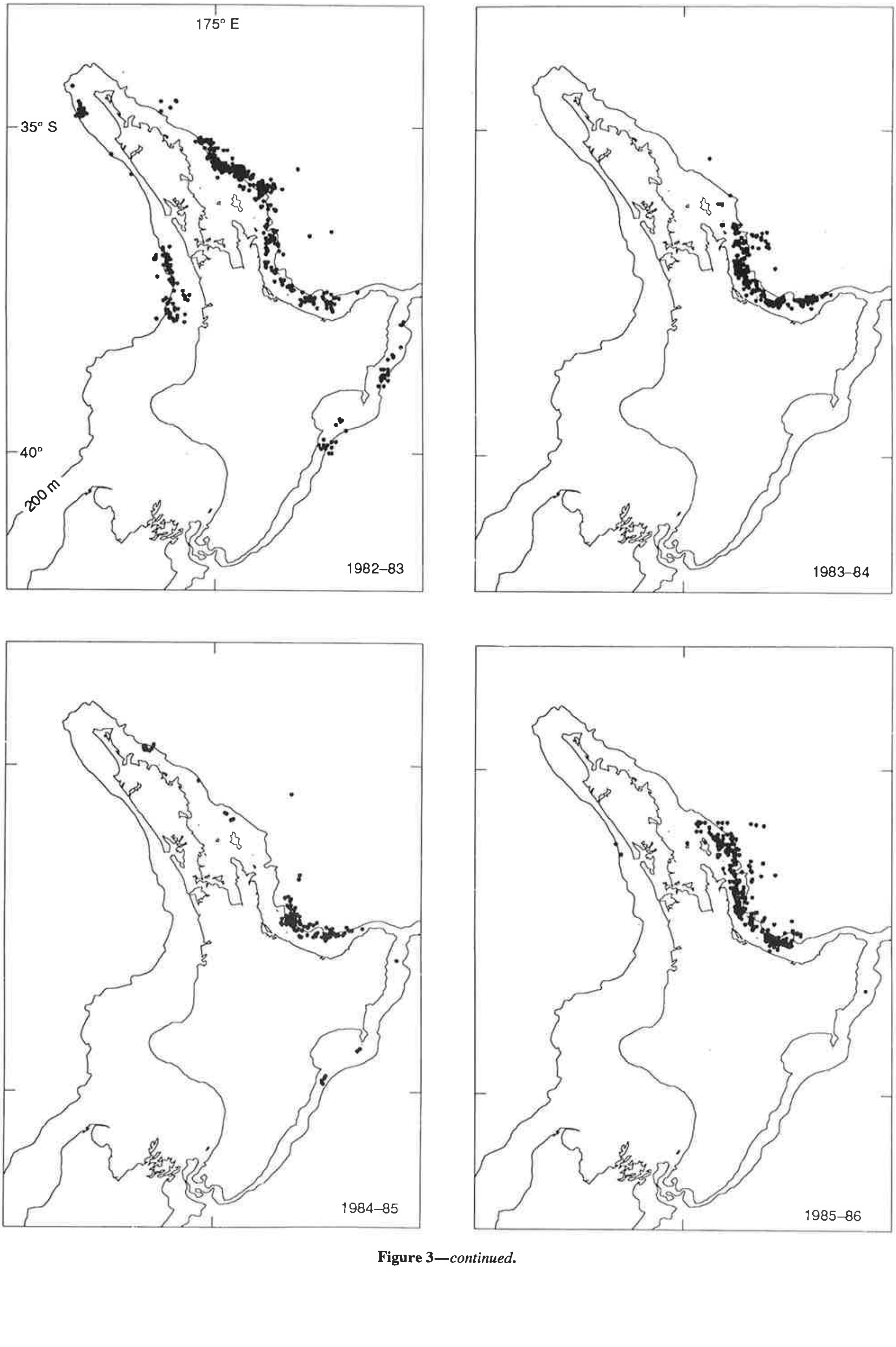


Figure 3—*continued.*

Vessels and restrictions on their activities

Details of vessels in the fishery between the 1975–76 and 1985–86 seasons are given in Table 1. Vessels over 52 m overall length and 837 t gross weight, except for *Finisterre*, were owned by and mainly crewed from the U.S., but licensed as joint ventures. In a joint venture the licence to fish was held by a New Zealand company which procured a foreign-owned fishing operation to carry out the fishing. Throughout the history of the fishery, joint venture vessels have had restrictions on where they may set. Before the 1978–79 season, joint venture vessels were not permitted to fish in the Bay of Plenty (statistical area D, *see* Figure 1) or within the 12 n. mile territorial sea unless a Ministry of Agriculture and Fisheries officer decided there was no likelihood of competition with domestic vessels. From the 1978–79 season joint venture vessels were excluded from setting within the 12 n. mile territorial sea.

All vessels below 38 m overall length and 544 t gross weight, and the larger seiner *Finisterre*, were owned by New Zealand registered companies. Although they were not subject to the legal restrictions which applied to the joint venture vessels, small seiners seldom set on the west coast. There were no vessels between 38 and 52 m.

Janet D, *Marine Countess*, and *(Irene M) Waihola* were Norwegian style seiners and set nets by using Dahn buoys. All other vessels used a motorised skiff for setting.

Measures of effort

Three basic measures of effort are derived from the vessel logbooks: number of days spent searching or fishing, the number of sets made, and the number of days a vessel participates in the New Zealand purseseine skipjack fishery each season. The last measure includes time when there is no activity because of adverse weather, unloading of fish or loading of stores, repairs, time off for crew, and travelling while repositioning the vessel in the New Zealand Exclusive Economic Zone, as well as time searching or fishing.

Catch and effort

Catch and effort statistics for the whole fishery for the seasons 1975–76 until 1985–86 are summarised in Figures 4–7 and Table 2. Where data have been separated into east coast and west coast, the former refers to statistical areas B–G for 1975–76 to 1981–82 (*see* Figure 1) and statistical areas 1–23 from 1982–83 (*see* Figure 2), and the latter refers to statistical areas A and H–K for 1975–76 to 1981–82 and statistical areas 33–48 from 1982–83.

The fishery on the west coast is mainly north of Cape Egmont, although purseseinable aggregations of skipjack are regularly seen as far south as Bruce Bay in Westland (43° 30′ S). Vessels less 38 m have seldom

Table 1: Vessels in the purseseine fishery for skipjack tuna in New Zealand waters for 1975–76 to 1985–86

		Overall length	Gross tonnage	Capacity carrying	Days in the fishery*										
Vessel	Ownership	(m)	(t)	(t)	1975–76	1976–77	1977–78	1978–79	1979–80	1980–81	1981–82	1982–83	1983–84	1984–85	1985–86
South Pacific	U.S.	68	1 089	1 100	85	0	0	0	0	0	0	0	0	0	0
Kerri M	U.S.	54	830	740	121	120	111	0	0	0	0	0	0	0	0
Michelangelo	U.S.	62	1 066	1 270	105	50	41	0	0	0	0	0	0	0	0
Zapata Discoverer	U.S.	69	1 499	1 650	0	111	107	94	0	0	0	0	0	0	0
(Apollo) Adriatic Sea	U.S.	79	1 588	2 000	0	137	116	85	83	69	0	0	0	0	0
Voyager	U.S.	73	1 472	1 600	0	66	48	64	69	77	29	0	0	0	0
Finisterre	N.Z.	62	1 063	1 150	0	79	117	90	82	152	112	0	0	0	0
Jeanette C	U.S.	54	1 091	–†	0	0	0	78	67	0	0	0	0	0	0
Frontier	U.S.	67	1 172	1 500	0	0	0	91	7	104	0	0	0	0	0
Island Princess	U.S.	69	1 274	1 350	0	0	0	90	8	113	117	74	0	0	0
Royal Pacific	U.S.	66	1 080	1 150	0	0	0	0	84	0	0	0	0	0	0
Tifaimona	U.S.	72	1 435	1 470	0	0	0	0	58	100	0	0	0	0	0
Captain M.J. Souza	U.S.	67	1 172	1 150	0	0	0	0	85	121	53	0	0	0	0
Montana	U.S.	68	1 070	1 150	0	0	0	0	0	90	0	0	0	0	0
Captain Frank Medina	U.S.	68	1 093	1 150	0	0	0	0	0	78	0	0	0	0	0
Pacific Princess	U.S.	67	991	980	0	0	0	0	0	108	0	0	0	0	0
White Star	U.S.	53	837	862	0	0	0	0	0	90	0	0	0	0	0
Western Pacific (U.S.)	U.S.	60	894	1 050	0	0	0	0	0	74	36	26	0	0	0
Cindy Ann	U.S.	68	1 049	1 010	0	0	0	0	0	94	56	51	0	0	0
Lone Wolf	U.S.	68	1 042	1 100	0	0	0	0	0	0	0	53	0	0	0
Toro Bravo	U.S.	77	1 518	1 800	0	0	0	0	0	0	0	7	0	0	0
Carol Linda	U.S.	68	1 049	1 100	0	0	0	0	0	0	0	18	0	0	0
Marine Countess	N.Z.	27	135	130	70	4	79	21	63	120	0	0	0	0	0
Lindberg	N.Z.	23	159	90	80	67	68	31	108	185	118	137	125	88	183
(Irene M) Waihola	N.Z.	35	498	330	0	69	0	38	82	0	0	0	0	0	0
San Benito	N.Z.	33	248	120	0	37	73	45	116	166	0	0	0	0	0
Janet D	N.Z.	35	498	330	0	57	47	34	87	130	113	119	0	0	0
Western Pacific (N.Z.)	N.Z.	36	544	350	0	0	0	0	32	152	87	126	87	0	145
Western Ranger	N.Z.	36	544	350	0	0	0	0	0	61	96	132	124	59	0
San Columbia	N.Z.	33	260	195	0	0	0	0	0	0	101	144	160	112	174

*The time that a vessel spent in activity related to the skipjack fishery; it includes days fishing, searching, travelling, in port, and sheltering from bad weather.

