DISTRIBUTION OF PHYLLOSOMA LARVAE OF THE RED ROCK LOBSTER *JASUS EDWARDSII* OFF THE EAST COAST OF NEW ZEALAND IN RELATION TO THE OCEANOGRAPHY

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Abstract

In plankton samples taken during 1987-88 from the east coast of New Zealand south of East Cape, mid- and late-stage phyllosomas of the rock lobster *Jasus edwardsii* were much more abundant off the North Island than off the South Island. Larvae were sampled seasonally at night beyond the continental shelf edge with a fine-meshed midwater trawl, and occurred to a distance of at least 600 km from shore. The high larval abundance off the North Island was probably determined by several factors including high levels of local larval production, larval behaviour, and the oceanography. The latitudinal position of the larvae broadly coincided with that of the East Cape Current system, the most conspicuous area of circulation and eddying present off the east coast of New Zealand. Off the South Island, there are no similar oceanographic features to retain larvae near shore, and the numbers of phyllosomas caught were low. Low larval production south from Banks Peninsula may have contributed to this result. The high abundance of phyllosomas off the south-east of the North Island is probably of considerable significance to the fishery, contributing not only to high puerulus settlement in the region, but possibly also leading to juvenile migrations to other areas.

Introduction

In most shallow-water palinurid lobsters, eggs hatch and larvae are released near shore. The leaf-like phyllosoma larva passes through a number of instars (grouped and referred to as stages) over several months in offshore waters before metamorphosing to the settlement stage, the puerulus. Phyllosoma larvae are reported to be poor swimmers (Phillips and Sastry 1980), and their body form appears suited to passive drift. This, together with the long larval period offshore, means that oceanographic features, particularly currents and eddies, may play an important role in the dispersal and subsequent return to shore of larvae.

The red rock lobster *Jasus edwardsii* (Hutton) (Decapoda: Palinuridae) supports one of the most valuable fisheries in New Zealand. In recent years about 60% of the 3500-5500 t annual landings of this species have come from the east coast of the country (MAF Fisheries data). A knowledge of larval recruitment processes is important to management of this major resource.

Female *J. edwardsii* breed annually, with egg-hatching taking place during spring (mainly September and October). There is large geographic variation in larval production because size at onset of breeding (Annala *et al.* 1980; unpublished MAF Fisheries data), breeding female abundance (based on recent fishery landings), and egg-per-recruit (Annala and Breen 1989) vary markedly with locality. Annual larval production is high along the east coast of New Zealand from East Cape to Motunau, in the southwest of the South Island from Jackson Head to Foveaux Strait, and at the Chatham Islands; moderate in the northeast of the North Island north of East Cape; and it is low elsewhere.

Lesser (1978) described 11 phyllosoma stages; those at stage V and beyond (= advanced larvae in this paper) occurred beyond the edge of the continental shelf and to the end of his 185 km long transect. Later sampling (Booth unpublished data) confirmed this pattern, with most of the advanced phyllosomas being found at distances at least 20 km seaward of the shelf edge. At night, advanced phyllosoma larvae were found mainly in surface waters (down to about 60 m), and they dispersed to greater depths during the day. Duration of the larval period is at least 12-23 mo (Lesser 1978; Booth 1979; unpublished data).

This paper describes the distribution and abundance of advanced phyllosoma larvae of *J. edwardsii* sampled seasonally along a series of transects off the east coast of New Zealand south of East Cape, and examines how the nearshore oceanography might have influenced the result.

Flow patterns along east coast of New Zealand

New Zealand lies in a general west to east oceanic drift zone (Heath 1985) (Figure 1). Flowing south of East Cape, on the western side of the Hikurangi Trough, is the inshore arm of the East Cape Current (ECC) system. Near the head of the Hikurangi Trough the direction of flow is reversed, mainly because of constraints of the bottom topography. Part of the flow of the inshore arm of the ECC does not join the eddy thus formed, but moves northeast along the eastern side of the Hikurangi Trough and the Kermadec Trench as the outer arm of the ECC system (Heath 1975a; 1980) (Figure 2). The rest of the flow meanders generally east to contribute to the Subtropical Convergence.

South of Cook Strait, the flow along the east coast of the country is generally from the south as the Southland Current (Figure 1). The primary flow of this current departs eastward near Banks Peninsula, but some water flows as far north as about Cape Turnagain, where it turns east and combines with the south-moving ECC water.

