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Observations on the Biology, Distribution and Abundance of *Trachurus declivis, Sardinops neopilchardus* and *Scomber australasicus* in the Great Australian Bight

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OBSERVATIONS ON THE BIOLOGY, DISTRIBUTION AND ABUNDANCE OF *TRACHURUS DECLIVIS, SARDINOPS NEOPILCHARDUS* AND *SCOMBER AUSTRALASICUS* IN THE GREAT AUSTRALIAN BIGHT

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Abstract

Trachurus declivis and *Scomber australasicus* have a summer spawning season in the Great Australian Bight whereas that of *Sardinops neopilchardus* extends over the summer and autumn periods. Copepods were the principal item in *S. neopilchardus* stomachs, and euphausids and mysids occurred most frequently in the stomachs of *T. declivis* and *S. australasicus*. The main feeding period for these three species was between midday and early afternoon. *S. australasicus* shows rapid initial growth, reaching sexual maturity at around 30 cm FL in three years. *T. declivis* and *S. neopilchardus* mature during their first and second year at about 17 and 12 cm FL respectively. Juvenile *T. declivis* have an inshore distribution which is probably related to the abundance of suitable sized prey. Large catches of *S. australasicus, T. declivis* and *S. neopilchardus* were made sporadically by commercial fishing ventures in the Great Australian Bight between July 1978 and March 1980. Acoustic surveys and pelagic trawling indicated little pelagic activity in the area between April and December 1980.

INTRODUCTION

The fishery potential of the Great Australian Bight has been investigated by a number of feasibility and commercial fishing ventures (Collins and Baron 1981; Maxwell 1981; Walker *et al.* 1982). None of the commercial ventures has achieved economic viability and, other than small-scale, selective operations, no commercial fishery exists in the Bight.

Of the pelagic fish resources in the Bight, the Australian 'salmon' *Arripis trutta* and the southern bluefin tuna *Thunnus maccoyii* are already fully exploited (Murphy 1979; Stanley 1980). Other pelagic species considered to be of commercial potential are blue mackerel *Scomber australasicus*, jack mackerel *Trachurus declivis* and pilchard *Sardinops neopilchardus* (Maxwell 1981). Information on the life histories and fishery potential of these species in the Bight is limited. Whitley (1946) and Blackburn (1950) reported up to 10 000 schools a day of *S. neopilchardus* from aerial surveys off southern Western Australia in autumn. Rapson (1953) estimated that some 20 000 t of *S. neopilchardus* were present in bays and inlets between Albany and Doubtful Island from an echosounder survey while Zmiyevskiy (1968) reported average demersal catch rates of 4.5 t/h in the western Bight during winter and spring. Some preliminary observations on the life history of *S. neopilchardus* off South and Western Australia were provided by Blackburn (1950). Makarov and Pashkin (1968) concluded that the general productivity of the Bight was low and that commercially profitable quantities of pelagic and demersal fish were related to seasonal localized areas of enrichment. Shuntov (1969) considered that pelagic fish were concentrated along the shelf break, the result of increased productivity in this area. He noted that these species were concentrated near the bottom in winter and spring but were more dispersed during summer and autumn. He provided limited observations on spawning, feeding, size and age composition of *T. declivis*, *S. australasicus* and *Caranx georgianus* (silver trevally). Of the commercial ventures in the Bight, British United Trawlers (BUT) made pelagic catches of up to 590 t a month (5 t/h) of *S. australasicus* and 480 t a month (750 kg/h) of *T. declivis* while a catch rate of 9 t/h of *S. neopilchardus* was achieved by the 'Denebola' during pelagic trawling (Collins and Baron 1981). *T. declivis* made up 25.9% of the catch of a Taiwanese demersal operation and this species was also an important component of a Korean demersal trawling venture (Walker *et al.* 1982; Marek 1981).

In view of the limited information on the biology and extent of the pelagic fish resource in the area, CSIRO carried out a series of research cruises during which the life histories, distribution and abundance of *T. declivis*, *S. australasicus* and *S. neopilchardus* were examined.

MATERIALS AND METHODS

Nine cruises were carried out in the Great Australian Bight between January 1979 and December 1980 (Table 1). The abundance and distribution of fish were assessed by trawling and, after April 1980, from systematic acoustic surveys. Earlier pelagic fishing and echo sounding were opportunistic and as the sounder was not run continuously no quantitative data were available.

Pelagic fishing gear consisted of an Aberdeen Delagic trawl with a 41.4-m headline, Engel 800 mm x 308 mesh, and 1800 mm x 152 mesh midwater trawls and an International Young Gadoid Pelagic Trawl. Demersal nets consisted of a 50-m headline Engel high-opening bottom trawl and a Frank and Bryce 30.5-m headline trawl. Cod-end liners of 10-40 mm mesh were usually fitted to all nets. Trawls were normally of 30 minutes duration. The distribution of all shots by month, depth and time of trawl is given in Table 2. Demersal trawl sites were chosen to give even coverage by depth across the Bight. Fish finding equipment consisted of a Simrad 27-kHz SQ sonar and 50- and 120-kHz Simrad echosounders. Trawls were monitored either by a Simrad Trawleye and Trawlwatch or by a Simrad Trawl-link.

Biological information was collected from fish taken in the trawls together with some additional materials obtained from the commercial trawler 'Denebola' in January and March 1980. Fork lengths (FL) for length-frequencies were measured to the nearest centimetre on an offset measuring board and for biological information, to the nearest millimetre on a standard board. Weights were taken to the nearest gram on a triple beam balance. Gonads were staged visually using a scale of 1-7 (Blackburn and Gartner 1954). Stomach fullness was estimated on a scale of 0 (empty) to 4 (distended). Stomachs were removed by cutting the oesophagus at a standard position and fixed in 5-10% formalin. In the laboratory, gonads were weighed and samples examined microscopically to check the visual staging. The wet weight of stomach contents was recorded, the contents identified to major taxa and the average length of each prey type measured. Otoliths were immersed in water or glycerine and examined under reflected light against a black background. Two 24-h feeding studies were carried out, one in August and another in December, at the same location in 60 m of water. Demersal trawls of 30 minutes duration were made every 2 h.

Plankton stations were located along three standard transects, one each in the western, central and eastern Bight (Fig. 1). Each transect consisted of five or six stations extending from about 30 m depth to several kilometres off the shelf edge. On some cruises not all transects were completed while on others additional stations were located outside of the standard transects (Fig. 1). Samples were taken, using a vertical drop net with a 200-µm mesh, through the water column on the shelf, and down to 240 m off the shelf. Oblique 30-minute tows with paired 333-µm mesh Bongo nets, together with a 15-minute surface net tow, were carried out to collect larval fish. The Bongos were operated down to 300 m off the shelf. Plankton from dropnets was examined under a binocular microscope at X16 magnification, identified to major taxa, and counts obtained from a Folsom splitter (technique modified after F.B. Griffiths pers. comm.). Since the objective of the plankton work was to compare plankton in fish diets with that available in the water column on a seasonal basis, it was not considered necessary to carry identifications further than to major taxa.

The general area surveyed acoustically was between Cape Pasley at 123°E and Kangaroo Island, 137°E (Table 1 and Fig. 2). Cruises followed a rectangular grid pattern approximately 48 km wide over a depth range of about 40-300 m (Fig. 2). Between 124.5° and 126°E the grid pattern was closed to 24 km wide as previous catches and sightings of pelagic fish suggested that this area might be more productive. All cruises other than SO3/80 which followed a W-shaped search pattern, were similar to SO5/81 illustrated in Figure 2. Any variations were due to weather conditions or mechanical problems with the ship and the individual acoustic tracks are shown on cruise summaries which can be obtained from the Librarian, CSIRO Marine Laboratories. The 50-kHz echosounder was monitored throughout the 24-h period while on the acoustic survey. Sonar searches were carried out on a less regular basis. Where possible the echosounder settings were held constant throughout the survey (bandwidth 3 kHz, pulse duration 0.6 ms, recorder gain 4-5 on 10 kW external transmission). Pelagic fish marks were classified, based on their size and shape, into either individual schools or continuous layers (Cushing 1957). A transparent overlay printed with a series of circles and rectangles of known area was then placed over the marks on the echosounder paper. An individual school was 'fitted' into the circle and a layer into the rectangle estimated to contain the particular mark. The number of marks of different areas occurring during each hourly period was recorded on a log sheet.