†Not available.

participated in the west coast fishery, and their total catch from 1975-76 to 1985-86 was 290 t from 36 sets (2.3% of the catch from 4.4% of the sets made in this area). The main west coast areas are 20 km or more from land on a coast that provides little shelter from poor weather, and this may have discouraged smaller vessel

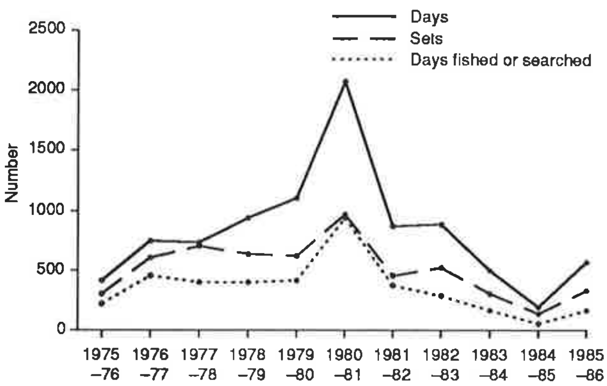


Figure 4: Effort in the fishery from 1975-76 to 1985-86.

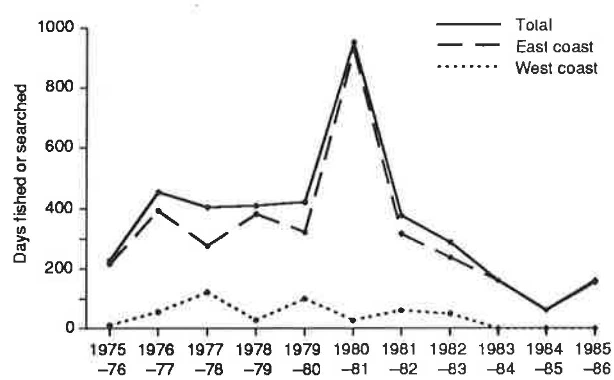


Figure 6: Days fished or searched on each coast from 1975-76 to 1985-86.

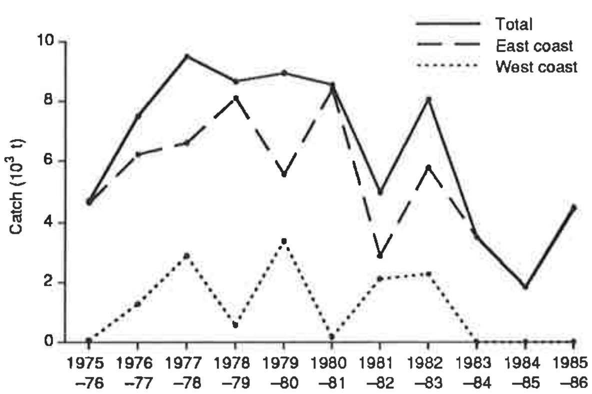


Figure 5: Catch in the fishery from 1975-76 to 1985-86.

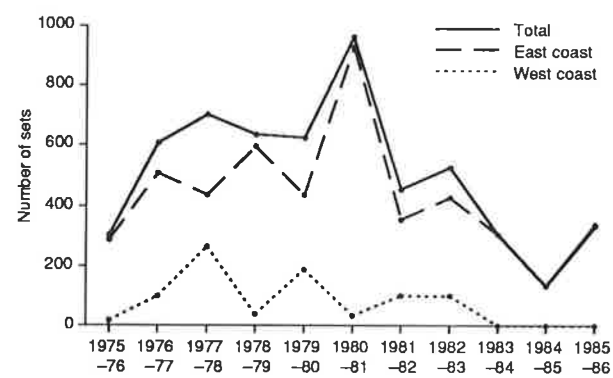


Figure 7: Sets made from 1975-76 to 1985-86.

Table 2: Catch and effort on each coast from 1975-76 to 1985-86

Season	Vessel size*	No. of vessels		Catch (t)		No. of sets		No. of successful sets†		Days fishing or searching	
		East	West	East	West	East	West	East	West	East	West
1975-76	S	2	0	215	0	52	0	27	0	60	0
	L	3	3	4 420	58	236	14	145	8	153	12
1976-77	S	5	0	435	0	116	0	52	0	104	0
	L	6	5	5 828	1 251	394	98	225	37	289	58
1977-78	S	4	1	1 099	0	174	0	65	0	136	2
	L	6	5	5 548	2 862	262	265	125	103	142	122
1978-79	S	5	1	1 345	0	260	0	85	0	167	0
	L	7	6	6 774	557	336	40	156	18	214	28
1979-80	S	6	4	1 382	0	233	2	101	0	167	4
	L	9	9	4 205	3 345	205	185	97	97	152	97
1980-81	S	6	0	2 561	0	369	0	192	0	345	0
	L	13	6	5 855	139	560	31	370	12	576	27
1981-82	S	5	3	2 302	255	316	30	179	13	238	19
	L	6	3	571	1 870	38	70	17	47	77	42
1982-83	S	5	2	3 895	10	331	2	196	1	188	2
	L	5	4	1 923	2 264	95	95	54	45	53	47
1983-84	S	4	0	3 502	0	303	0	173	0	159	0
	L	0	0	0	0	0	0	0	0	0	0
1984-85	S	4	0	1 830	0	134	0	66	0	62	0
	L	0	0	0	0	0	0	0	0	0	0
1985-86	S	3	1	4 442	25	333	2	206	1	157	2
	L	0	0	0	0	0	0	0	0	0	0

*S, a small vessel is less than 38 m overall length (less than 544 t gross and 350 t carrying capacity); L, a large vessel is greater than 52 m overall length (greater than 837 t gross and 740 t carrying capacity).

†Skipjack was targeted and at least 1 t was caught.

participation. However, the smaller New Zealand owned vessels were not restricted to setting outside the 12 n. mile territorial sea; therefore, they may have been able to continue fishing profitably without needing to fish the west coast.

Catch per unit of effort (CPUE) for the east and west coasts for 1975-76 to 1985-86 is shown in Figures 8 and 9, and catch by vessel length is shown in Figure 10.

From 1975-76 to 1982-83, vessels below 38 m increased their total catch and their proportion of the catch. This was mainly due to increasing effort, because catch per day fishing or searching and catch per successful set were almost constant between 1977-78 and 1981-82. There was a marked rise in their catch per day and catch per successful set from 1982-83. This may have been due to the decline in competition from vessels over 52 m and to the equipping of the fleet with fast winches. The increase in average catch per successful set by small vessels since 1982-83 suggested that these vessels were setting on larger schools. This may have been because of a greater choice of schools on which to set (a consequence of decreased competition) or because of increasing skills of the local fishers. Most of the sets by vessels less than 38 m were within the 12 n. mile territorial sea. The mean size of catch per successful set was similar for small vessels inside and outside the 12 n. mile territorial sea (Table 3), except for 1979-80, when catch per successful set outside the 12 n. mile limit was twice that inside the limit. This may reflect a spatial distribution in school size. However, in most years it appears that vessel characteristics and methods of fishing govern the differences in mean catch per successful set between vessels less than 38 m and those greater than 52 m, rather than whether vessels fish inshore or offshore. Net circumference is less on small vessels, and this may limit the setting success on large schools, because large schools are more likely to find the gap or to be disturbed and sound while the net is set. The maximum size of school on which a vessel can safely set depends on vessel size. This is not likely to be the main cause of the difference in mean catch per successful set, because the smallest vessel in the fleet has caught schools of 130 t.

The 1980-81 season was unusual because of the calm weather. Fishable schools of skipjack were scattered widely, and the total catch exceeded 8000 t. Although this quantity was similar to those of the previous four seasons, vessels over 52 m spent twice as long searching and made twice as many sets to catch this amount. However, for vessels under 38 m, though the calm weather allowed them to fish more days in the season, catch per day fishing or searching and catch per successful set were similar to those of adjacent years.

The 1980-81 season was the only one in which the average catch per successful set was similar for both vessel classes. This suggests that for this season the mean skipjack school size was about 15 t, and that this determined the mean catch per successful set rather than the fishing characteristics of the fleet.

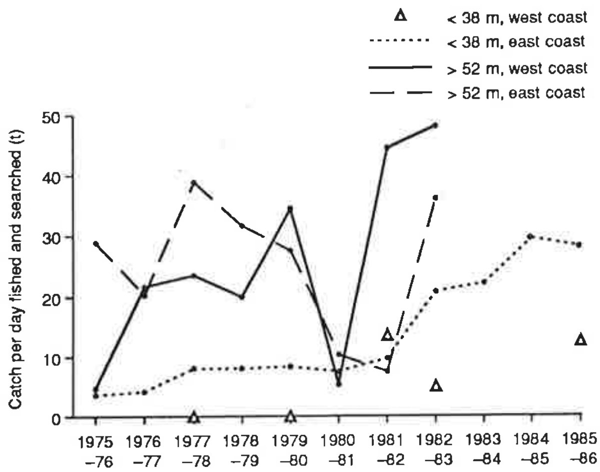


Figure 8: Catch per day fished or searched by vessel length and area for 1975-76 to 1985-86.

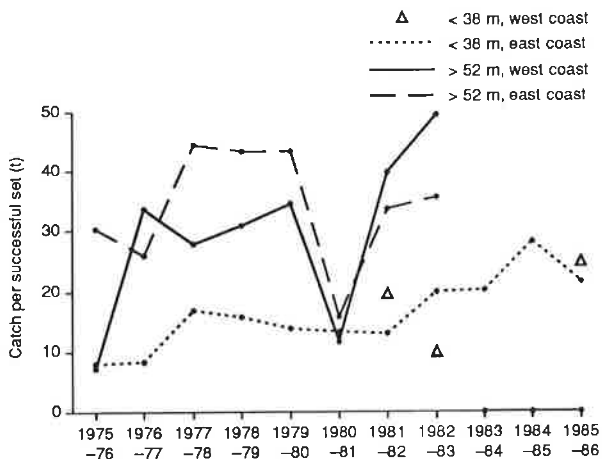


Figure 9: Catch per successful set by vessel length and area for 1975-76 to 1985-86. (A successful set is defined as a set targeted at skipjack and in which at least 1 t of skipjack was caught.)

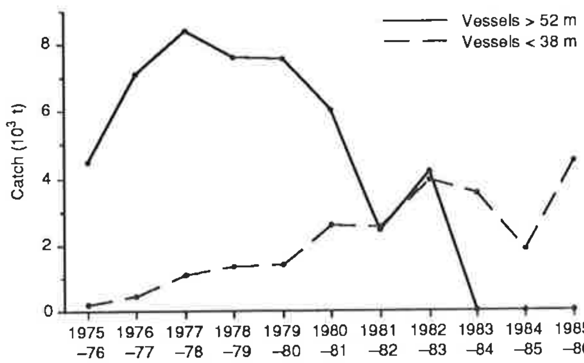


Figure 10: Catch by vessel length for 1975-76 to 1985-86.