The most conspicuous water circulation off the east coast of New Zealand is within the ECC system. The southward flow of the ECC may take the form of eddies (Ridgway 1970); there is sometimes continuity at about 39.5°S between the north and south flows (eg., Heath 1975a; Figure 8); and there is possibility of some recirculation of the ECC system as a whole (Garner 1969). There is a 'permanent' eddy centred near the head of the Hikurangi Trough around 41° S, 178°E, and others long-lived have been reported over seamounts to the north (Bradford *et al.* 1982). A small, persistent eddy lies off the eastern approach to Cook Strait, and variable eddy patterns are common as far south as Banks Peninsula (Barnes 1985). A weak, anticyclonic flow 50-100 km wide has been reported in the southwest corner of the Bounty Trough (Heath 1975b).

Methods

Phyllosoma larvae were sampled along six transects off the east coast of New Zealand approximately 3-monthly during June 1987-March 1988 (Figure 3). Some transects had to be altered or omitted because of heavy sea conditions. Some additional transects between Cape Runaway and Cook Strait were sampled in order to define more clearly the boundaries of high larval abundance (Figures 3 and 4). Sampling was carried out with a fine-meshed midwater trawl (FMMWT) similar to that used by Robertson *et al.* (1978). The trawl had a mesh size reducing from 150 mm (stretch measure) near the mouth to 12mm in the codend. The effective mouth area of the trawl was much less than the nominal mouth area (about 70 m^2) because of the large meshes and because phyllosomas cannot be 'herded'. Nevertheless, catches were comparable because all tows were made in a similar manner. Coefficient of variation (CV) values for 3-6 tows made in rapid succession in the same direction at the same station were determined 7 times on the Mahia transect.

Most transects started from points 20-30 km seaward of the edge of the continental shelf and extended generally eastward a further 110 km. Each transect usually consisted of 6 half-hour tows of the FMMWT, each tow separated by 18 km, made in the course of one night. Sampling started at least one hour after sunset and ended at least one hour before sunrise. The headline of the mouth was set at 30m depth, and the tows were made at 1.0-1.3 m sec^{-1}.

Phyllosoma larvae were identified and staged according to Lesser (1978). Mid-stage larvae were those at Stages V-VII; late-stage larvae at Stages VIII-XI.

Results

Just over 1200 (940) advanced (late-stage) phyllosomas (and 3 pueruli) of *J. edwardsii* were taken in the seasonal sampling in Figure 3 and Table 1. In June 1988, a further 600 and 170 advanced phyllosomas (but no pueruli) were caught in the nearshore and offshore sampling respectively (Figure 4).

In the seasonal sampling, advanced phyllosomas were most abundant along the Mahia transect (Table 1). CV values on this transect for consecutive tows at the same station were mostly 35-45%. The mean catch of larvae per tow was significantly lower each season for the Castlepoint transect compared with Mahia (Mann-Whitney *U*-test, $P < 0.05$), and only a single phyllosoma was caught south of Cook Strait. Within transects, there was high variability between stations in the phyllosoma catches (Table 1). The highest catches of mid-stage larvae were made in late summer/early autumn and winter, and the highest catches of late-stage larvae in spring and early summer, indicating that phyllosoma development takes at least about 12 months.

The northern boundary (at least in inshore waters) of the area of high phyllosoma abundance was near to but south of East Cape; the southern boundary was near the Castlepoint transect (Figures 3 and 4; Table 1). In June 1988, phyllosomas were equally abundant from Tolaga to Castlepoint (one-way ANOVA; probability, *P*, of phyllosoma densities being the same on all transects = 0.520) (Figure 4).

Both mid- and late-stage phyllosomas occurred along the entire lengths of transects, including the Offshore transect in Figure 4. In June 1988, the mean catch of advanced larvae per tow for the Mahia transect was not significantly different to that for the Offshore transect (Mann-Whitney *U*-test, $P >> 0.05$) (Figure 4).

Discussion

In all seasons, the only significant catches of phyllosomas made along the east coast of New Zealand south of East Cape were from off the North Island (Figures 3 and 4; Table 1). This was in the region of the ECC system, the most conspicuous area of strong circulation, eddying and water retention off the east coast of the country. Eddies and fronts are well known for their mechanical ability to limit dispersal, and collect individuals and conserve concentrations of species (Owen 1981). Only a single phyllosoma was taken off the South Island.

Catches from occasional other FMMWT sampling off the east coast of New Zealand were consistent with the present results. Transects were sampled off the northeast (November 1979) and southeast (seasonally, 1979-81) coasts of the North Island, and off the southeast of the South Island (May 1985 and June 1990, including offshore samples from the southwestern part of the Bounty Trough); only samples off the southeast of the North Island contained phyllosomas (Booth 1980; unpublished data).

The pattern of phyllosoma abundance is consistent with levels of puerulus settlement. Along the east coast of New Zealand, settlement of pueruli on collectors over the last 10 years has been several times higher in the North Island south of about East Cape than elsewhere (Booth and Tarring 1986; Booth 1991).