BIOLOGY OF FISH

Trachurus declivis

Length-frequency distributions show that *T. declivis* size increases with increasing bottom depth (Fig. 3) although for depths of less than 50 m or more than 200 m the sample numbers are small. Monthly length-frequency distributions are given in Figure 4 and show a general absence of fish larger than 25 cm FL.

The presence of stage 3 (or later) gonads was taken to indicate sexually mature fish. Using this criterion, it is estimated that *T. declivis* of both sexes attain maturity at lengths of 16-18 cm FL. The distribution of gonad stages by month indicates summer spawning (Fig. 5).

Of 1277 *T. declivis* stomachs examined, 384 (30%) were empty. The prey items are compared by season in Figure 6. These data show that crustaceans, in particular euphausids, mysids and copepods, are the major prey items in *T. declivis* stomachs from the Bight. Some notable differences were apparent in the frequency of occurrence of particular prey items on certain cruises. Euphausids and mysids were found less frequently in the stomachs examined from SO6/80 (spring) than in stomachs examined from SO5/81 (summer) or SO3/81 (winter), whereas the reverse was true for copepods, amphipods and pteropods. Foraminiferans, zoea and megalopa larvae were more numerous in winter stomach samples whereas natantians and siphonophores were more numerous in summer stomach samples. Ostracods were found less frequently in stomachs from the summer cruise.

The prey taken by *T. declivis* was between 1 and 18 mm in length. Fish of less than 20 cm FL tended to contain smaller items (1-4 mm), while fish over 25 cm FL took more prey over 10 mm (Fig. 7). With the exception of fish over 25 cm FL, in which the stomachs contained few copepods, natantians or mysids, all other sizes of *T. declivis* examined appeared to feed on the same type of prey (major taxa).

To determine at what time *T. declivis* feed, two 24-h studies were carried out. Both studies involved fish of 14-23 cm FL (69% between 15 and 17 cm in August and 99% between 17 and 19 cm in December). In August the proportion of fish with empty stomachs was highest between 0200 and 0600 hr (although the data were limited), after which the stomach contents increased, reaching a peak between 1400 and 1600 hr (Fig. 8). Subsequently the amount of food present in the stomachs declined through the evening and night. This indicated that the main feeding period was around midday. In December the amount of food present in the stomachs was fairly constant at all times with the exception of the period from 0600 to 1000 hr, when the majority of fish had empty stomachs. No clear feeding period was evident although the data suggested increased feeding activity around midday. An additional 24-h study was attempted in December, but had to be aborted due to lack of fish. However, 136 fish were collected between 0400 and 1800 hr and these showed a high incidence of empty stomachs between 0400 and 0600 hr. From 0900 to 1800 hr only one fish had an empty stomach and the majority contained considerable quantities of food ranging from 0.4 to 2.0% of body weight.

Otoliths were used for age determination of *T. declivis* from the Bight. Of 736 otoliths examined 11% were unreadable. This compared with only 2% unreadable of 1000 *T. declivis* otoliths examined from south-east Australia, where the hyaline and opaque zones were more distinct (Stevens and Hausfeld 1982). The age range of *T. declivis* caught in the Bight was very restricted, with 51% of the fish being aged 0 or 1 year. Rings on the otoliths were assumed to be annual on the basis of studies carried out off south-east Australia (Stevens and Hausfeld 1982). No distinct difference was found between the growth rates of males or females (Table 3). Table 4 compares mean fish lengths-at-age for *T. declivis* from the Bight and south-east Australia.

Sardinops neopilchardus

Very few *S. neopilchardus* were caught over water depths greater than 100 m in either demersal or pelagic trawls during this program. The size distribution of specimens taken from all depth categories was similar and monthly length-frequency distributions were essentially unimodal (Fig. 9).

The gonads of 984 *S. neopilchardus* were examined, of which 3.8% were juveniles, 58.4% females and 37.8% males. Sexual maturity in both sexes is assumed to be attained at about 12 cm FL, based on the size of the smallest fish having stage 3 (or later) gonads. The distribution of gonad stages through the year indicates spawning in summer and autumn (Fig. 10). The large numbers of clupeoid larvae (the majority of which were almost certainly *S. neopilchardus*) collected only in plankton samples taken during April and May provide confirmation of the spawning period. These clupeoid larvae were taken mainly over bottom depths of 50-150 m.

Of 964 *S. neopilchardus* stomachs examined, 6.2% were empty. Crustaceans, and in particular copepods, were the commonest items in the diet. Unidentified material made up a large proportion of all *S. neopilchardus* stomach contents (Fig. 11*c*). Copepods were more abundant in winter and autumn (30-58% by occurrence) than at other times of the year (10-17%). Fish and invertebrate eggs comprised between 16-33% by occurrence except during the autumn period when numbers were very low (1.3-1.6%). Other notable variations were the relatively high quantities of euphausids and mysids during autumn 1980 (27%) and of tunicates in winter (12%). These groups usually represented less than 3% of stomach contents, as did euphausids and mysids during autumn 1979. A 24-h feeding study was carried out in August 1980, but data were limited and few fish were recorded with empty stomachs and none with full stomachs. The quantity of food in the stomachs increased from around 0800 hr to a maximum between 1400 and 1800 hr, after which it declined again until 0800 hr. This suggests a period of increased feeding around midday.

Otoliths from 220 *S. neopilchardus* were used in an attempt to age the fish. However, considerable difficulty was experienced in interpreting the opaque and hyaline zones and the results show a large variation in fish length for a given age. Due to the small sample sizes and limited length-frequency distributions it was not possible to validate the time scale of the rings. There was no detectable difference in length-at-age between the sexes. The length-at-age data are shown in Table 5.

Scomber australasicus

Most *S. australasicus* were taken at 50-150 m depth. No relationship between fish length and depth was found over this range. Although catches of this species were made over an eight-month period, mature fish were obtained essentially in only two months. Based on gonad condition it is estimated that sexual maturity in both sexes is reached at about 28 cm FL. Almost all fish caught in February and September were immature. The majority of gonads from fish taken in January were in stage 3-4, while those in March were in stage 4-5. Since *S. australasicus* is a serial spawner (Jones 1983), this indicates that spawning probably occurs around the March period. Small numbers of *S. australasicus* of 1-3 cm FL were obtained from tows with the Bongo and IYGPT net in May. No fish of this size were taken at other times of the year, providing further support for a summer spawning period.

The stomachs of 536 *S. australasicus* were examined, of which 64.9% contained food. Crustaceans, in particular euphausids and mysids, were the most common items in the diet, with siphonophores, fish, salps, natantians and brachyurans also of importance (Fig. 11*b*). Siphonophores occurred in the stomachs mainly in spring and summer, and euphausids, mysids and ostracods in summer.

To determine periods of feeding activity in *S. australasicus* the total sample of fish was combined since insufficient numbers were available from the specific 24-h feeding studies. The greatest number of empty, or nearly empty stomachs, occurred between 0600 and 0700 hr while stomachs containing the greatest amount of food were found between 1500 and 1600 hr. This suggests an increase in feeding activity during the early afternoon.

Otoliths from 367 *S. australasicus* were available for ageing, of which 14% were unreadable. Owing to the lack of seasonal coverage and the paucity of length-frequency data it was not possible to determine the time at which the otolith rings were laid down. Assuming the rings to be annual, on the basis of studies on other species of *Scomber* (Baird 1977), the initial growth rate is rapid with fish reaching sexual maturity at about 30 cm FL in three years (Table 6). No difference in growth rate between the sexes was apparent. The largest specimen aged during this study was 44 cm FL and was at least 8 years old.

Other Species

Yellowtail, *Trachurus novaezelandiae*, were caught in depths down to 140 m and were often taken together with *T. declivis*. Where the two species occurred together the modal length of *T. novaezelandiae* was always slightly larger than that of *T. declivis*. Stomach content analysis of 240 fish showed that crustaceans, notably copepods, euphausids and mysids, were the major items in the diet (Fig. 11*a*).

Length-frequency distributions of *Caranx georgianus* showed an increase in size with depth over the range (43-150 m) in which this species was taken (Fig. 12).