Table 3: Mean catch per successful set (t) inside and outside the 12 n. mile Territorial Sea by vessels less than 38 m overall length for 1977-78 to 1981-82

	Inside		Outside	
Season	No. of successful sets	Catch per successful set	No. of successful sets	Catch per successful set
1977-78	47	17.06	18	16.48
1978-79	46	17.06	39	14.38
1979-80	72	10.86	29	20.68
1980-81	162	13.60	30	11.91
1981-82	167	12.97	12	11.33

Fish dynamics

Aerial sightings of surface-schooling skipjack

In calm seas surface aggregations of skipjack are visible from aircraft. In New Zealand, light fixed-wing aircraft are used commercially to locate fishable aggregations of skipjack and estimate tonnages of schools. When there is poor visibility from vessels, such as at twilight or when there are sea swells, observers from aircraft may guide vessel skippers during net setting.

The Ministry of Agriculture and Fisheries commissioned a few survey flights between 1975-76 and 1981-82 in areas that were not being exploited by the purseseine fleet or surveyed by commercial flights.

Aerial survey data were reported by Habib (1978), Habib *et al.* (1980a, 1980b, 1980c, 1981, [1982]), Wood and Fisher (1983, 1984), and Swanson and Wood (1986a, 1986b).

Quantitative analysis of aerial survey data presents some difficulties, mainly quantifying effort and skill, eliminating duplicate sightings, and the incomplete coverage of potential fishing areas. Pilot skill includes the location and identification of surface-schooling fish and the estimation of school size. School appearance changes substantially in different sea and light conditions. Species identification and school size estimation can be checked where vessels subsequently catch a specified school. Pilots use such occasions to refine their estimation techniques. Pilots in the purseseine skipjack fishery identify species accurately, and their school size estimates are seldom more than 20% in error. Furthermore, for each season, the mean of pilot estimated school sizes accords closely with the mean catch per successful set (Figure 11). Fish location skills are not as easily checked, and my observation is that when the water surface is disturbed by wind or at twilight, fishable surface-schooling skipjack can be difficult to locate even for experienced pilots. Perseverance in such conditions is governed by the pressure on a pilot to locate fish for an idle vessel. Measurement of effort is crude because the division of flight time into travel time to likely areas, searching time, enumeration time after surface schools of fish are located, and vessel setting guidance time is not possible from the records kept.

The total flying hours of aerial spotting flights for the east coast north of Cape Palliser and the west coast north of Cape Egmont are shown for November to May inclusive for each season from 1976-77 to 1985-86 (Figure 12). This includes some flights for which the primary spotting target was not skipjack.

Aerial sightings effort, measured as total flying hours, is plotted against catch (Figure 13); fishing effort, measured as days fished or searched (Figure 14); and the CPUE measure catch per day fished or searched (Figure 15). Spearman rank correlation coefficients and the associated statistical significance are given. However, unless selected seasons are considered to be outliers, there is no systematic relationship in these plots. The only statistically significant correlation is between flying time and days fished or searched on the west coast. This is probably because of the extra flying that occurs when boats request assistance in setting. In two seasons boats did not attempt to fish this coast.

The failure of aerial surveys to locate skipjack does not mean there were no surface schools of skipjack in that area. Light, sea conditions, and flight path all influence ease of fish location. For the years covered by this review there was sufficient commercial interest from the fishing industry to ensure that all significant surface skipjack concentrations were located and estimated in the Bay of Plenty (area D) and off the Hauraki Gulf (area C). Furthermore, the times of first and last sightings of surface schools in a season were probably accurately recorded, even if there were no concurrent purseseining, because these areas are on commuter routes flown by the airlines that employ the pilots used in fish spotting.

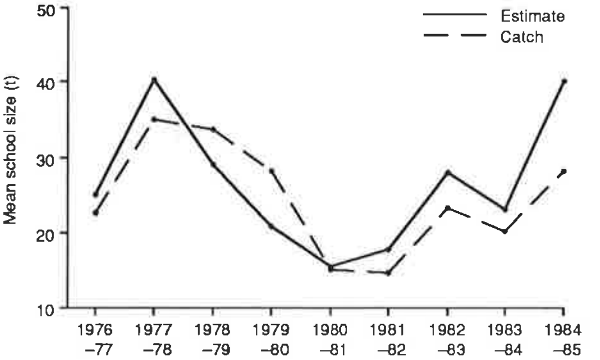


Figure 11: Mean of pilot estimated school sizes for all flights in a season and the mean catch per successful set for east coast sets from 1976-77 to 1984-85. (Spearman's ρ for these two series is 0.733 (n = 9), which is significant at 5%.)

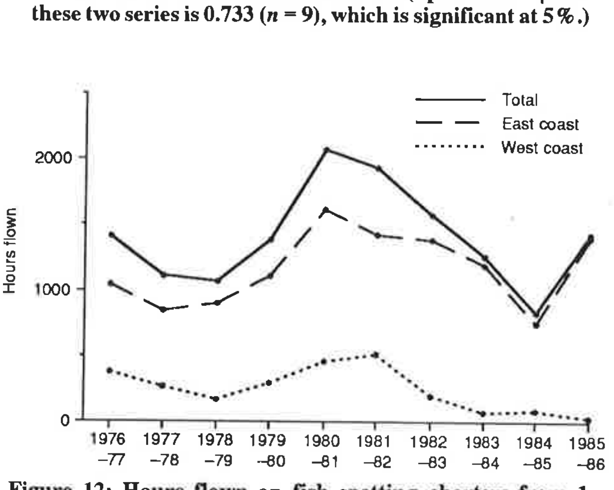


Figure 12: Hours flown on fish spotting charters from 1 December to 31 May each season from 1976-77 to 1985-86 on the east coast north of Cape Palliser and the west coast north of Cape Egmont.

There is no continuous commercial fishing on the west coast north of Cape Egmont. This means that estimates of surface concentrations and the times of first and last sightings are much less reliable, particularly after the departure of the larger vessels at the end of the 1982–83 season.

The season-to-season variation in the time surface-schooling skipjack were in New Zealand waters is shown in Figure 16, which plots times of first and last aerial sightings for the Bay of Plenty, Hauraki Gulf, and the west coast north of Cape Egmont from 1976-77 to 1984-85.

Minimum abundance estimates

In New Zealand waters purseseinable quantities of skipjack often occur as surface clusters of schools which persist in an area for up to 20 days. These clusters at any time typically occupied an area of less than 10 km in radius and were widely separated during the seasons of this review. The presence of such clusters led Habib *et al.* (1980a) to postulate the existence of "bodies" of fish. They suggested that a cluster of schools visible at the surface represented a portion or all of a body of fish which stayed together for the time fish of that body were

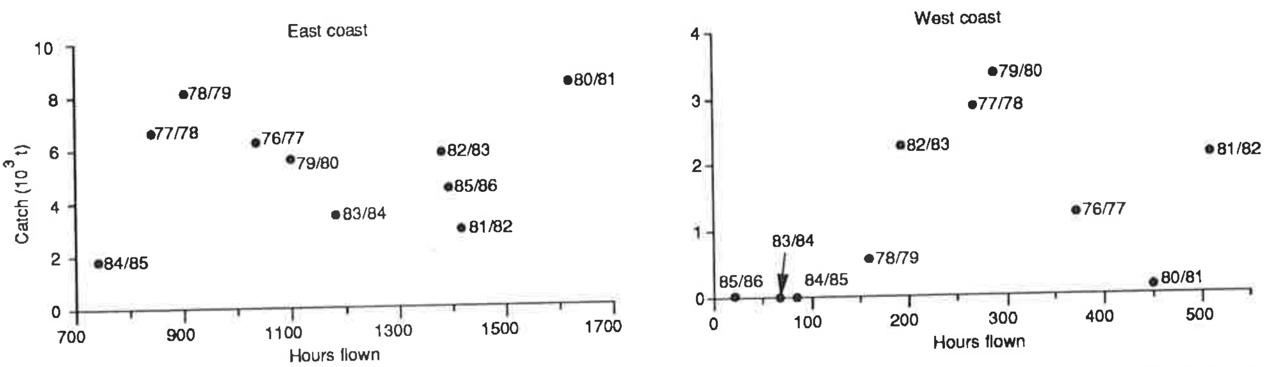


Figure 13: Hours flown on each coast plotted against catch. (East coast, Spearman's ρ is 0.055 (n = 10), which is not significant; west coast, Spearman's ρ is 0.559 (n = 10), which is not significant.)

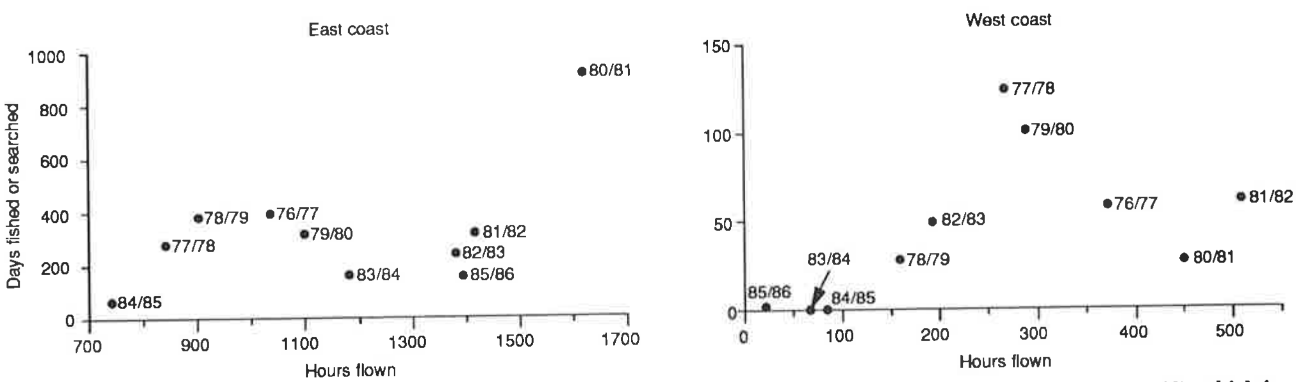


Figure 14: Hours flown on each coast plotted against days fished or searched. (East coast, Spearman's ρ is 0.236 (n = 10), which is not significant; west coast, Spearman's ρ is 0.644 (n = 10), which is significant at 5%.)

