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Distribution, Abundance and Size Structure of Arrow Squid (*Nototodarus* sp.) off New Zealand

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Abstract

Two species of arrow squid (*Nototodarus* sp.) were sampled with bottom trawl during nine research surveys along the north and east coast of South Island, New Zealand, from January 1982 to March 1983. There was minimal overlap between the two species. Species 1 was associated with subtropical water along the north coast (Tasman Bay) of South Island and Species 2 with the Subtropical Convergence Zone and subantarctic water along the east coast. Catches of Species 2 varied markedly with geographic location, depth (from 50 to 500 m) and sampling period, but were consistently lowest in January of both years. Differences in the size composition of Species 2 with depth were associated with differences in the relative abundance of juveniles. Juveniles of Species 2 were most abundant at 50 and 100 m and were rare or absent at 30 and 500 m. Size distributions of males and females of both species were generally similar for each depth and sampling period. Modal sizes (dorsal mantle length) of Species 1 indicated growth rates of 3.0–4.5 cm per month for three cohorts which were separated by about 6 months. Spawning of Species 1 probably occurs around November and April of each year, and maximal size (about 40 cm) is attained in about 1 year. Size distributions of Species 2, were polymodal and did not give clear indications of growth or spawning period. This may be due to a mixture of several subpopulations of Species 2 along the east coast of South Island, differing in age structure, spawning period and growth rate.

Introduction

Arrow squid of the genus *Nototodarus* (family Ommastrephidae) occur throughout the continental shelf waters of New Zealand, eastward to Chatham Islands and southward to Campbell Island (Roberts, 1978). Two species of *Nototodarus* have been identified from New Zealand waters on the basis of genetic and morphological differences (Smith *et al.*, 1981; Kawakami and Okutani, 1981). However, their taxonomy remains unresolved, and they are referred to in this paper as *Nototodarus* Species 1 and Species 2. The two species occupy different geographical ranges with limited overlap. In general, Species 1 occurs to the north of the Subtropical Convergence and Species 2 within and to the south of the convergence (Mattlin, 1983).

A major fishery for arrow squid has taken place off New Zealand since the early 1970's. The squid are jigged or trawled primarily by vessels from other countries (Japan, Korea, Taiwan and the Soviet Union) which are licensed to fish in New Zealand's 200-mile exclusive economic zone. The total catch of *Nototodarus* sp. in the 1981/82 fishing season was approximately 64,000 metric tons (Mattlin, 1983).

Studies of the population biology of arrow squid off New Zealand have been based mainly on data collected during commercial fishing operations or short-term research programs (Hamabe *et al.*, 1974; Kawakami, 1976; Kawakami *et al.*, 1972, 1973; Tung, 1978). This paper outlines the distribution, abundance and population structure of *Nototodarus* sp. in Tasman Bay and along the east coast of South Island, as part of a broader study of the population biology of arrow squids, based on a series of research surveys in 1982 and 1983.

Materials and Methods

Nototodarus sp. were sampled during nine surveys by the New Zealand research vessel *James Cook* from January 1982 to March 1983. Squid were caught in a Mark IV Boston trawl (60-mm mesh codend) which was towed on the bottom for 1 hr at about 3 knots. All trawling was done during daylight between 0700 and 1700 hr at stations on six transects (Fig. 1). Transect A (two stations) was in Tasman Bay, and transects B to F (five stations each) were located along the east coast of South Island from Kaikoura to Stewart Island. Stations 1–5 were at depths of 50, 100, 200, 300 and 500 m respectively. The stations were selected on the basis of depth records on hydrographic charts and were located by satellite navigation. Bottom depth and trawl depth were recorded continuously during each haul.

Freshly-caught *Nototodarus* were individually measured (dorsal mantle length, DML) to the nearest millimeter and weighed to the nearest 5 g. Sex was determined by the presence of the hectocotylus in males or by macroscopic examination of the gonads, except for juveniles with no identifiable gonads. Male squid were identified as *Nototodarus* Species 1 or Species 2 by the morphology of the hectocotylus (Smith *et*