CATCH RATES

Catch rates of *Trachurus* spp., *S. neopilchardus*, *S. australasicus* and *C. georgianus* from pelagic and demersal trawls in this program are given in Table 7. *T. declivis* was not caught in any of the 84 pelagic trawls but occurred in 95 (36.8%) of the 258 demersal shots. The average catch rate was 11.2 kg/h from all trawls or 30.4 kg/h from hauls in which this species was present. There was no apparent difference in the catch rate of *T. declivis* by season or, time of trawl (Table 8), or depth strata or gear type (Frank and Bryce or Engel demersal net). *S. neopilchardus* occurred in 25 of the 84 pelagic shots (29.8%) and 36 of the 258 demersal trawls (14.0%). The average catch rates for this species from all pelagic and demersal trawls were 7.4 and 0.5 kg/h respectively, or 24.9 and 3.0 kg/h respectively from shots in which *S. neopilchardus* was present. *S. australasicus* was taken in only 4.8% of pelagic shots and 12.0% of demersal trawls. Catch rates were low, averaging 0.03 kg/h from all pelagic and 0.2 kg/h from all demersal trawls. Catch rates of *T. novaezelandiae* and *C. georgianus* were 1.0 and 1.4 kg/h respectively from demersal trawls (Table 7).

ACOUSTIC SURVEYS

On cruise 045 (Table 1) pelagic marks were extensive in the eastern Bight in water shallower than 50 m. Five night-shots were made with the Aberdeen Delagic trawl on very dense echosounder traces. These all resulted in small catches of *S. neopilchardus* (11-16 cm FL), the largest haul being 41 kg from a one-hour tow. On all planned acoustic cruises very few sounder marks were observed and at no time were sufficient fish caught from aimed shots to calibrate the marks against the quantity of fish. The number of marks recorded, the distance travelled over the acoustic track and the number of marks per kilometre are shown by cruise and season in Table 9. A gross approximation of the quantities of fish involved was calculated based on Rapson (1953) and Smith (1970). The width of a fish school represented by an individual mark can be calculated from the ship's speed and the paper speed of the echosounder. The height of the school can be estimated from the height of the mark and the scale range of the sounder. Assuming that fish schools are rectangular, the length of the school was taken to be equal to the largest of the previous two dimensions, enabling the school volume to be calculated. All marks were standardized to a ship's speed of 10 knots and to a depth range of 0-125 m. If fish weight and packing density in the school are known the total mass of fish can be estimated. An average fish weight of 100 g was calculated from the mean size of *Trachurus* spp., *S. australasicus* and *S. neopilchardus* taken in the trawls. Estimates of pelagic fish density vary widely (Runnstom 1942; Rapson 1953; Smith 1970). Using a fish density of 1 fish/m^3, the school weights corresponding to different sized marks were estimated. The percentage of marks representing schools of less than 225 kg are shown in Table 9. The acoustic results from all cruises indicate only small quantities of pelagic fish. The average number of marks per kilometre was 0.2 and 84% of marks represented less than 225 kg.

DISCUSSION

Biology of Fish

Seasonal variation in gonad condition indicated summer spawning for *T. declivis* and *S. australasicus* while the spawning season for *S. neopilchardus* extended over the summer and autumn period. These observations are in general agreement with those of Blackburn (1950) and Shuntov (1969).

Ageing studies of pelagic fish from the Bight were affected by small seasonal samples and the restricted length range of fish captured. A growth curve for *T. declivis* was produced on the assumption, made on the basis of studies carried out off south-east Australia (Stevens and Hausfeld 1982), that the otolith rings were annual. Slight differences in growth curves between the two areas (Tables 3 and 4) may reflect sampling problems rather than a real variation in growth rates. Shuntov (1969) reported similar age-at-length values to ours, for *T. declivis* from the Bight, but did not say how they were obtained. Ageing of *S. neopilchardus* and *S. australasicus* produced only preliminary growth estimates as the time scale of the otolith rings could not be determined. Length-at-age values for *S. neopilchardus* (assuming the rings to be annual) suggest a faster growth rate than reported by Blackburn (1950) from scale readings of Victorian fish. However, Blackburn (1950) noted that *S. neopilchardus* from southern Western Australia may have a faster growth rate than Victorian specimens and he gave some length-at-age values similar to those reported here. No age estimates for *S. australasicus* have previously been reported from Australian waters. Values obtained in this study are in agreement with provisional estimates from New Zealand (Jones 1983).

Shuntov (1969) recorded that *T. declivis* and *S. australasicus* feed mainly during daylight hours with feeding rates often increasing around midday. *T. declivis* were also shown to feed mainly near midday in this study, whereas results for *S. australasicus* indicated the main feeding period to be early afternoon. Euphausids and mysids were the most frequent prey items in *T. declivis* stomachs. Euphausids were also an important item in the diet of *T. declivis* from south-east Australia (Maxwell 1979). However, these crustaceans were caught only in small numbers from dropnets, suggesting either that they avoided the net or that *T. declivis* were selectively feeding on them. Copepods were the most abundant group from plankton samples and were also important in the diet of *T. declivis*. Copepods occurred more frequently in fish less than 20 cm FL while fish of over 25 cm took less copepods and more euphausids. Copepods were most abundant inshore, as was also noted by Shuntov (1969). The inshore distribution of juvenile *T. declivis* (Fig. 3) thus appears to be related to the abundance of small prey items, such as copepods, on which they feed (Fig. 7). Seasonal variations in the abundance of prey items from stomachs of all fish species examined generally reflected their availability in the plankton (Tables 10, 11, Fig. 13). Copepods were the most abundant taxon in absolute numbers from dropnet samples, being most numerous in spring and, to a lesser extent, in autumn. Lowest numbers were found in winter, although their abundance relative to other groups was high at this time (Table 11). More zoeas and natantians occurred in the diet of *T. declivis* when their numbers were low in dropnets, while the reverse was true for ostracods.

Inshore waters of the Bight out to about 50 m are inhabited by *T. declivis* of 10-20 cm FL in the 0+ to 2 year age class while only sexually mature fish above 24 cm FL and age group 3-7 are found near the shelf break (Fig. 3, Table 4). Similarly *C. georgianus* of 10-20 cm FL are restricted to inshore waters, with individuals of 30-50 cm FL found only over bottom depths in excess of 100 m (Fig. 12). This size-depth relationship was also reported for *S. australasicus* by Shuntov (1969) but was not evident for either this species or *S. neopilchardus* in this study. The length-frequency distributions for *S. neopilchardus* were unimodal in samples from January to September, consisting mainly of age group 2 fish (modal length 14 cm FL) while the December sample was bimodal, comprising fish of age groups 0+ and 4 (Fig. 9). Shuntov (1969) suggested that the inshore distribution of juvenile *T. declivis*, *S. australasicus* and *C. georgianus* was related to the abundance of suitably sized prey. Results obtained for *T. declivis* in this program support his view.

Pelagic Fish Resource

No reliable stock or yield estimates are available for *T. declivis*, *S. australasicus* or *S. neopilchardus* from the Bight. Makarov and Pashkin (1968) gave a stock estimate of 25 000 t for *S. neopilchardus* but this figure was extrapolated for the entire Bight from Rapson's (1953) echo sounding survey which was restricted to bays and inlets between Esperance and Albany. These authors also gave a yield estimate for *T. declivis* from the Bight of 9000 t. However, this figure was derived from Hynd and Robins' (1967) calculations off Tasmania and catch rates cannot be assumed to be the same in the two areas.

Commercial and exploratory pelagic fishing operations have produced varying results. Between November 1977 and May 1979 three BUT vessels caught 1196 t of *S. australasicus*, 873 t of *T. declivis* and 16 t of *S. neopilchardus* from pelagic trawls. *S. australasicus* was taken in a nine-month period at an average catch rate of 840 kg/h with largest catches taken in July, August and November. Fishing effort was lower in the other eight months and no fish of this species were caught. *T. declivis* and *S. neopilchardus* were caught in a twelve- and three-month period respectively, at catch rates of 600 and 20 kg/h. *T. declivis* catches were highest from September to November and in January while *S. neopilchardus* was taken only in April, August and October. However, the 'Denebola' made large catches of *S. neopilchardus*, averaging 595 kg/h from 51 trawls down to 200 m, between January and March 1980, but took only small quantities of *S. australasicus* (21.7 kg/h) and *T. declivis* (3.8 kg/h).

Catches of these three species from demersal trawls were small; average catch rates from the BUT vessels, 'Denebola' and from a Taiwanese and a Korean feasibility fishing venture varied from 0 to 31 kg/h (Collins and Baron 1981; Marek 1981; Walker *et al.* 1982). The only exception was *T. declivis* which made up 25.9% of the catch, and was taken at 103 kg/h by the Taiwanese venture (Marek 1981). The average demersal catch rate achieved in this program was 219.4 kg/h (range 96.1-373 kg/h) compared to 74 and 304 kg/h achieved by 'Denebola' and the BUT vessels respectively. Catch rates of *T. declivis*, *S. australasicus* and *S. neopilchardus* were low but were of the same order as those obtained by commercial and feasability fishing vessels. However, pelagic catches never approached those achieved at times by commercial vessels. *S. neopilchardus* was the only species taken with any regularity, occurring in about 30% of shots, but the average catch rate was only 7.4 kg/h.