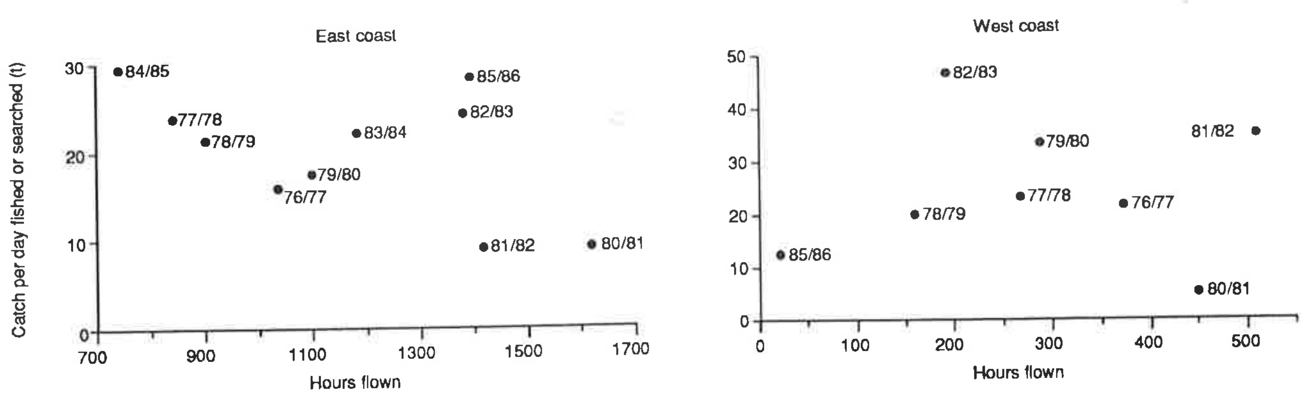


Figure 15: Hours flown on each coast plotted against catch per day fished or searched. (East coast, Spearman's ρ is 0.467 (n = 10), which is not significant; west coast, Spearman's ρ is 0.167 (n = 8), which is not significant.)

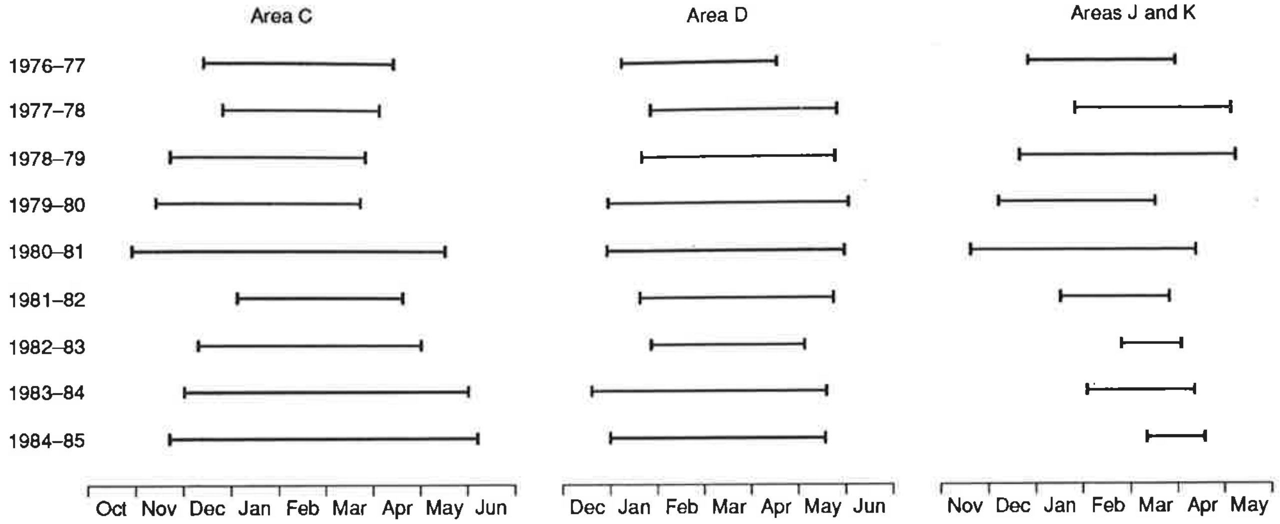


Figure 16: Time between the first and last aerial sighting in a season of schooling skipjack in areas C, D, and J plus K for 1976–77 to 1984–85.

in New Zealand waters. If fish do remain associated in bodies, and if unique bodies are identifiable, then a lower bound estimate of the tonnage of fish in a body is the maximum value for all aerial sightings of the tonnage estimated for each aerial sighting plus the total catch taken from the body before that sighting. Thus, if W is the lower bound of the weight of skipjack in a body, then

$$W = \sup_{\forall k} \left[\sum_{i=1}^{k-1} C_i + S_k \right] \qquad (1)$$

where k = 1, 2, 3, ... number of days a body exists, C_i is the tonnage caught on day i, and S_k is the tonnage sighted on day k.

For the 1977-78, 1978-79, 1979-80, and 1981-82 seasons Habib *et al.* (1980a, 1980b, 1980c, [1982]) listed all aggregations of surface-schooling skipjack they considered to be bodies. By comparing pilot and vessel logbooks they were able to eliminate within-day multiple sightings of schools reported by aerial survey. I was able to duplicate their calculations for the 1981-82 season without difficulty; there was clear physical separation among bodies existing at the same time, and the location of schools within bodies was recognisable from the logbooks of different pilots. Habib *et al.* (1980a, 1980b, 1980c, [1982]) then calculated seasonal estimates of minimum absolute abundance by summing over all bodies seen in a season. (This assumes that fish in one body do not appear in a subsequent body.) These estimates are shown in Figure 17. Habib *et al.* made estimates for 1977-78, 1978-79, and 1979-80 by adding the maximum estimate by aerial sighting for a body to all catches from a body before that sighting. This is a suboptimal technique and may yield smaller estimates than equation 1, but the difference is small relative to the estimate of total abundance when summed over all bodies in a season. I have not corrected their figures. In the 1980-81 season Habib *et al.* (1981) could not identify bodies, because surface-schooling skipjack appeared in small schools scattered over a wide area. For the 1982-83, 1983-84, and 1984-85 seasons

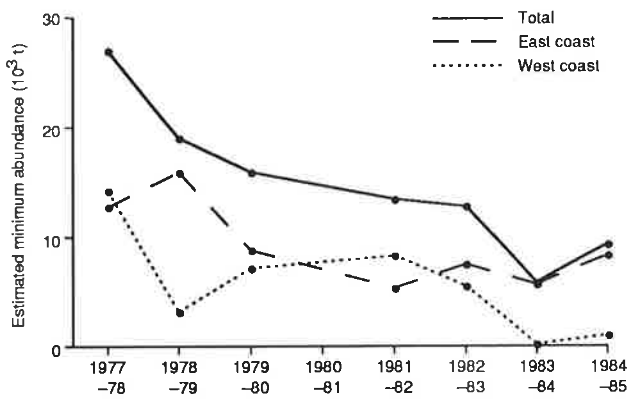


Figure 17: Estimates of minimum abundance for 1977–78 to 1984–85 made by the method of summing catches and sightings of bodies of fish as proposed by Habib *et al.* (1980a). (Estimates for 1977–78 to 1981–82 are from Habib *et al.* (1980a, 1980b, 1980c, 1981, [1982]); estimates for 1982–83 to 1984–85 are mine.)

I grouped surface-schooling skipjack into bodies by temporal and spatial proximity and calculated minimum absolute abundance estimates by use of equation 1. Estimates for the west coast for 1983-84 and 1984-85 may be low because there was no fishing on the west coast in these seasons and only two flights reported in 1983-84 and three flights in 1984-85.

Estimated minimum abundance is plotted against catch (Figure 18). The significant Spearman rank correlations (significant at 5% for both coasts individually and collectively) were expected, because much of the estimated minimum abundance is caught each year. Thus, for the period reviewed here, catch is a good measure of minimum abundance.

Minimum abundance is plotted against days fished or searched (Figure 19) and number of successful sets (Figure 20). There were significant positive correlations on the west coast, but not on the east coast, which suggested that different mechanisms drive aerial sightings effort on each coast. There is more effort devoted to sighting on the west coast in years in which it is fished. As more observations are made the estimate of minimum abundance rises towards real abundance. Thus, more comprehensive aerial effort will refine the minimum abundance estimate upwards.

Minimum abundance for each coast is plotted against the CPUE measures catch per day fished or searched (Figure 21) and catch per successful set (Figure 22). On the east coast there was a significant positive correlation between minimum abundance and catch per successful set. If catch per successful set were a measure of school size, schools would be larger in years of high abundance. One mechanism for this might be that higher densities of fish give a higher probability of contact between individuals and established schools, and between schools. This could increase the rate of lone individuals joining schools or of schools coalescing. Mean catch per successful set cannot be advocated as a measure of abundance because of fish behaviour in 1980–81, when there was a high catch, but fish were spread over a wide area in small schools.

Estimated minimum abundance is plotted against aerial sightings effort (total hours flown) (Figure 23). On the east coast there was a statistically significant negative correlation, and on the west coast there was a statistically significant positive correlation. Fishing is mostly on the east coast, and in years of low abundance high investment is made in aerial fish location there to sustain the catch; however, when fish are abundant and localised, such investment is not made. The 1980–81 season on the east coast had a high catch and therefore possibly abundant fish, but the schools were scattered widely and the industry required high flying effort (*see* Figures 5 and 13).

The west coast fishery is of secondary importance and is fished only when fish are not readily available on the east coast, when settled weather makes fishing on the west coast possible, and when significant amounts of surface-schooling fish are available. In the period of this review it appears that all these conditions appeared simultaneously. Active fishing on this coast requires aerial observation for accurate fish location and for assistance with setting; thus, there is a positive correlation between estimated minimum abundance and flying effort.

Tagging studies

The SPC Skipjack Survey and Assessment Programme tagged 11 623 skipjack around New Zealand in February and March 1979 and 1111 in March 1980. These fish were caught by pole and line. An analysis of the returns from this tagging and an assessment of the New Zealand skipjack fishery and its interaction with other skipjack fisheries in the SPC area was given by Argue and Kearney (1983). The methods of analysis were detailed by Kleiber *et al.* (1983) and Sibert (1984).