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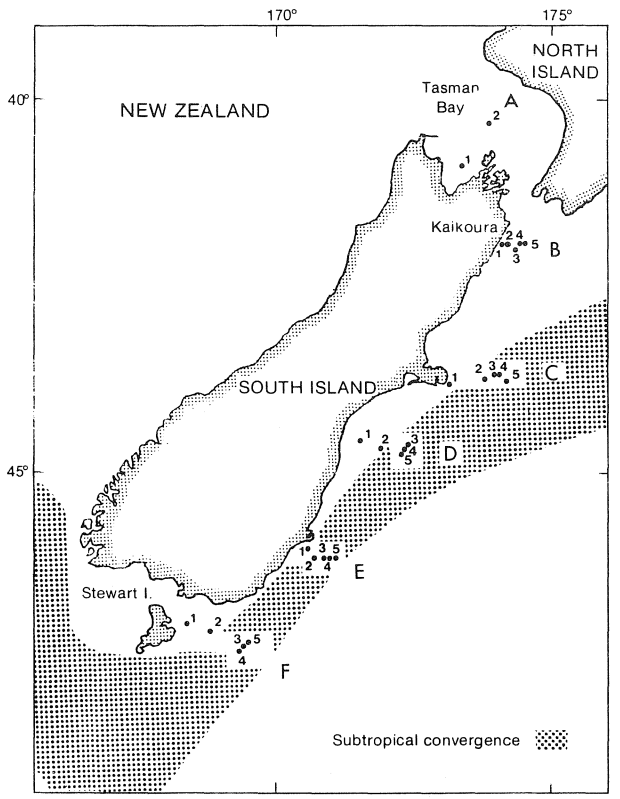

Fig. 1. The area around South Island, New Zealand, showing locations of transects and stations and position of the Subtropical Convergence Zone (shaded).

al., 1981). Samples of mantle tissue (1–5 g) from females and juveniles were frozen at -20° C for subsequent electrophoretic identification of species (Smith *et al.*, 1981). When catches were large, random samples were analyzed and the total catch was weighed.

Modal analysis of size frequencies was made with the aid of probability paper (Harding, 1949; Cassie, 1954).

Results

Distribution of catches

Data from all seasons of the year indicate that there was little overlap in the distributions of the two types of *Nototodarus* among transects (Table 1). Species 1 constituted 96% (n = 793) of the total catch on transect A and only 13% (n = 136) of the total catch on transect B for all sampling periods. Only Species 2 was caught on transects C to F.

Species 1 was caught throughout the year although catches were low during July–September (Table 1). This species was most abundant at 50 m on transect A

The catches of Species 2 varied markedly with geographical location, depth and sampling period (Table 1). Maximum catches were recorded in February 1982 (330 kg) and June 1982 (267 kg) at 50 m on transects D and C respectively and in September 1982 (301 kg) at 300 m on transect F. Catches at other locations, depths and times ranged from 0 to 57 kg. Catches of Species 2 were consistently low at all stations in January 1982 and 1983. Combination of the survey data by sampling period, transect and depth (Fig. 2) resulted in average catch trends whose maxima were largely determined by the three largest catches noted above.

Length distributions

Species 1 juveniles represented a smaller proportion of the catch at 50 m (15%) than at 100 m (50%) (Fig. 3). They were most abundant in February 1982 (56% of total catch) and were rare or absent in January 1982 and from May 1982 to January 1983 (Fig. 4). The size distributions of Species 1 males and females were generally similar in the samples from the various depths and sampling periods.

Species 2 juveniles were most abundant at depths of 50 and 100 m where they represented 47% of the total catch at each of these depths (Fig. 3). They constituted 27% of the catch at 200 m but were rare or absent at 300 and 500 m. There was an increase in size with depth, the modal sizes being 5 and 10 cm at 50 m, 10 cm at 100 m and 13 cm at 200 m. The relative abundance of these juveniles was highest in January of 1982 and 1983 (63 and 87% of total catches respectively) (Fig. 4). Juveniles were also abundant in April and May 1982 (46% and 32% respectively of total catch) but were rare or absent during the remaining surveys. The size distributions of Species 2 males and females were generally similar in the samples from the various depths and sampling periods.

Growth

Although sample sizes were small ($n<25$) in some instances, the trends in progression of modes for Species 1 with time (arrows in Fig. 4) indicate the growth of three cohorts which differed in age by about 6 months (Fig. 5). For squid between 10 and 34 cm DML, growth appeared to be linear, with incremental increases in length of about 3.0–4.5 cm per month.