On the few occasions when aimed pelagic shots were made on dense echosounder marks in this study, catch rates were low. This suggests that the efficiency of pelagic fishing may have been low. It is also possible that local concentrations of fish may have been missed due to the broad coverage of the acoustic track which did not always allow concentrated searching in particular areas. Although large pelagic catches were made sporadically by commercial vessels, the species and time were variable, suggesting a patchy distribution of fish. The possibility of pelagic fish concentrating around features on the bottom, such as pinnacles, or other areas of local enrichment has been noted by Makarov and

Pashkin (1968) and Shuntov (1969). The fact that sonar was not used continuously in this study would also contribute to some fish schools not in the direct track of the ship being missed.

Few pelagic marks were observed during the acoustic surveys and little information could be obtained on the weight of fish in these schools in the absence of any calibration between echosounder marks and catch rates. Theoretical calculations of school size are at best a gross approximation. Assumptions on school shape can lead to non-linear errors which increase with size of the mark. Values for packing density of pelagic fish in a school vary from less than 1 to more than 10 fish/m^3 (Rapson 1953; Smith 1970) which could alter calculated school weights by a factor of ten.

Given the limitations of this program neither the catch rates nor acoustic surveys indicated large concentrations of pelagic fish. The irregular catches made by other vessels supports the view of Natarov and Pashkin (1968) and Shuntov (1969) that the abundance of pelagic fish in the Bight is subject to considerable fluctuations. It seems most likely that these fluctuations reflect changes in the spatial distribution of the fish. This may be associated with differences in the timing and duration of enrichment events in the Bight (K. Kitani, personal communication) as the general productivity of the area is low (Rochford 1962; Motoda *et al.* 1978). However, *Scomber* species elsewhere are noted for their large changes in annual yield. This has been related to irregular recruitment, as their larvae are susceptible to adverse environmental conditions (Jones 1983).

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Table 1. Great Australian Bight cruises by CSIRO vessels between January 1979 and December 1981

Vessel and Cruise		Dates	Area	Procedures
'Courageous'	045	25. 1.79-13. 2.79	130-134° E, 32-35° S	Demersal and pelagic trawling
"	046	22. 2.79-14. 3.79	124-132° E, 33-34.5° S	Demersal trawling
"	047	22. 3.79-10. 4.79	124-129° E, 32-34.5° S	Demersal and pelagic trawling
"	048	12. 4.79-17. 4.79	118° E, 35° S	Pelagic trawling and trolling
'Soela'	SO1/80	10. 1.80-24. 1.80	124-136° E, 32-35° S	Demersal and pelagic trawling
"	SO3/80	26. 4.80-18. 5.80	123-137° E, 32-37° S	Demersal and pelagic trawling and acoustic survey
"	SO6/80	1. 9.80-23. 9.80	123-128° E, 32.5-35° S	" "
"	SO3/81	23. 7.81-22. 8.81	123-137° E, 32-36° S	" "
"	SO5/81	18.11.81-15.12.81	123-137° E, 32-36° S	" "

Table 2. Total number of trawls* made in the Bight by month, depth category and time period. (Unbracketed figures-demersal, bracketed-pelagic)

	Day			Night		
Month	0-100 m	101-200 m	>200 m	0-100 m	101-200 m	>200 m
Jan.	15	9	(1)	6 (2)		1
Feb.	20	6	4	(3)		
March	20 (1)	17	20	(1)		
April	12 (2)	1		(4)		(1)
May	(6)	2 (2)	(2)	(7)	3 (4)	(2)
June						
July	5 (3)	2 (3)	2	5	2	(1)
Aug.	11 (5)	3	4	14 (3)	6	3 (2)
Sept.	1 (2)	2 (2)		1	4	
Oct.						
Nov.	3 (3)	1		2 (2)		(2)
Dec.	20 (2)	12 (3)	3 (2)	12 (3)	3 (2)	1 (1)

*Excluding 5 pelagic trawls for which full data are not available.

Table 3. Von Bertalanffy growth constants for *T. declivis* from the Bight and south-east Australia. (S.E. Standard error)

Area	Sample size	L_∞(S.E.) (cm)	K (S.E.)	t_0(S.E.) (yr)
South-east Australia*	1000	46.4 (0.8)	0.20 (0.01)	-0.87 (0.08)
Bight (total)	652	41.7 (1.9)	0.19 (0.02)	-2.08 (0.15)
Bight (male)	266	43.8 (3.9)	0.16 (0.03)	-2.53 (0.37)
Bight (female)	231	42.3 (3.4)	0.17 (0.03)	-2.54 (0.36)

*Values from Stevens and Hausfeld (1982).

Table 4. Observed mean length-at-age for *Trachurus declivis* from the Bight and south-east Australia (SEA)

Age (yr)	Fork length (cm)		Standard deviation		Sample size	
	Bight	SEA	Bight	SEA	Bight	SEA
0	14.2	9.31	2.2	3.6	64	24
1	17.6	14.5	2.4	3.7	270	44
2	22.8	19.1	3.0	3.5	167	130
3	25.5	25.2	2.3	3.9	57	145
4	28.0	28.5	2.7	3.6	37	195
5	30.3	33.3	2.0	2.2	26	139
6	31.8	35.0	2.0	2.5	19	137
7	34.3	36.5	1.7	3.0	7	92
8	34.9	37.9	0.4	1.8	3	18
9	38.8	39.5		2.5	2	26

Table 5. Observed mean length-at-age for *S. neopilchardus* from the Bight. (FL Fork length; S.D. Standard deviation)

Age (yr)	FL (cm)	S.D.	Sample size
0	9.7	1.5	6
1	12.6	1.4	49
2	14.3	1.2	81
3	15.4	1.5	52
4	16.0	1.0	23
5	16.4	1.9	6
6	15.8	1.0	3

Table 6. Observed mean length-at-age for *S. australasicus* from the Bight (von Bertalanffy growth parameters and standard errors: L_∞= 44.1 cm (1.2), K = 0.24 (0.02), t_0 = -1.79 yr (0.16))

Age (yr)	FL (cm)	S.D.	Sample size
1	20.9	2.2	40
2	25.4	2.4	53
3	29.4	2.8	54
4	33.6	2.4	83
5	35.7	1.5	52
6	36.8	1.4	33
7	37.9	0.8	14
8	38.0	1.0	6
9	39.8		2

Table 7. Catch data for five species of pelagic fish from the Bight between January 1979 and December 1981

	T. declivis		*T. novaezelandiae*		*S. neopilchardus*		*S. australasicus*		*C. georgianus*	
	Pelg.	Dem.	Pelg.	Dem.	Pelg.	Dem.	Pelg.	Dem.	Pelg.	Dem.
Trawls in which occurred	0	95	1	46	25	36	4	31	0	49
Largest catch (kg/h)	0	1068	54	56	204	34	1.3	14	0	50
Average catch rate (kg/h)	0	11.2 (30.4)	0.3 (54)	1.0 (5.3)	7.4 (24.9)	0.5 (3.0)	0.03 (0.7)	0.2 (1.5)	0	1.4 (7.2)
Total catch (kg)	0	1504.9	27	132.4	307.9	61.6	2.6	33.6	0	214.8

Total number of trawls: 84 pelagic, 258 demersal. Figures in brackets are for trawls in which that species occurred.