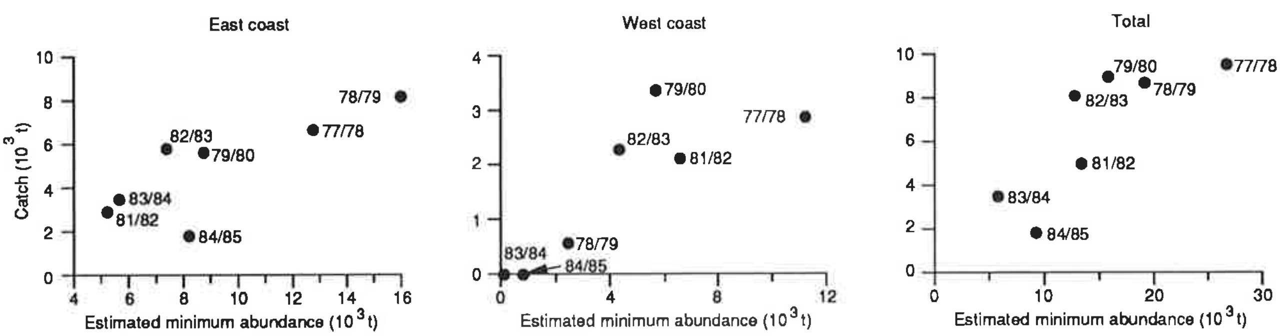


Figure 18: Estimated minimum abundance plotted against catch for all seasons from 1977–78 to 1984–85 except 1980–81. (East coast, Spearman's ρ is 0.714 (n = 7), which is significant at 5%; west coast, Spearman's ρ is 0.811 (n = 7), which is significant at 5%; total, Spearman's ρ is 0.893 (n = 7), which is significant at 1%.)

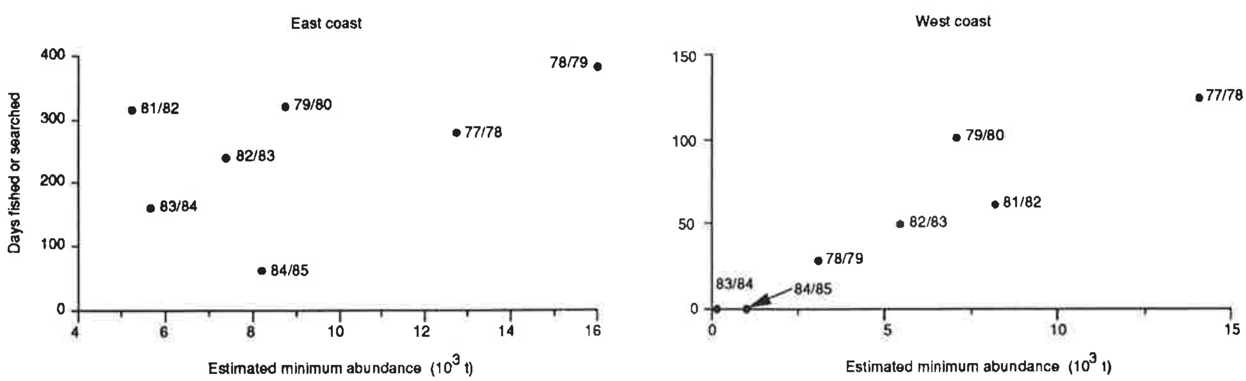


Figure 19: Estimated minimum abundance plotted against days fished or searched for all seasons from 1977–78 to 1984–85 except 1980–81. (East coast, Spearman's ρ is 0.464 (n = 7), which is not significant; west coast, Spearman's ρ is 0.955 (n = 7), which is significant at 1%.)

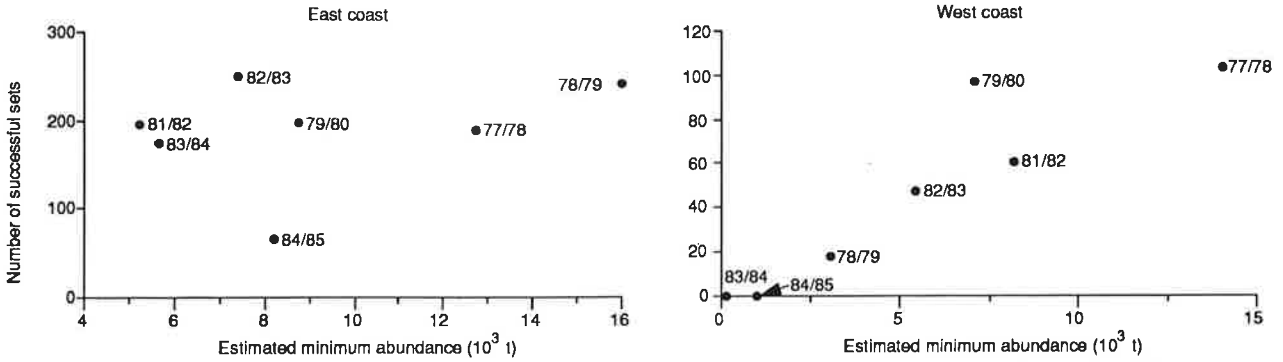


Figure 20: Estimated minimum abundance plotted against number of successful sets for all seasons from 1977–78 to 1984–85 except 1980–81. (East coast, Spearman's ρ is 0.214 (n = 7), which is not significant; west coast, Spearman's ρ is 0.955 (n = 7), which is significant at 1%.)

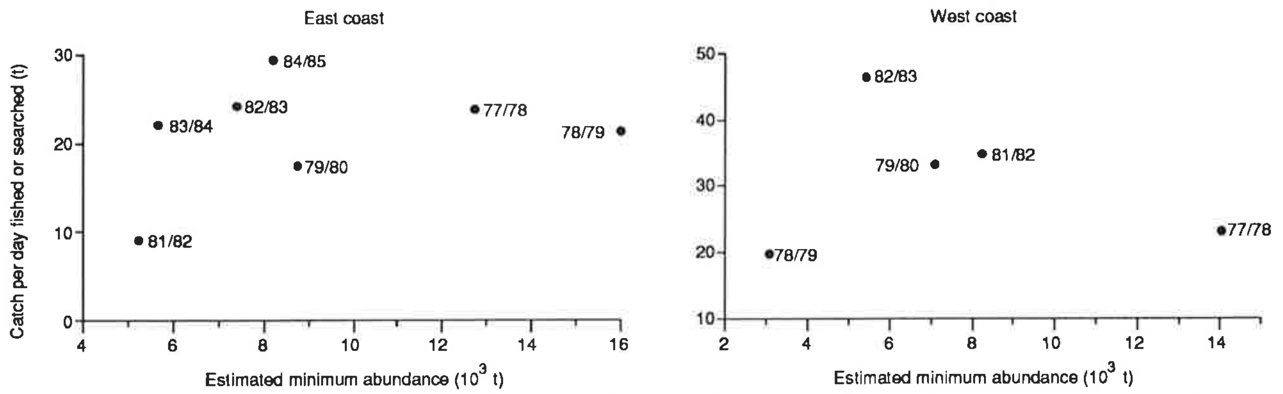


Figure 21: Estimated minimum abundance plotted against catch per day fished or searched for all seasons from 1977–78 to 1984–85 except 1980–81. (East coast, Spearman's ρ is 0.143 (n = 7), which is not significant; west coast, Spearman's ρ is 0.1 (n = 5), which is not significant. (No days were fished or searched on the west coast in 1983–84 or 1984–85.))

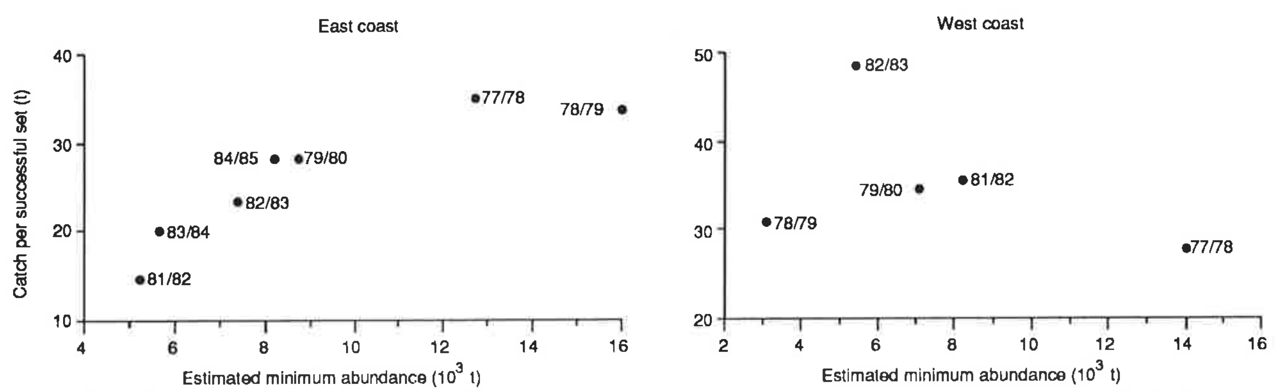


Figure 22: Estimated minimum abundance plotted against catch per successful set for all seasons from 1977–78 to 1984–85 except 1980–81. (East coast, Spearman's ρ is 0.964 (n = 7), which is significant at 1%; west coast, Spearman's ρ is 0.3 (n = 5), which is not significant. (No successful sets were made on the west coast in 1983–84 or 1984–85.))

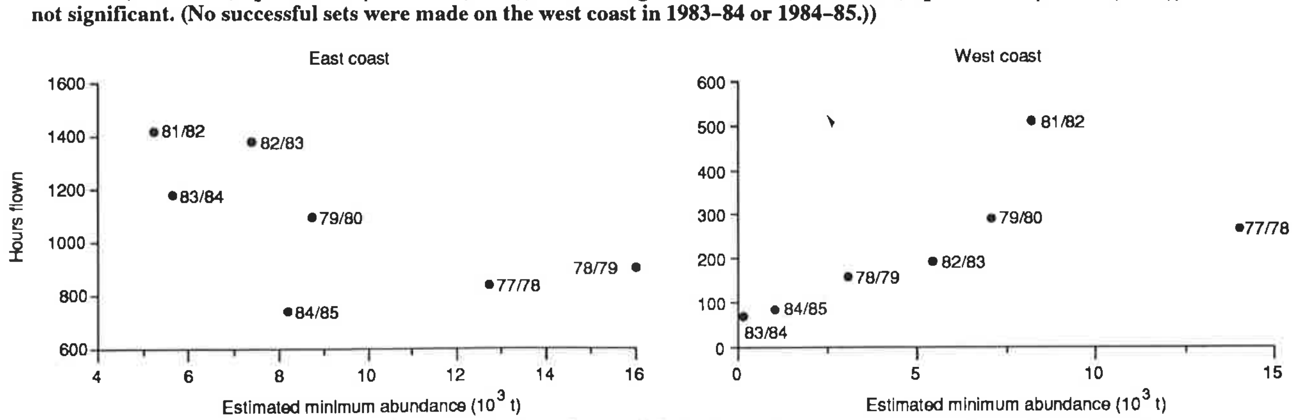


Figure 23: Estimated minimum abundance plotted against aerial sightings effort for all seasons from 1977–78 to 1984–85 except 1980–81. (East coast, Spearman's ρ is 0.714 (n = 7), which is significant at 5%; west coast, Spearman's ρ is 0.893 (n = 7), which is significant at 1%.)