The size distributions of Species 2 were generally polymodal, but there was no consistent pattern in the number or progression of modes to indicate growth of particular cohorts (Fig. 4)

Length-weight relationships

Least-squares regression equations were calculated from the logarithmically transformed length (L cm) and weight (W g) data for Species 1 and Species 2. Due to non-linearity of the transformed data, a spline technique (Draper and Smith, 1981) was applied to

TABLE 1. Catches (kg/hour, fresh weight) by depth and sampling period of *Nototodarus* sp. off New Zealand in 1982-83 (— indicates station not sampled.)

Transect	Station depth (m)	1982 Jan 08-20	Feb 15-28	Apr 07-22	May 28 Jun 10	Jul 23 Aug 06	Aug 30 Sep 12	Nov 12-25	1983 Jan 08-19	Mar 04-16
					***Nototodarus* Species 1**					
A	50	0.5	12.3	12.6	9.6	0.5	1.3	18.9	17.5	11.8
	100	10.7	11.7	3.2	6.9	0.8	0	0.8	—	—
B	50	2.5	—	0	1.3	0	0	0	0	1.5
	100	0	—	0	0	0	0	—	0.5	1.7
	200	0	0	—	—	—	—	—	—	—
	300	0	0	—	—	0	—	—	0	0
	500	0	0	—	—	0	—	—	—	—
					***Nototodarus* Species 2**					
A	50	0.1	0	0	1.1	0	0	0.1	0.7	0
	100	0	0.1	0	0	0	0.9	0	—	—
B	50	1.7	—	0.3	15.2	3.4	1.0	2.5	1.5	29.8
	100	1.1	—	0.6	9.5	0	0.8	—	0.6	7.9
	200	3.8	0.8	—	—	—	—	—	—	—
	300	1.0	0	—	—	1.5	—	—	1.9	3.2
	500	0.9	6.8	—	—	0.9	—	—	—	—
C	50	0	24.0	4.0	267.0	0	0.2	0	1.8	42.8
	100	6.1	2.1	32.5	1.9	0.8	1.0	44.0	0.4	5.3
	200	—	5.3	9.6	15.0	—	—	—	0.8	—
	300	1.9	6.3	0.9	3.5	8.5	46.0	1.8	1.5	4.7
	500	—	—	—	—	—	—	1.8	—	1.2
D	50	0.9	330.0	12.7	51.5	0	0	0.8	3.3	30.0
	100	1.7	17.0	25.3	1.8	1.2	0	0.8	1.1	40.0
	200	0.7	4.1	22.8	15.0	—	1.3	0.6	4.3	—
	300	0.7	5.9	0.7	0.3	—	301.0	4.4	0.5	6.4
	500	3.6	—	—)	—	—	1.5	3.9	4.2	1.0
E	50	0	—	1.6	1.5	0	8.0	0.5	1.1	1.8
	100	0.5	—	38.6	4.2	1.6	0	1.5	0.6	0.7
	200	0.9	—	38.9	5.5	31.0	—	—	0	0
	300	0	—	56.9	2.5	8.5	11.0	0	0	0.1
	500	1.3	—	1.2	2.7	3.4	—	—	0.7	0.6
F	50	2.8	3.7	4.2	2.5	0	1.5	0.2	0.1	0.2
	100	0.6	6.8	4.9	0.4	0	0	0.4	0.2	0.9
	200	0	4.5	—	—	0	—	5.8	—	—
	300	1.6	—	0	11.5	27.3	—	1.9	0.3	2.0
	500	—	—	—	—	1.4	—	—	—	—