Table 8. Number and percentage of trawls resulting in a given catch category (10- and 100-kg size classes) by time and season (winter samples July-September, summer November-March) for *T. declives* from the Bight

Catch Category (kg)	Night No.	Night %	Day No.	Day %	Winter No.	Winter %	Summer No.	Summer %
0	84	69.4	79	57.7	28	43.1	117	66.5
0.1- 9.9	21	17.4	40	29.2	21	32.3	40	22.7
10- 19.9	5	4.1	6	4.4	7	10.8	4	2.3
20- 29.9	2	1.7	1	0.7			3	1.7
30- 39.9	3	2.5	4	2.9	2	3.1	5	2.8
40- 49.9	1	0.8	3	2.2	1	1.5	3	1.7
50- 59.9	1	0.8	1	0.7	1	1.5	2	1.1
60- 69.9								
70- 79.9	1	0.8			1	1.5		
80- 89.9								
90- 99.9								
100- 199.9	1	0.8	2	1.5	2	3.1	1	0.6
200- 299.9			1	0.7			1	0.6
300- 399.9	1	0.8			1	1.5		
400- 499.9								
500- 599.9								
600- 699.9								
700- 799.9								
800- 899.9								
900- 999.9								
≥1000	1	0.8			1	1.5		

Table 9. The number of sounder marks per kilometre steamed and the percentage of marks representing school weights of less than 225 kg by cruise

Cruise	Season	Distance steamed (km)	No. of marks	Marks per km	% less than 225 kg
SO3/80	Autumn	4088	1511	0.4	93
SO3/81	Winter	4368	1506	0.3	81
SO6/80	Spring	2428	137	0.1	62
SO5/81	Summer	4456	392	0.1	66

Table 10. Percentage of stations containing plankton taxa by season (* number of stations - for locations see Fig. 1)

	Autumn	Winter	Spring	Summer	Combined
Plankton taxa	31*	18*	12*	18*	79*
Copepods	100	100	100	100	100
Invertebrate eggs	94	89	100	100	95
Phytoplankton[†]	100	56	100	100	90
Tunicates	90	78	92	83	87
Chaetognaths	90	78	92	83	86
Salps	90	50	92	94	82
Ostracods	61	33	50	100	62
Zoeas	52	28	83	72	56
Cladocerans	94	0	42	50	54
Gastropods	71	0	83	50	52
Echinoderm larvae	55	17	67	56	48
Bivalves	61	28	42	44	47
Siphonophores	29	33	67	72	46
Pteropods	71	6	50	22	42
Natantians	52	72	17	6	41
Mysid/Euph. larvae	55	0	50	44	39
Nauplii	39	0	42	61	35
Medusas	23	6	58	67	34
Polychaetes	32	28	33	28	30
Amphipods	55	0	8	28	29
Euphausids	35	11	17	22	24
Invert. egg clusters	19	17	8	17	16
Mysids	16	17	17	11	15
Megalopas	16	6	8	28	15
Isopods	6	0	33	17	11
Ctenophores	19	0	0	11	10
Veligers	10	0	0	17	8
Stomatopods	0	22	0	6	6

[†] It was estimated that less than 5% of available phytoplankton was retained by the 200-µm mesh, and that the dinoflagellate *Ceratium* comprised the majority of the retained component (G.M. Hallegraeff pers. comm.)

Table 11. Relative abundance (percentage by total number) of major plankton taxa by season (taxa which did not comprise at least 1% in any one season are combined)

Plankton taxa	Spring	Summer	Autumn	Winter
Copepods	73.2	36.3	58.4	94.0
Phytoplankton*	15.7	37.3	17.2	0.9
Tunicates	2.6	1.6	1.7	1.1
Invert. eggs	2.4	8.4	2.4	0.7
Nauplii	1.8	0.5	0.1	0
Cladocerans	0.1	1.2	11.1	0
Salps	0.9	5.9	2.4	0.2
Chaetognaths	0.8	0.7	2.2	0.3
Ostracods	0.2	4.9	0.7	0.6
Echinoderm larvae	0.5	1.1	0.5	0.1
Remaining taxa (combined)	1.8	2.1	3.3	2.1

*While the phytoplankton component retained by the 200-μm mesh dropnet was relatively abundant by number, it comprised an insignificant component of the biomass, owing to the small size of the individual cells.

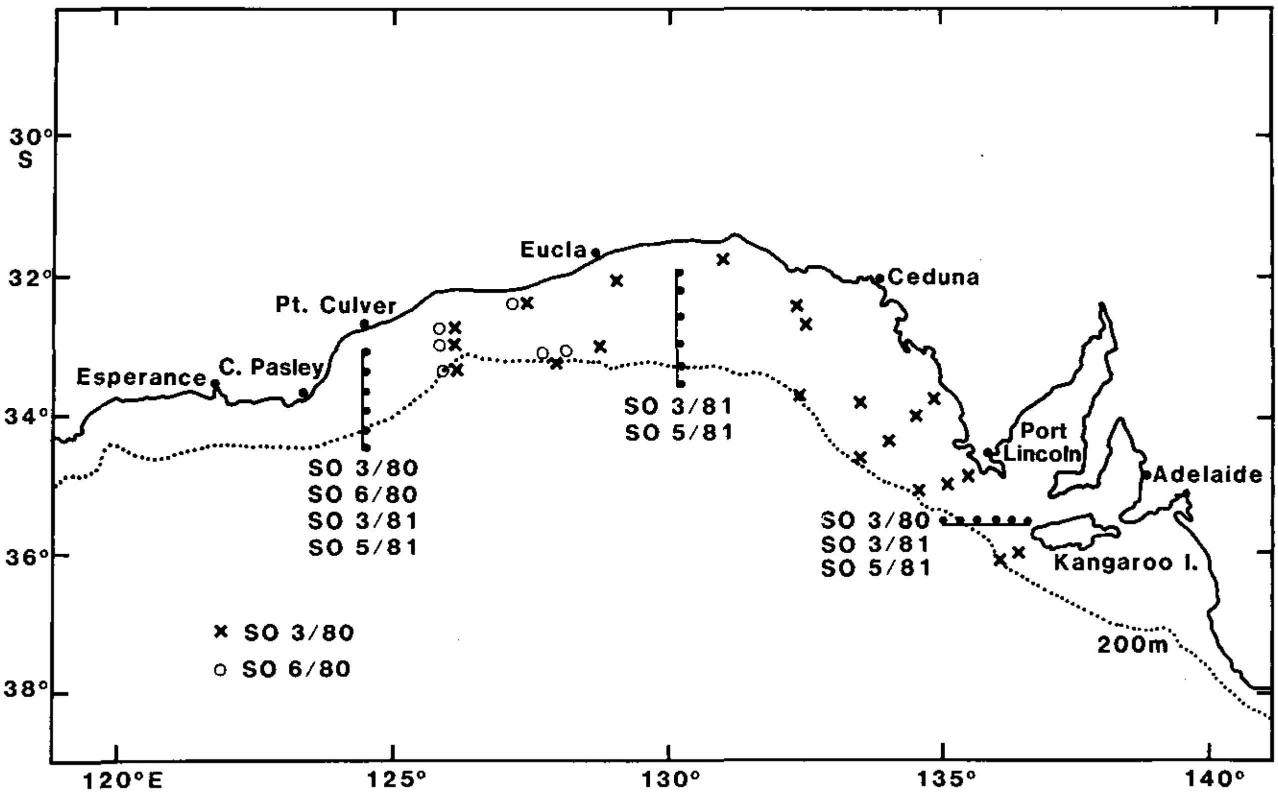

Fig. 1. Plankton stations occupied during four cruises showing standard transects and additional stations.