Argue and Kearney (1983) derived estimates of population size and average turnover from the tags released in east coast areas B, C, and D in the two 10 day periods 21-28 February 1979 and 1-10 March 1979. They used two methods of population estimation on each 10 day period (Table 4): fitting an exponential tag attrition model (Argue and Kearney 1983, Kleiber *et al.* 1983) and fitting the Petersen mark-recapture model. The coefficient p in the Argue and Kearney estimates is the proportion of recaptured tagged fish reported with usable information. An estimate of $p = 0.16$ was made by placing dead tagged skipjack in seiner catches. Unfortunately, this was not done until a year after the original tagging experiment, so the low proportion of tags recovered may reflect poor alertness at the processing plant because the main tagging experiment was known to have ceased months earlier.

The March estimate is higher than the February estimate. The March period coincided with the appearance in area C of a body of skipjack. Habib *et al.* (1980b) estimated a minimum real abundance of 3408 t for this body from aerial sightings and catches. The increase in population estimates made from tag returns when a body appears at the surface supports the hypothesis that the appearance of such bodies can represent a large migration of fish into an area. The uncertainty in estimating p makes it impossible to use the SPC tagging estimates to determine conclusively the extent to which the minimum abundance estimates of Habib *et al.* (1980a, 1980b, 1980c, [1982]) understate actual abundance. A p value of 0.16, as derived by the tag-plant experiment (Argue and Kearney 1983), gives population estimates of 4528 and 6384 t in areas B, C, and D for the February and March periods. These estimates are close to the estimate of minimum real abundance of 5389 t derived by Habib *et al.* (1980b) for these areas for the same period. Thus, it is likely that the minimum abundance estimation method is accurate.

Argue and Kearney (1983) also estimated an average monthly turnover rate based on the February and March tag releases and subsequent returns (*see* Table 4). This turnover rate is an average over the whole period of tag recovery (about 1 year) and is not representative of each month within the period. It is not possible to use a shorter averaging period because fishing in New Zealand (and thus local tag recoveries) finished shortly after tagging.

Changes in abundance

Estimates of minimum real abundance obtained by the method suggested by Habib *et al.* (1980a) and modified in accordance with equation 1 show a regular decline from 1977-78 to 1982-83 (Figure 17). The regularity of this decline is not evident when the east and west coasts are considered separately, which suggests that there is an interdependence between coasts and that the proportion of the total fish which appears on each coast differs from season to season.

For 1983-84 and 1984-85, estimates of minimum abundance on the west coast could not be made with confidence because of the lack of fishing and aerial spotting effort (values shown on Figure 17 for the west coast and both coasts combined, in these two seasons, are too low as a consequence). Thus, I am not sure that the regular decline in total minimum abundance continued into these seasons.

A regular decline in total estimated minimum abundance could be generated if pilots' estimates of school sizes declined over the same period. This could occur if pilots refined their estimation methods with increasing experience in the fishery. There was a decline between 1977-78 and 1980-81 in the mean school size estimated by pilots for each season from 1976-77 to 1984-85. School size estimates rose in 1981-82 and 1982-83 while the decline in estimated minimum abundance continued. The mean of pilots' estimates of school sizes follows closely the mean catch per successful set (*see* Figure 11). As purseseiners frequently catch an entire school, mean catch per successful set is a measure of seasonal school size. The agreement between pilots' estimates of school size and mean catch per successful set gives confidence in pilots' estimates. Therefore, it does not appear that the decline in abundance can be attributed to systematic changes in the way in which pilots made their school size estimates.

Migration to New Zealand

The way fish enter, move through, and leave the New Zealand fishery is crucial to the acceptance of the method of Habib *et al.* (1980a) for estimating minimum abundance.

Lester *et al.* (1985) used parasite fauna to conclude that fish 45-55 cm fork length in the New Zealand purseseine fishery had recently come from the tropics. They also concluded that fish longer than 57 cm had migrated from the tropics at 45-55 cm and had not returned there in the interim. Argue and Kearney (1983), reporting the SPC tagging programme which tagged 50 000 skipjack in areas north of New Zealand, listed 19 fish tagged outside New Zealand and recovered in the New Zealand fishery. Migrants came from the northeast (Fiji and Wallis and Futuna) and from the west (New South Wales) (*see* Argue and Kearney 1983, figure 11). Richardson and Habib (1987) used genetic markers in blood proteins to confirm the multiple origin of New Zealand fish.

Movement in New Zealand waters

Lester *et al.* (1985) also used parasite fauna to estimate the mixing of schools of different origin. They observed large school-to-school differences in infestation of the parasite *Tentacularia coryphaenae* (and of several tropical parasites), especially in schools whose tropical parasite fauna suggested recent arrival in New Zealand waters. The fish were caught by purseseine, so at least some schools in the New Zealand purseseine fishery had not mixed sufficiently to mask their distinct origins before capture.

Schools of skipjack have been seen breaking up when feeding (Forsberg 1980), and aerial observers in New Zealand have seen surface schools merge and divide (Habib, unpublished observations, cited by Lester *et al.* 1985). Mixing of schools was demonstrated by Argue and Kearney (1983, page 33), who reported the proportion of tags recovered in schools purseseined a day after being tagged.

Divergence from Hardy-Weinberg equilibrium (with an excess of homozygotes) for red blood cell esterase for samples from schools purseseined in March 1978 was reported by Richardson and Habib (1987). They concluded that this excess was because of the Wahlund Effect, which arises from mixing genetically different fish. Surface schools and bodies (if they exist) can, therefore, consist of fish from more than one place of origin. It is probable that mixing between schools increases as the season progresses. This would be consistent with observations by Lester *et al.* (1985), who showed separation between schools whose parasitic fauna suggested recent arrival in New Zealand waters.

Mixing of schools could occur without mixing of established bodies. In February 1982 a cluster of surface schools, interpreted by Habib *et al.* [1982] as a body, was observed at Reef Point, and 835 skipjack were tagged. Seventy-two were recovered from that body, but none from concurrent and subsequent bodies west of Manukau, 150 km south (Iwasa *et al.* 1982). Tagging by the SPC Skipjack Survey and Assessment Programme in February and March 1979 yielded 1002 certain same-season recaptures. About half the fish tagged in this programme came from bodies, and all but four of the recoveries also came from or near those bodies. Four fish were recovered from isolated schools after the bodies in which they had been tagged had disappeared from the surface. It is unfortunate that both the 1979 and 1982 tagging occurred late in the skipjack purseseining season, which allowed little time for migration from body to body before purseseining ceased (on 23 March in 1979 and 16 April 1982). There are no recorded migrations of tagged fish from body to body.

Catches attest there are scattered individuals and subsurface schools of skipjack in New Zealand waters. Trolling by GRV *Kaharoa* between 17 and 30 October 1985 in area A caught 19 skipjack, and on 27 June 1987 in area E caught 6 skipjack (MAF Fisheries Greta Point central data file reports on cruises K18/85 and K12/87). Habib and Cade (1978) reported that subsurface fish were frequently taken by trolling in areas where there were no skipjack visible on the surface. In addition, Argue and Kearney (1983) reported that during the SPC tagging in New Zealand waters in February and March 1979 about half the schools fished by the tagging pole-and-line vessel were found by strikes on trolling lines when there were no fish visible at the surface, and fish caught during trolling when no surface fish were seen were later recaught by purseseine. Iwasa *et al.* (1982), in their report on the exploratory albacore survey of the pole-and-line vessel *Kaio Maru No. 52* in the first 3 months of 1982, noted surface-schooling skipjack of 40–50 cm length near the 200 m contour. They also noted that in greater depths, generally at least 15 "miles" offshore, subsurface schools of skipjack contained fish over 50 cm in length. In addition, they observed that the inshore fish fed mainly on plankton, whereas the offshore fish fed on a mix of plankton, small fish, and squid.

Dispersal from the purseseine fishery

Fish tagged by the SPC in New Zealand waters have been recaught throughout the tropical South Pacific Ocean from Vanuatu (160° E) to the Society Islands (150° W) as well as off New South Wales (*see* Argue and Kearney 1983, figure 9).

Parasitic fauna studies by Lester *et al.* (1985) suggest that some fish never return to the tropics after their initial migration to New Zealand. In some fish they showed evidence of temporary migration from New Zealand, perhaps to the waters of Norfolk Island. Fish which are tagged in New Zealand waters, and then disperse and become resident in New Zealand or in temperate waters, are unlikely to be recovered, because of the small amount of trolling in these waters. In 1983 the New Zealand catch of skipjack taken by trolling was 1.925 t (King 1986).

Table 4: Skipjack population size and average monthly turnover for the New Zealand purseseine fishery in areas B, C, and D (from Argue and Kearney (1983))

Date of tagging and for which the population estimate applies	Population size estimate from the tag attrition model	Population size estimate from the Petersen mark-recapture model	Average monthly turnover obtained from catch data	Average monthly turnover obtained from effort data
21-28 Feb 1979	28 300*p**	31 544*p*	0.40	0.39
Lower 95% confidence limit	16 600*p*	-	-	-
Upper 95% confidence limit	54 800*p*	-	-	-
1-10 Mar 1979	39 900*p*	42 792*p*	0.39	0.41
Lower 95% confidence limit	31 700*p*	-	-	-
Upper 95% confidence limit	55 500*p*	-	-	-

**p* is a coefficient (<1.0) that corrects for shortterm tag loss, shortterm tagging mortality, nonreporting of recaptured tags, and exclusion of tags with poor recovery data.