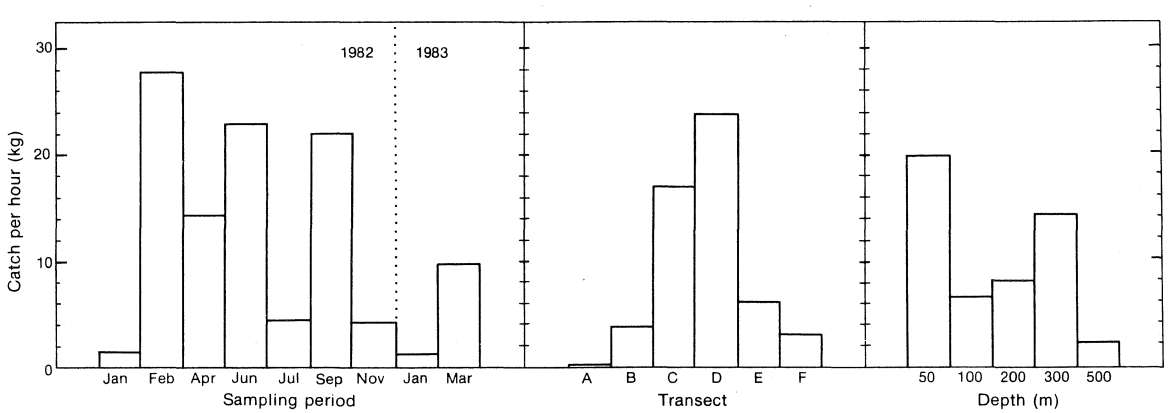

Fig. 2. Average catches (kg/hr) of *Nototodarus* Species 2 off New Zealand by sampling period, transect and depth in 1982-83.

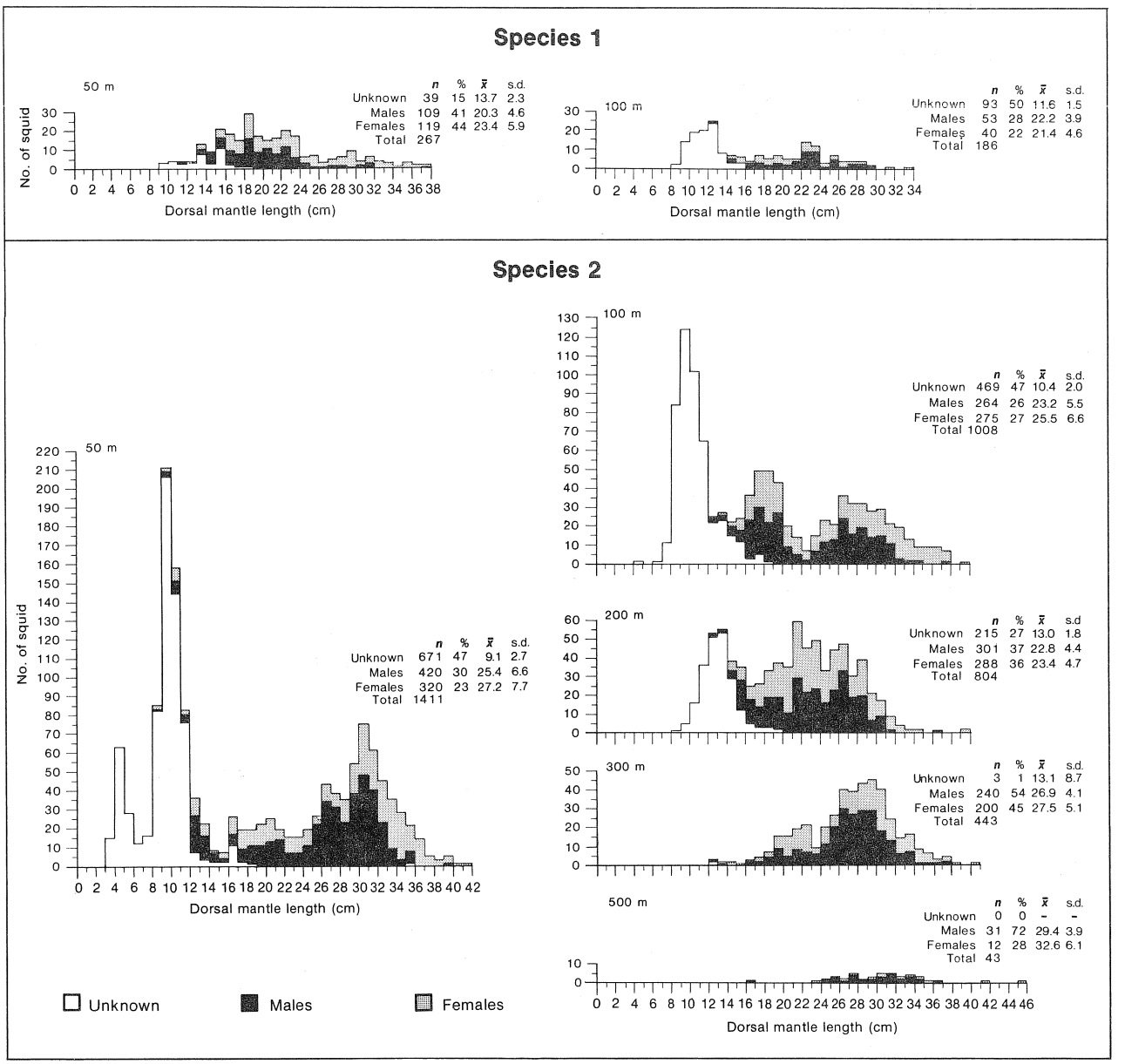

Fig. 3. Length distributions of *Nototodarus* Species 1 and Species 2 from surveys off New Zealand in 1982–83 by depth.