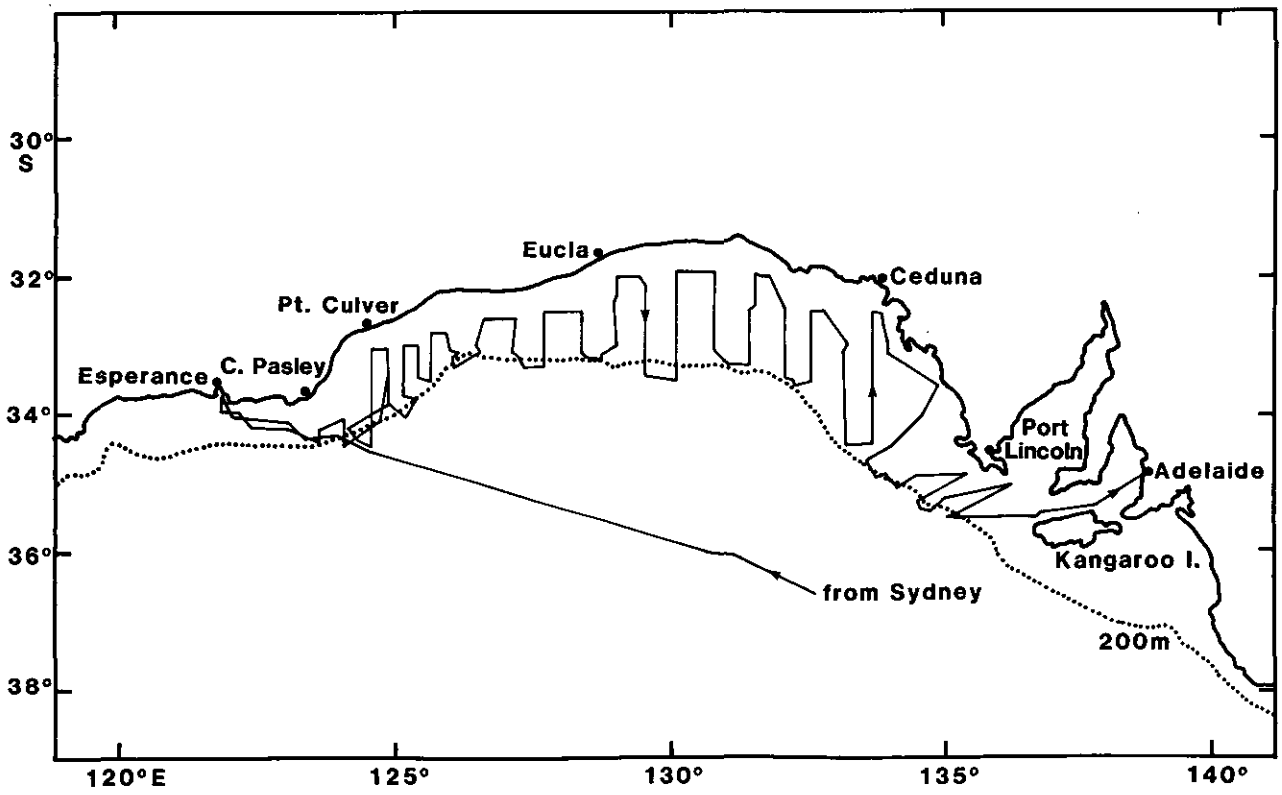

Fig. 2. Cruise track of SO5/81 in the Bight.

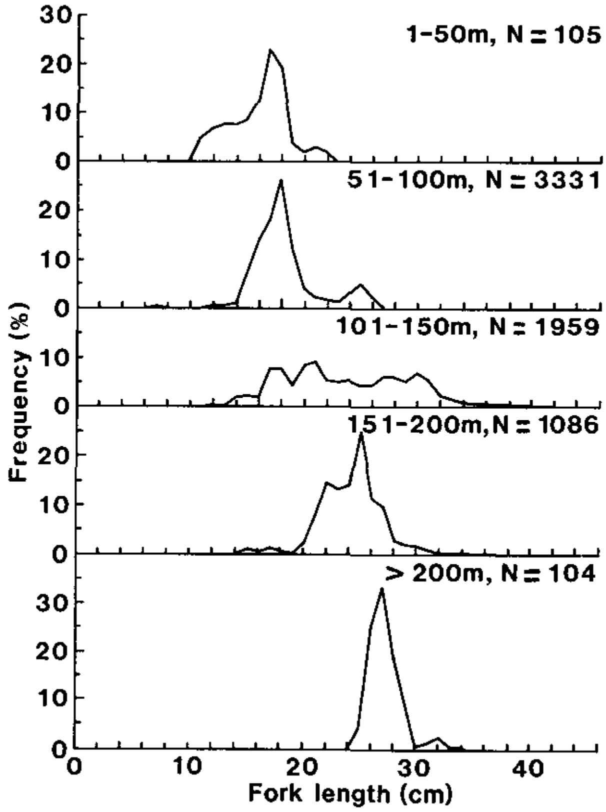

Fig. 3. The relationship between fish length and bottom depth for *T. declivis* from the Bight.

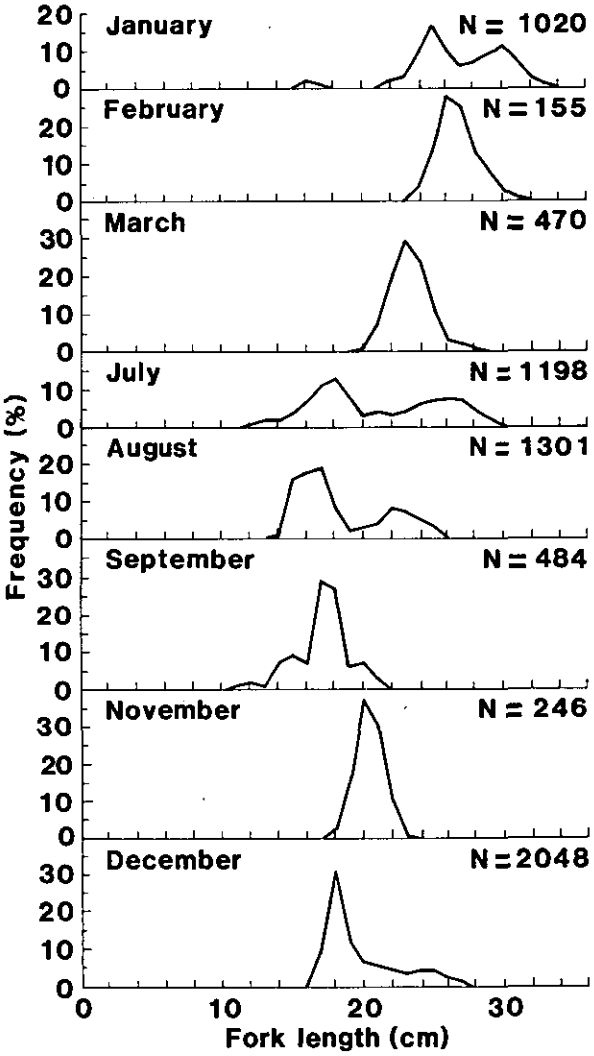

Fig. 4. Monthly length-frequency distributions for *T. declivis* from the Bight.

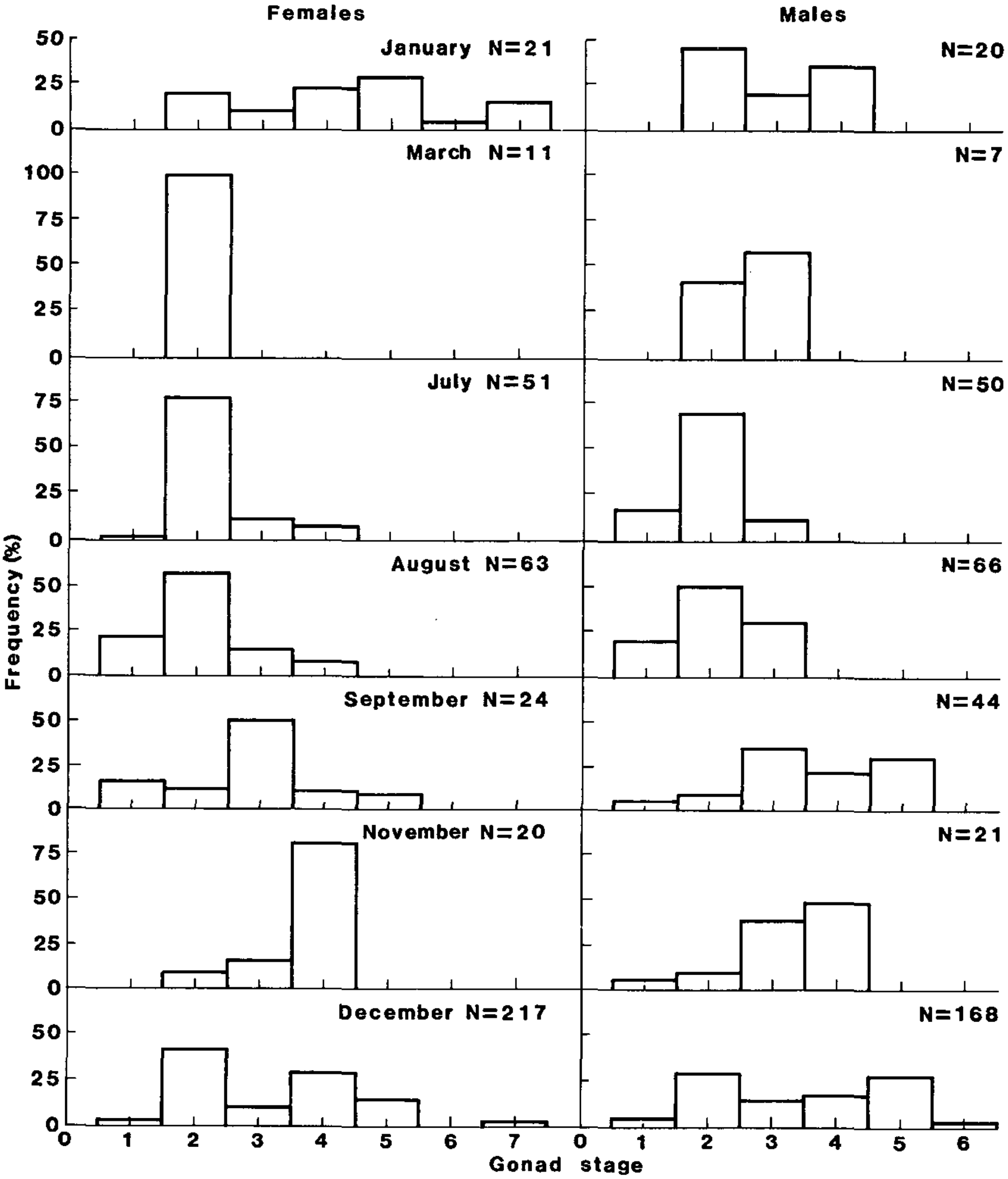

Fig. 5. The distribution of gonad stage by month for mature *T. declivis* from the Bight.