Because the SPC tagging in 1979 and the tagging from RV *Kaio Maru No. 52* in 1982 was carried out so late in the purseseine skipjack season, it revealed nothing about the turnover of fish through most of the season. The results of a non-steady-state simulation model of the New Zealand fishery were reported by Argue and Kearney (1983, page 49). A population of 24 000 t of skipjack was assumed to migrate to the New Zealand area over a 1-2 month period ending in December, was fished by a pattern of fishing effort similar to that of the 1978-79 and 1979-80 seasons, and then migrated from New Zealand over a 1-2 month period beginning in March. Recruitment and attrition rate (excluding fishing mortality) were fixed at 6000 t per month and 0.25 per month, respectively, and a catchability coefficient of 0.001 per purseseine set was assumed. Argue and Kearney showed that this model produced tag returns and catch and effort patterns similar to those seen in the New Zealand fishery.

Sea-surface temperature studies

Habib *et al.* (1980a, 1980b, 1980c, 1981, [1982]) showed that most skipjack purseseined in New Zealand were from areas where the sea-surface temperature was 19-22 °C. The percentage by weight of skipjack purseseined each season by sea-surface temperature is shown in Table 5. There are shifts in the temperature-catch distribution from season to season. In 1980-81, when small schools of skipjack were scattered over a wide area, substantially higher than usual quantities of skipjack were caught in water with a sea-surface temperature above 22 °C. In 1982-83, 1983-84, and 1985-86 substantially higher quantities of skipjack than usual were caught in waters below 19 °C.

Habib *et al.* (1980a, 1980b, 1980c, 1981, [1982]) examined the weekly charts of water surface temperature isotherms (GOSSTCOMP charts) published by the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce. They described the changes during each season, but did not report any attempt to discover whether there were any relationships, repeated in different seasons, between the sea-surface isotherm patterns around New Zealand and the purseseine skipjack fishery.

Table 5: Percentage catch by weight for each season from 1977–78 to 1985–86 by sea-surface temperature*

Season	Temperature (°C) <17	17.0 -17.9	18.0 -18.9	19.0 -19.9	20.0 -20.9	21.0 -21.9	22.0 -22.9	>23	% of total catch taken in sets where temperature was recorded
1977-78	0	2.5	5.9	23.7	37.4	23.9	5.9	0.7	100.0
1978-79	0	0.5	0.1	1.9	37.8	50.8	9.0	0	100.0
1979-80	1.1	0.2	0.5	26.9	32.4	29.8	7.9	1.2	97.7
1980-81	0.3	2.7	6.1	6.6	16.1	35.1	28.8	4.2	100.0
1981-82	0.0	1.2	2.9	9.3	42.7	35.8	8.1	0.1	100.0
1982-83	0.1	0.3	22.5	38.9	34.1	4.2	0	0	87.4
1983-84	3.1	10.1	9.0	36.7	31.0	10.1	0	0	78.7
1984-85	0	0	0.8	12.8	21.4	47.1	17.9	0	54.8
1985-86	0	9.7	5.1	9.3	19.2	46.2	10.5	0	96.2

*Temperatures are from vessel records.

I examined isotherm movement and the size and persistence of areas of sea with specified surface temperatures, and I tried to relate these to catch, catch-effort, and estimated minimum abundance. The NOAA GOSSTCOMP charts can be subject to bias close to land. Water vapour in the atmosphere can lower the computed sea-surface temperature by up to 4 °C. Brower *et al.* (1976) described GOSSTCOMP and discussed inherent errors. My isotherm movement studies depend on recording dates when the 18 °C isotherm passes specified latitudes on the coast. To lessen difficulties determining these dates, I selected latitudes which the isotherms usually passed quickly during isotherm advance or retreat. For persistence studies, area-time products were calculated by summing over several GOSSTCOMP charts, so they are minimally affected by shortterm changes in atmospheric water.

Each season, the southern limit of the 18 °C isotherm on the east coast was south of East Cape. On the west coast it was south of Cape Egmont. Dates on which the 18 °C isotherm passed each cape as it moved south and then north each season from 1975-76 to 1984-85 are given in Table 6. Spearman rank correlations of these dates and the days the 18 °C isotherm was south of each cape are given for catch, catch per day fished or searched, catch per successful set, and estimated minimum abundance (Table 7). Few of the correlations are statistically significant, but they show a pattern. On the east coast, early southward movement and long persistence are associated with high estimates of east coast minimum abundance. Relationships with catch and CPUE are less clear. On the west coast there is little evidence of a relationship with west coast abundance, but the correlation between the date of isotherm northward retreat and abundance for both coasts combined is statistically significant. There are also statistically significant negative correlations between CPUE and date of northward retreat, and between catch and northward retreat.

To examine changes in the area and persistence of sea-surface temperatures known to be associated with the purseseine fishery for skipjack (*see* Table 5), I determined the area of sea enclosed between each 1 °C isotherm above 18 °C, the coast, and the 500 m depth contour for each GOSSTCOMP chart. These areas were plotted against the dates of the GOSSTCOMP charts (Figure 24). Except for 1982–83, coasts do not both show the same pattern in any year; one coast shows a peaked curve and one a flat curve. I am hesitant to place much reliance on the maxima, because the maxima derive from a single GOSSTCOMP chart and thus may be biased by the effects of atmospheric water.

I assumed that the areas of sea enclosed by the isotherms, the coast, and the 500 m depth contour on each GOSSTCOMP chart approximated the mean area enclosed for the 3.5 days either side of the date of the chart, and I integrated over charts to estimate area-time products for sea of 19–22 °C and for sea warmer than 18 °C for 1975–76 to 1984–85 (Table 8). Spearman rank correlations of these area-time products with catch, catch per day fished or searched, catch per successful set, and estimated minimum abundance are given in Table 9.

The east coast area-time products were positively correlated with total minimum abundance and east coast minimum abundance, significantly so for water with a surface temperature above 18 °C. All area-time products were positively correlated with catch and the catch-effort measures of catch per day fished or searched and catch per successful set; large areas of suitable sea or long persistence of areas of suitable sea being associated with good fishing.

On the west coast there was little relationship between area-time products and minimum abundance. Catch and the measures of catch-effort were negatively correlated with area-time products, significantly so for water 19–22 °C.

In interpreting the patterns seen in Tables 7 and 9, I considered the possibility that different physical or biological processes might control the behaviour of fish and their availability to purseseining on each coast. There is no evidence that west coast fish are consistently of different origin from east coast fish, nor do I have sufficient hydrological detail to work out the fine behaviour of currents or the thermocline. The simplest interpretation of the correlations found involves purseseine fleet behaviour. Purseseining needs calm seas for fish location and net setting. The east coast

Table 6: Dates on which the 18 °C sea-surface temperature isotherm passed East Cape and Cape Egmont for the seasons 1975–76 to 1984–85

	East Cape		Cape Egmont	
Season	Southward movement	Northward movement	Southward movement	Northward movement
1975–76	19 Nov	8 Jun	11 Feb	3 May
1976–77	7 Dec	3 May	1 Feb	26 Apr
1977–78	13 Dec	11 Apr	18 Jan	2 May
1978–79	28 Nov	22 May	19 Dec	1 May
1979–80	27 Nov	25 Mar	1 Jan	8 Apr
1980–81	23 Dec	30 Jun	10 Feb	26 May
1981–82	29 Dec	5 Apr	29 Dec	20 Apr
1982–83	14 Dec	10 May	1 Mar	1 Mar
1983–84	6 Dec	5 Jun	21 Feb	10 Apr
1984–85	4 Dec	21 May	7 Jan	30 Apr

Table 8: Area-time products (day per km^2 × 10^6) for sea between the coast and the 500 m depth contour with sea-surface temperatures of 19–22 °C and above 18 °C for 1975–76 to 1984–85

	East coast		West coast	
Season	19–22 °C	>18 °C	19–22 °C	>18 °C
1975–76	1.29	2.05	1.92	2.52
1976–77	1.08	2.38	1.40	1.84
1977–78	1.59	2.68	1.20	1.69
1978–79	1.46	1.97	1.50	3.01
1979–80	1.14	1.84	0.97	2.34
1980–81	1.45	1.97	1.63	2.96
1981–82	0.92	1.48	1.55	2.87
1982–83	0.86	1.39	0.38	0.69
1983–84	1.27	1.81	1.10	1.98
1984–85	1.58	2.15	1.77	3.09

Table 7: Spearman rank correlation coefficients† of the 18 °C sea-surface isotherm's movements with catch statistics and estimated abundance

	Catch	Catch per day fished or searched	Catch per successful set	Estimated minimum abundance	Estimated minimum abundance for both coasts combined
East coast					
Date of southward movement past East Cape	0.164	-0.248	-0.588*	-0.643	-0.500
Time south of East Cape	0.231	0.146	0.024	0.429	0.200
Date of northward movement past East Cape	-0.152	0.370	-0.152	0.000	0.100
West coast					
Date of southward movement past Cape Egmont	-0.608*	-0.095	-0.143	0.300	-0.300
Time south of Cape Egmont	0.438	-0.143	-0.119	-0.100	0.500
Date of northward movement past Cape Egmont	-0.839**	-0.881**	-0.952**	0.400	0.900*

†Correlations between isotherm movements and catch statistics are for 1975–76 to 1984–85 (10 seasons); correlations between isotherm movements and estimated minimum abundance are for 1977–78 to 1979–80 and 1981–82 to 1984–85 (7 seasons) on the east coast and for 1977–78 to 1979–80 and 1981–82 to 1982–83 (5 seasons) on the west coast and for both coasts combined.

*Significant at 5%.