give separate equations for squid ⩽12 cm and >12 cm DML. The resulting power functions are as follows:

Species 1, ⩽12 cm DML $W = 0.07380\ L^{2.63}$

>12 cm DML $W = 0.02900\ L^{3.00}$

Species 2, ⩽12 cm DML $W = 0.10970\ L^{2.43}$

>12 cm DML $W = 0.01546\ L^{3.11}$

The coefficients of correlation (r) for all least-squares regression equations were greater than 0.99. It is evident from the plotted length-weight relationships (Fig. 6) that the weight per unit length for Species 1 is greater than that for Species 2 over the entire length range of the squid.

Discussion

Although *Nototodarus* sp. off New Zealand are fished by distant-water fleets of several countries mainly during December–May (i.e. the austral summer and autumn), this study and others (Roberts, 1979) indicate the potential for a year-round fishery. The highest catches by weight in this study (but not of commercial scale) were in February, June and September 1982, whereas the lowest occurred in January of 1982 and 1983. New Zealand trawlers catch arrow squid throughout the year, and there are no clear seasonal trends in the landings (Roberts, 1979).

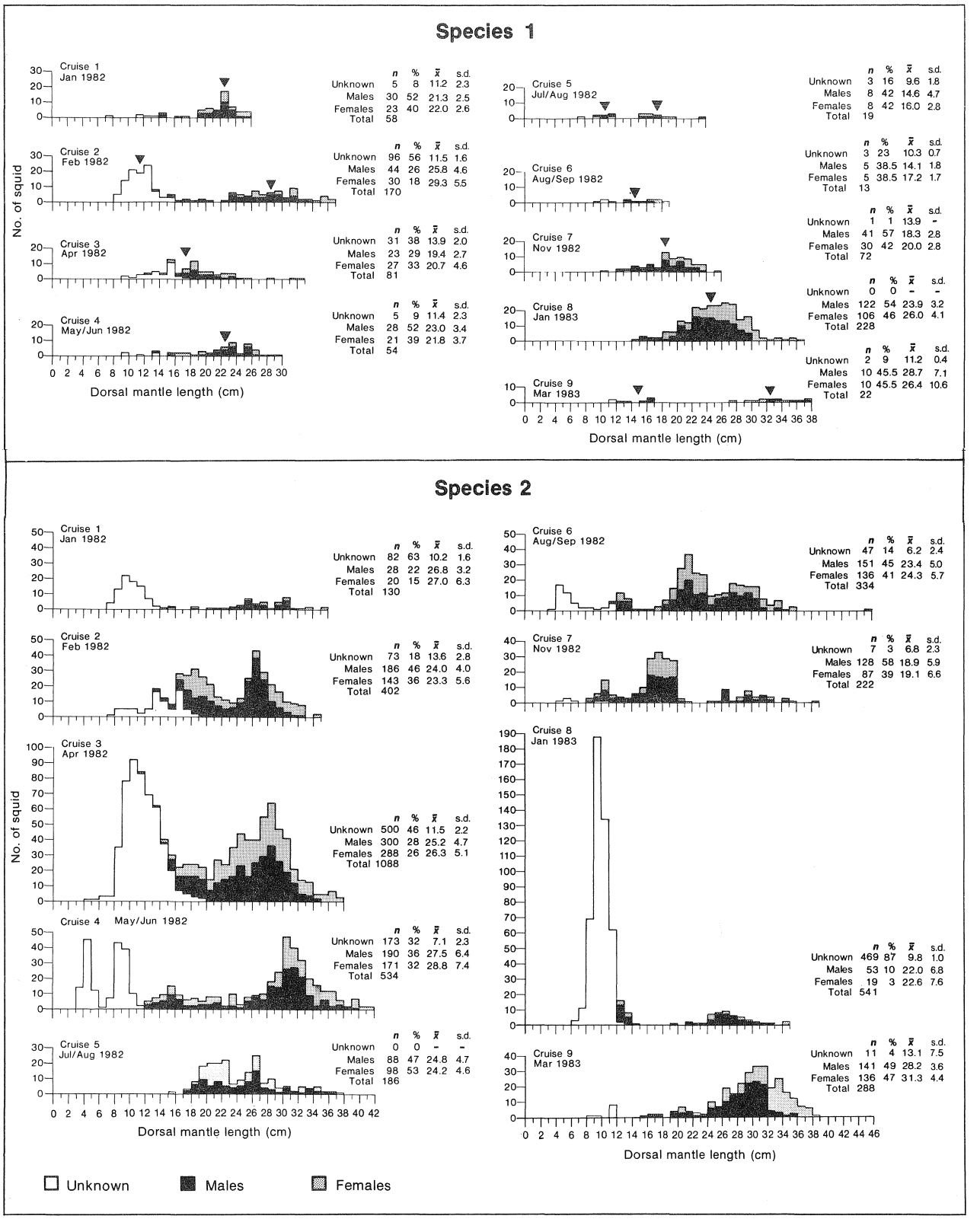

Fig. 4. Length distributions of *Nototodarus* Species 1 and Species 2 from surveys off New Zealand in 1982–83 by sampling period. (Arrows indicate modes used in Fig. 5.)

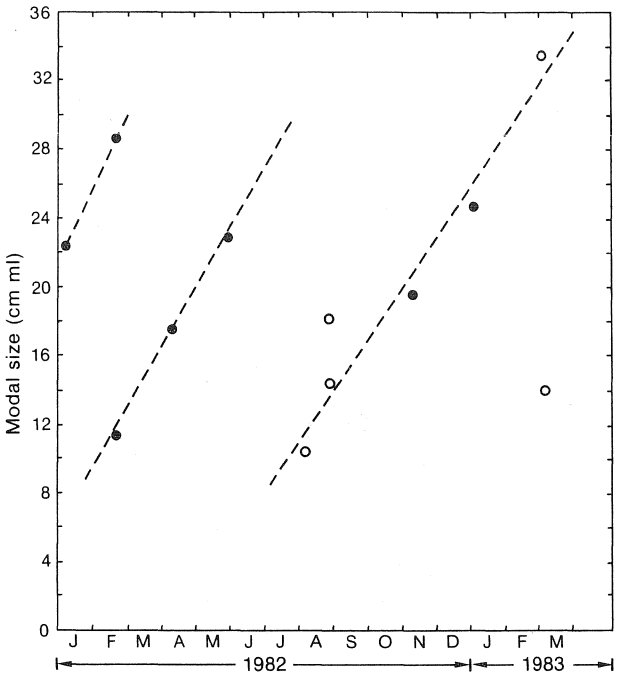

Fig. 5. Relationship between modal sizes of *Nototodarus* Species 1 (arrows in Fig. 4) and sampling period, showing growth of different cohorts. (Open circles represent samples with less than 25 squid; lines were fitted visually.)

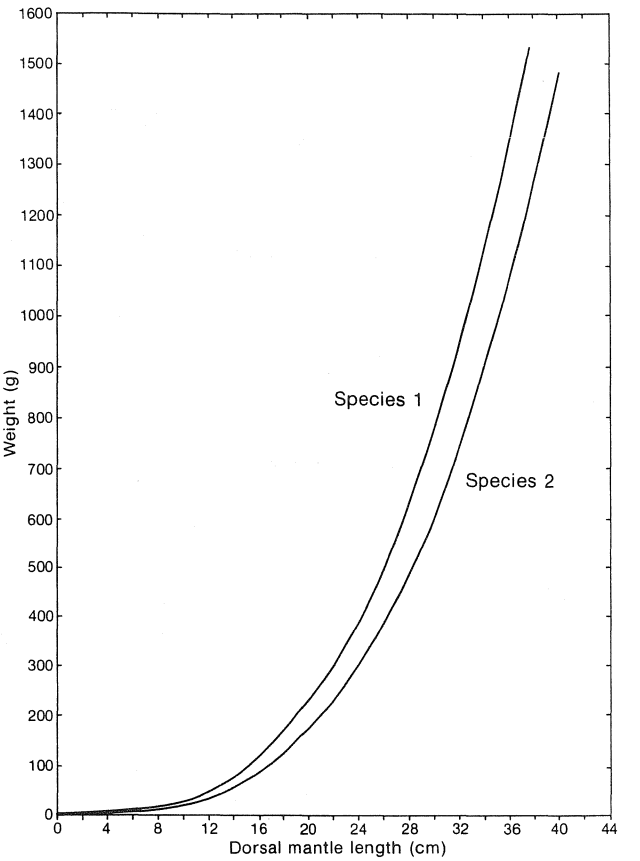

Fig. 6. Length-weight relationships for *Nototodarus* Species 1 and Species 2, based on data from surveys off New Zealand in 1982–83.