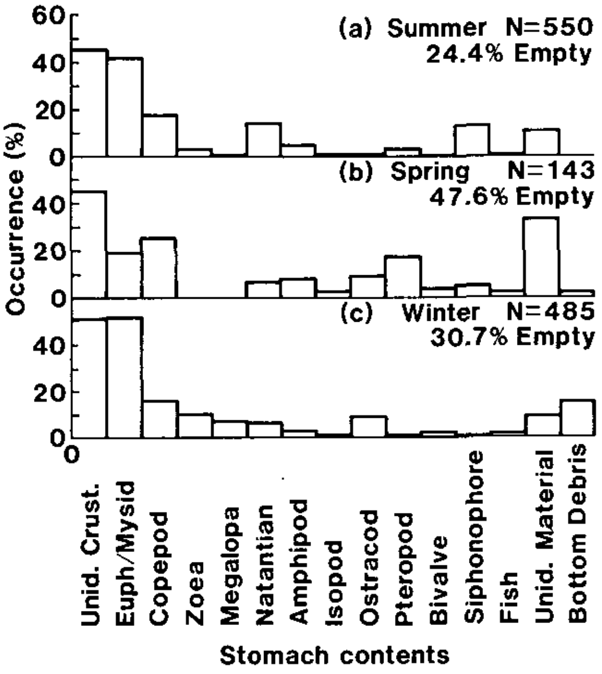

Fig. 6. Stomach contents of *T. declivis* from the Bight by season: *a*) summer (November/December) *b*) spring (September) and *c*) winter (July/August).

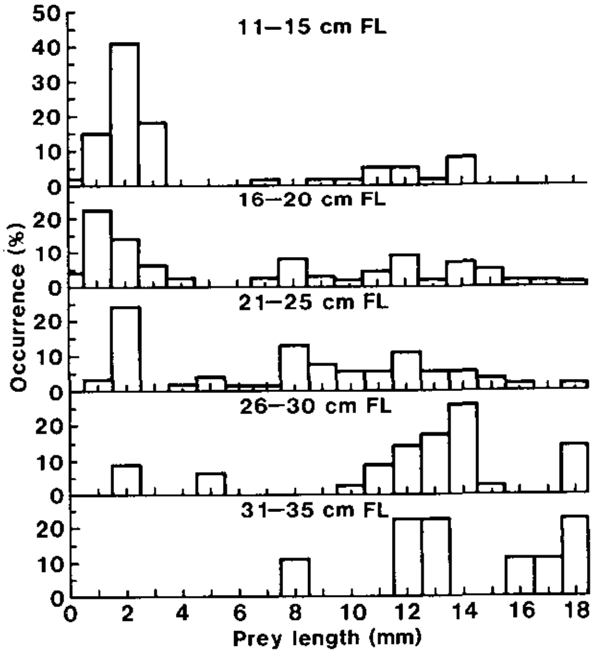

Fig. 7. The distribution of prey size with fish length in *T. declivis* from the Bight.

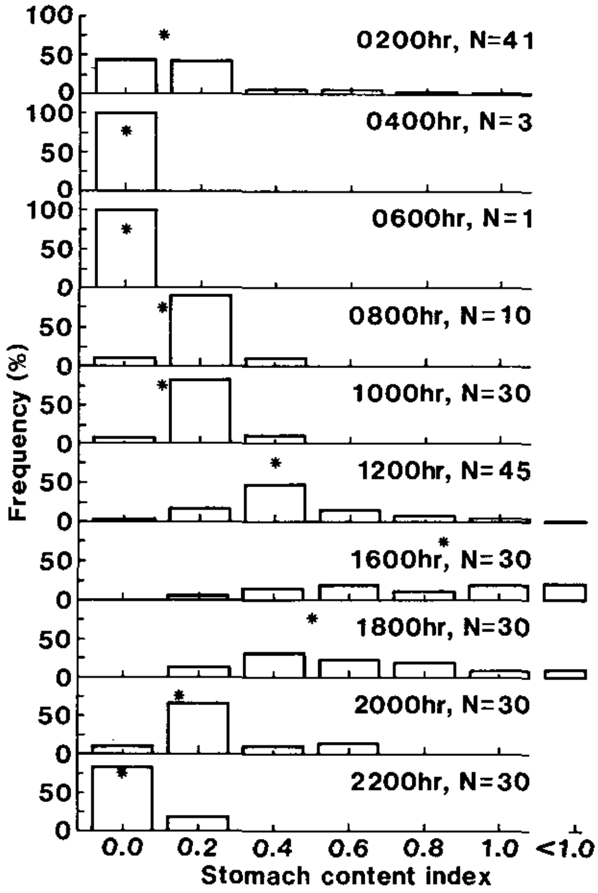

Fig. 8. Stomach content index (stomach content weight as a percentage of body weight) at two hourly intervals through the 24-h cycle for *T. declivis* from the Bight (* = mean stomach content index).

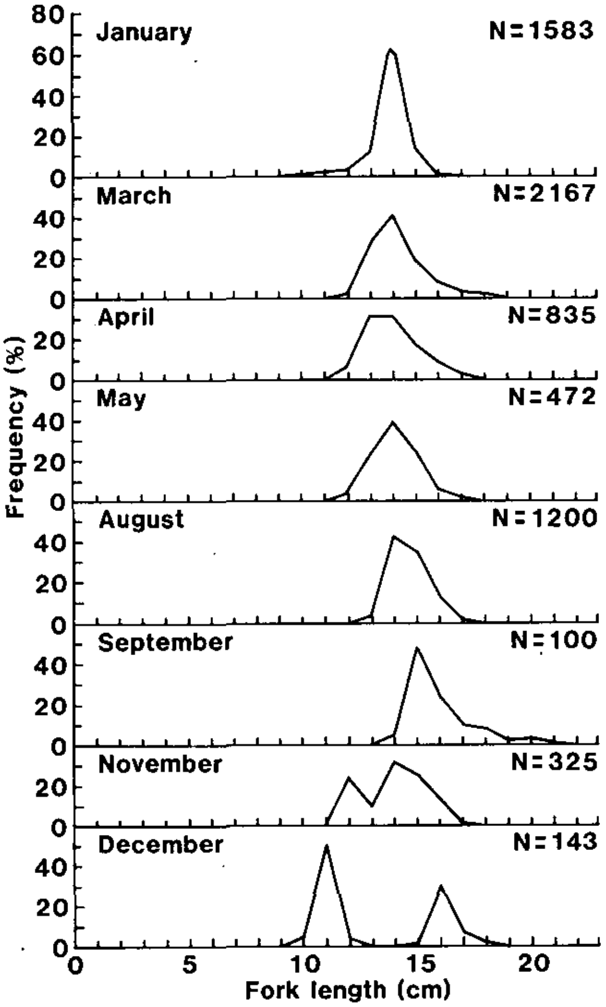

Fig. 9. Monthly length-frequency distributions for *S. neopilchardus* from the Bight.