**Significant at 1%.

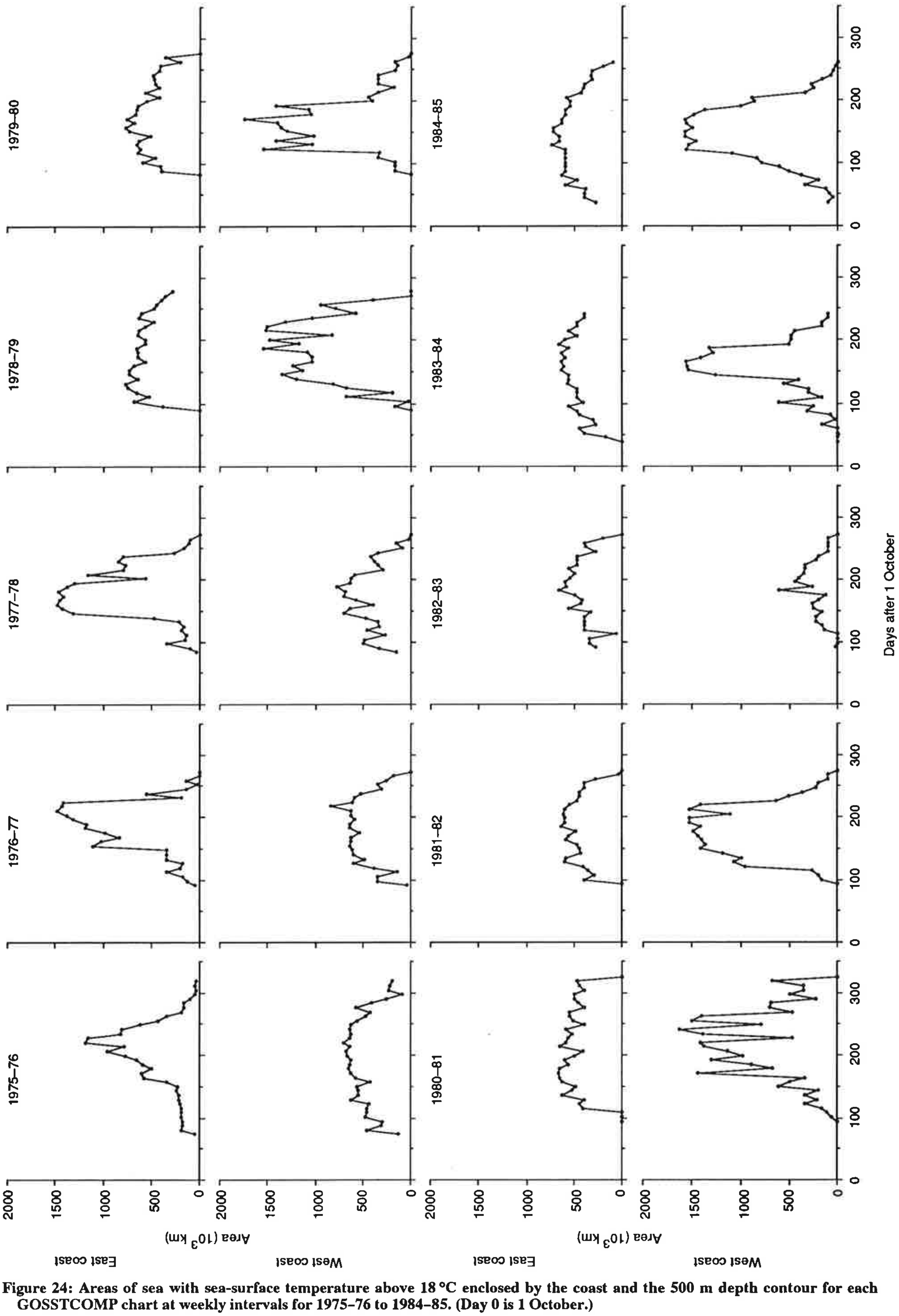


Figure 24: Areas of sea with sea-surface temperature above 18 °C enclosed by the coast and the 500 m depth contour for each GOSSTCOMP chart at weekly intervals for 1975–76 to 1984–85. (Day 0 is 1 October.)

offers calmer seas and more shelter than the west coast, which is exposed to westerly winds and sea swells, and weather patterns affecting New Zealand come mainly from the west. The New Zealand companies that land skipjack have their processing plants in the east coast ports of Tauranga and Gisborne. Therefore, in seasons of good fish abundance, it is sensible for successful fishing units to stay on the east coast. Only in seasons of poor fish abundance or when the sea-surface temperature isotherms retreat northward early, ending the east coast season, do vessels attempt to fish the west coast. This could be why early sea-surface isotherm retreat and small area-time products are associated with the best catches and catch-effort statistics on the west coast.

In Table 7 the date of northward movement of the 18 °C sea-surface isotherm on the west coast is much more highly correlated with total abundance than the northward movement on the east coast. This may simply be a consequence of the choice of latitude for the statistic on the west coast. The lower correlation between northward movement on the west coast and estimated west coast abundance may be due in part to the greater uncertainties in the estimate of west coast abundance.

Table 9: Spearman rank correlation coefficients† for area-time products for sea having surface temperatures of 19–22 °C and above 18 °C with catch statistics and estimated abundance

	Catch	Catch per day fished or searched	Catch per successful set	Estimated minimum abundance	Estimated minimum abundance for both coasts combined
East coast					
19–22 °C	0.224	0.248	0.588*	0.607	1.000**
Above 18 °C	0.243	0.073	0.486	0.714*	1.000**
West coast					
19–22 °C	-0.602*	-0.782**	-0.724*	0.200	0.300
Above 18 °C	-0.529	-0.533	-0.372	-0.300	0.300

†Correlations between area-time products and catch statistics are for 1975–76 to 1984–85 (10 seasons); correlations between area-time products and estimated minimum abundance are for 1977–78 to 1979–80 and 1981–82 to 1984–85 (7 seasons) on the east coast and for 1977–78 to 1979–80 and 1981–82 to 1982–83 (5 seasons) on the west coast and for both coasts combined.

*Significant at 5%.

**Significant at 1%.

Conclusions

Estimates of abundance

It is likely that clusters of surface schooling skipjack, termed "bodies" by Habib *et al.* (1980a), represent most or all of the potentially purseseinable skipjack on the New Zealand coast. Minimum abundance estimates made from catches and aerial counts (equation 1) accord well with abundance estimates made from the SPC tagging in the Bay of Plenty in February and March 1979.

The relationship between fish seen at the surface and subsurface fish is not clear. The SPC tagging studies showed some subsurface fish were recaptured in surface schools. Unfortunately, the SPC tagging activities in New Zealand waters were always late in the season and thus did not allow investigation of fish dynamics throughout a season.

Genetic and parasitic fauna studies show that surface schools mix in New Zealand waters. There was no evidence of fish appearing in more than one body, but there were few opportunities to detect this. If the same fish do appear in more than one body, then the seasonal estimates of minimum abundance (*see* Figure 17) made by summing over aerial sightings and catches from bodies may be too high.

Changes in abundance

Estimates of minimum abundance for both coasts combined show a regular decline from 1977–78 to 1982–83 (*see* Figure 17). The regularity of this decline is not evident when each coast is considered separately, which suggests that there is an interdependence between coasts and that the proportion of the total fish that appears on each coast differs from season to season. For 1983-84 and 1984-85, estimates of minimum abundance on the west coast could not be made with any confidence because of lack of fishing and aerial spotting in these years. Thus, I am not sure that the regular decline in total minimum abundance continued into these years. However, the estimates for the east coast are of the same magnitude as the two immediately preceding years and none of the fishing catch-effort statistics (Tables 2 and 5, Figures 3, 8, and 9) or isotherm movements (Table 6) suggest seasons with radically different characteristics from others in this review.

A regular decline over time in pilots' estimates of school sizes could have resulted in the regular decline in total estimated minimum abundance. There are season to season differences in the mean school size estimated by pilots, with a decline between 1977-78 and 1980-81 (*see* Figure 11). Mean school size estimated by pilots rose in 1981-82 and 1982-83, while the estimates of minimum abundance declined. The mean of pilots' estimates of school sizes closely follows the mean catch per successful set (*see* Figure 11). As purseseiners frequently appear to catch an entire school, mean catch per successful set is a measure of school size in the fishery. The agreement between pilots' estimates and mean catch per successful set encourages confidence in pilots' estimates of school size.

Therefore, it appears that there was a real and regular decline in the amount of surface schooling skipjack available to the New Zealand purseseine fishery between 1977-78 and 1982-83. I am unable to explain this decline. I examined sea-surface temperature patterns around New Zealand and could detect no systematic change in these.

Competition

A decline in the number of vessels purseseining for skipjack in New Zealand has occurred simultaneously with the decline in abundance. This may explain why there has not been a simultaneous decline in catch per day fishing or searching. There was evidence that competition between vessels reduced catch per day fished or searched in the late 1970s and early 1980s (Argue and Kearney 1983).

Outlook

For 1982-83 to 1985-86 the catching capacity of the vessels in the fishery was generally less than the amount of surface schooling fish available at any one time. For catches of 4000-5000 t per year, a catch per day fished or searched of 25-30 t can probably be sustained, provided the decline in abundance was close to its horizontal asymptote in 1982-83. It may be possible to increase local purseseine catches if increased vessel competition and lower CPUE were acceptable. This assumes that fish passing through New Zealand waters are not the principal spawners of fish coming to New Zealand in the future. If the decline in available surface-schooling skipjack is caused by some cyclic biological or oceanographic phenomenon, and if the decline is near the bottom of the trough, as Figure 17 suggests, then the amount of surface skipjack may increase in seasons after 1982-83. However, if the decline is due to some systematic non-cyclic change, then Figure 17 suggests that the decline is approaching an asymptote, and the amount of surface schooling skipjack may stabilise at about 10 000 t per season.

Behaviour of the fleet

High abundance, and thus fishing success, is associated with an early southward movement of the 18 °C sea surface isotherm and high area-time products for sea with surface temperatures of 19-22 °C. High area-time products arise when a large area of sea surface is warmed for a short period, a smaller area stays warm for a long period, or a large area stays warm for a long period (giving exceptionally high values). The differences between coasts in correlation between isotherm patterns with catch, CPUE, and minimum abundance can be interpreted by a preference by purseseine vessels for the east coast fishing grounds. Substantial expansion in annual catch will require fishing on the west coast, and this may not be practical or economic for the small seiners that now make up the New Zealand fleet.

Unresolved issues

To further assess the value of aerial survey techniques, the relationship between surface schooling skipjack and subsurface skipjack needs further elucidation. The relationship in a body at a given time could be investigated by side-scanning sonar. Investigation of wider dynamics in New Zealand waters (e.g., the mixing of bodies and turnover of fish) requires a tagging programme that starts early in a fishing season. Such tagging would be conducted from pole-and-line vessels and would require an active purseseining sector to ensure adequate tag recoveries.

It is not known whether the spawning of skipjack that pass through New Zealand waters contributes to subsequent recruitment in these waters. As it is not known where fish recruited to New Zealand are spawned, it is difficult to suggest ways in which the stock recruitment uncertainty can be resolved. Because of the large population of skipjack in the Pacific Ocean, it is reasonable to manage the New Zealand fishery on the assumption that the New Zealand catch will not affect recruitment to New Zealand waters.

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