The limited overlap in the distribution of the two species of *Nototodarus* indicates that they are associated with different water types: Species 1 in subtropical water and Species 2 in the Subtropical Convergence Zone and in subantarctic water. On the east coast of South Island, Species 1 extends south to Kaikoura (transect B) where it occurs (in low abundance) with Species 2, as shown in this study and by Smith *et al.* (1981). Species 1 also occurs off the north and west coasts of South Island and off the east and west coasts of North Island with little or no overlap with Species 2 in most areas (Smith *et al.*, 1981; Mattlin, 1983). Species 2 occurs off the east and south coasts of South Island, southward to the Auckland Island Shelf, Campbell Plateau and Antipodes Islands, and eastward to the Chatham Islands (Mattlin, 1983). Two morphs of Species 2 off the east coast of South Island have been distinguished by the number of suckers on the hectocotylus (Kawakami and Okutani, 1981), but genetic differences have not been found (Smith *et al.*, 1981). The presence of two geographically separate species of arrow squid off New Zealand may ultimately necessitate separate management strategies. The logical geographical division of the fishery would be through Cook Strait between North Island and South Island.

Bimodal or polymodal size distributions of *Nototodarus* sp. indicate the presence of two or more cohorts in the catches. The progression in modal size of Species 1 in Tasman Bay (transect A) indicated growth rates of 3.0–4.5 cm per month for three cohorts which were followed over a period of 15 months. If growth is approximately linear over the entire life cycle, it is likely that spawning of species 1 in Tasman Bay occurs twice yearly in about November and April (austral spring and autumn) and that the squid attain maximum size about 1 year after spawning. The estimated growth rate for Species 1 are consistent with previous estimates for *Nototodarus* sp. and other ommastrephid species (Table 2).

Polymodal size distributions of Species 2 for each sampling period do not give clear indications of the growth of cohorts or of spawning periods. This may be due to the presence along the east coast of South Island, of several subpopulations of Species 2 which differ in age structure, spawning period and growth rate. However, it may also be due to differences in survival and growth that are caused by environmental variables and to a protracted spawning season of a single population. Previous studies have distinguished up to eight subgroups of *Nototodarus* sp. off New Zealand, based on differences in spawning time and area, and size at spawning (Kawakami *et al.*, 1972; Hamabe

TABLE 2. Growth rates of ommastrephid squids from various regions.

Species	Area	Period	Size range (cm/DML)	Growth (cm/month)	Reference
Nototodarus sp.	Tasman Bay, N. Z.	Jan 1982–Mar 1983	10–34	3.0–4.5	This study
Nototodarus sp.	New Zealand	1980–81	25	3.0	Förch (1983)
Nototodarus sp.	West Coast, N. Z.	Dec 1976–Apr 1977	18–24 24–33	2.5–4.0 1.5–3.0	Roberts (1983)
Nototodarus sp.	New Zealand	Dec–Apr	...	2.0–2.5	Tung (1978)
Ommastrephes bartrami	Japan	Summer Winter	... ...	3.0–4.0 0.5–1.0	Murata and Ishii (1977)
Todarodes sagittatus	Iceland	Summer Winter	... ...	5.0–7.5 2.0	Fridriksson (1943)
Dosidicus gigas	Gulf of California	...	...	1.0–9.0	Ehrhardt *et al.* (1983)

et al., 1974; Kawakami, 1976; Nesis, 1979). Different subpopulations or spawning groups have been distinguished for ommastrephid species off Japan, namely, *Ommastrephes bartrami* (Murata and Ishii, 1977) and *Todorodes pacificus* (Doi and Kawakami, 1979).

The marked decrease in the abundance of Species 2 juveniles with depth indicates that the squid migrate to deeper offshore waters as they mature.

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