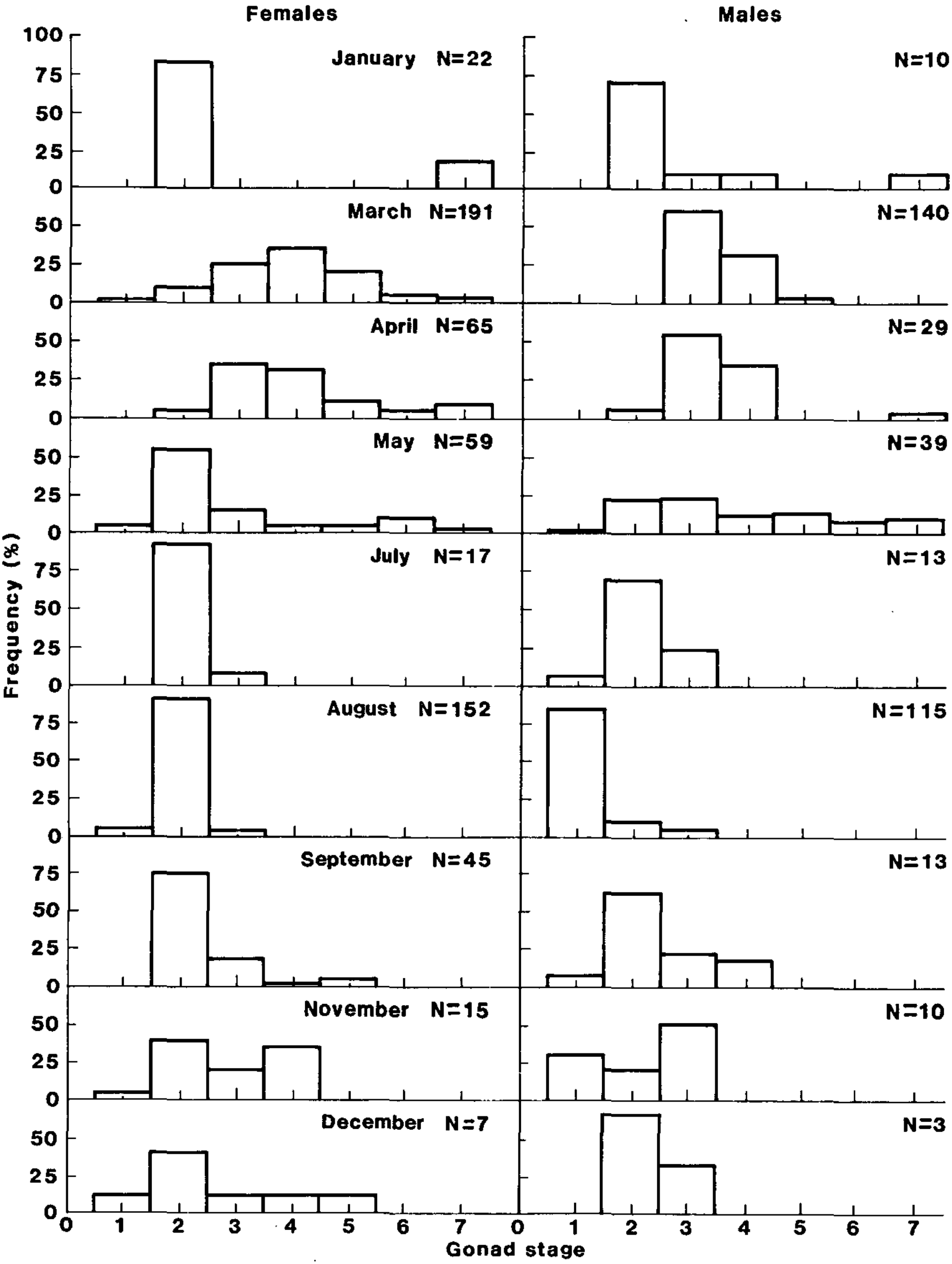

Fig. 10. The distribution of gonad stage by month for mature *S. neopilchardus* from the Bight.

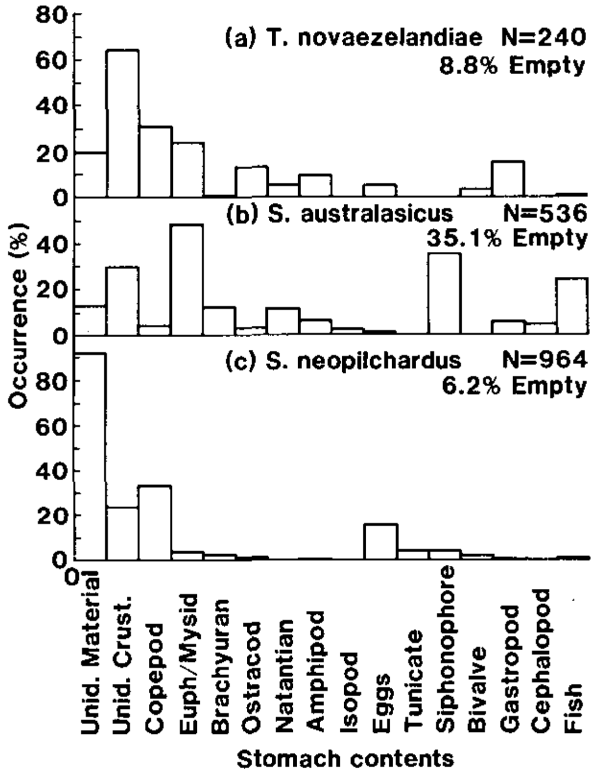

Fig. 11. Stomach contents of *a) T. novaezelandiae b) S. australasicus* and *c) S. neopilchardus* from the Bight.

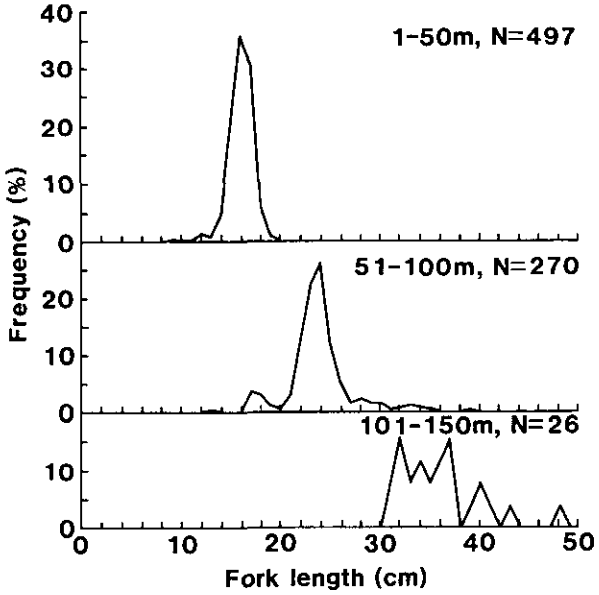

Fig. 12. The relationship between fish length and bottom depth for *C. georgianus* from the Bight.

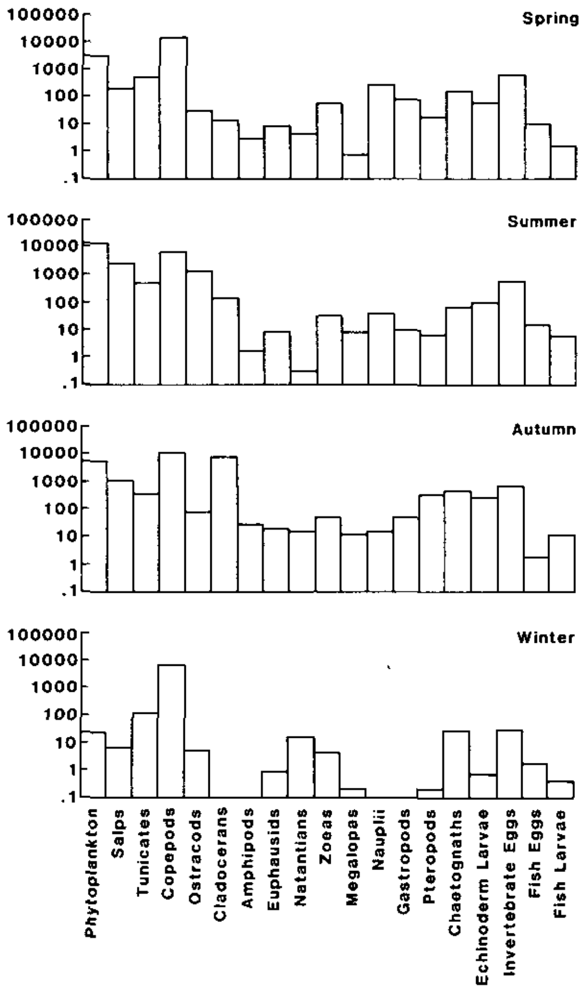

Fig. 13. Seasonal abundance of major plankton taxa in the Bight.

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