Phyllosomas were widespread along North Island transects, and were taken almost 600 km from shore. The outer arm of the ECC system lies offshore between 150 km and at least 400 km, depending on season and latitude (Heath 1975a), and was probably traversed by the Offshore transect. However, most transects off the North Island probably sampled only the inner arm of the ECC system, where high variability between stations within transects (high SD values and high variance to mean ratios from Table 1) indicated a contagious distribution of larvae. The eddy indicated at 41°S in Figure 1 was not sampled.

Factors influencing phyllosoma abundance along the east coast of New Zealand include local larval production, survival (in turn linked to food and predator abundance) and behaviour, and the oceanography. Larval production is high between East Cape and Motunau, and lower to the south. Nutrient levels and productivity are moderate to high off the entire east coast (Bradford and Roberts 1978).

Components of the oceanography influencing larval abundance include currents which bring larvae into the area; features such as eddies which retain larvae in the area for long periods; and currents which return larvae after transport offshore. It seems likely that some larvae are carried into the study area by the East Auckland Current from the north and by the Southland Current from the south (Figure 1). The obvious difference between the oceanography of the southeast of the North Island and the east of the South Island is the presence off the North Island of a large pattern of strong circulation and eddying which may provide an effective mechanism for larval retention and shoreward transport of larvae. In contrast, eddies are weaker and more variable off the east coast of the South Island, and water flows are more direct, running to the north (as the Southland Current) and east (as the West Wind Drift).

The ECC system may not be the only oceanographic system important in the larval recruitment process off the North Island. The eastward extent of the area of high larval abundance is unknown, and larger scale patterns of offshore transport and return of larvae may exist, similar to that for *Panulirus cygnus* off Western Australia (Phillips and McWilliam 1986).

Phyllosoma larvae may be able to exert some control over their horizontal transport by altering their vertical distribution so as to exploit currents flowing in particular directions or at different speeds (Phillips and McWilliam 1986). The high abundance of advanced *Jasus* larvae in the general area of adults revealed in sampling of southern waters (Booth and Grimes 1991) is consistent with larvae having some control over their horizontal position. It is unclear for the present study what role larval behaviour played in determining the pattern of phyllosoma abundance off the North Island because the degree of recirculation of water within the ECC system is unknown. Southward flow in the inner arm of the ECC system is about 0.5 m sec^{-1}; the rate in the north-moving outer arm is somewhat less (Hydrographic Department 1958; Heath 1975a); and it is 0.2-0.5 m sec^{-1} near the southern part of the eddy off Castlepoint (Sdubbundhit and Gilmour 1964; Barnes 1985). Using an average drift rate of 0.35 m sec^{-1}, larvae would be held in the ECC system for as few as 40 days unless a) significant overall recirculation of the ECC system were taking place; b) larvae were retained for long periods in eddies and meanders within the ECC system; or c) larvae through their behaviour influenced their horizontal distribution.

In conclusion, advanced phyllosomas were present in high numbers throughout the year off the east coast of the North Island in a region which coincides in latitudinal position with the ECC system, a conspicuous area of strong eddying and circulation. Off the South Island, numbers of advanced phyllosomas were low, and there are no oceanographic features similar to the ECC system to retain larvae nearshore. Levels of larval production (high in the north; low south of Motunau) probably contributed to the disparity in larval abundance. Further work is required to determine the mechanism and duration of larval retention in the ECC system and the degree to which these are influenced by larval behaviour, and whether any other oceanographic systems are important in the retention and return of larvae. Examination of sea surface temperatures from satellite imagery in relation to puerulus settlement patterns on shore may lead to improved understanding of the larval recruitment process. The high abundance of phyllosomas off the southeast of the North Island is probably of considerable significance to the fishery, contributing not only to high puerulus settlement in the area, but possibly also leading to juvenile migrations to other areas (Booth 1983).

Acknowledgements

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Table 1. Numbers of mid-stage (Stages V-VII) and late-stage (Stages VIII-XI) phyllosoma larvae of *Jasus edwardsii* per station taken in seasonal sampling off east coast of New Zealand, 1987-88

n, total number of larvae for the transect; SD, standard deviation.

		Mid-stage larvae				Late-stage larvae				Total larvae			
Transect	Date	n	Mean	Range	SD	n	Mean	Range	SD	n	Mean	Range	SD
Runaway	Dec 87	0				0				0			
East Cape	Feb 88	0				0				0			
Tokomaru	Sep 87	6	1.5	0-6	3.0	112	28.0	0-112	56.0	118	29.5	0-118	59.0
Mahia	Jun 87	42	8.4	0-21	8.4	112	22.4	8-44	13.4	154	30.8	8-48	15.8
	Sep 87	18	3.0	0-5	2.3	388	64.7	29-182	57.9	406	67.7	34-186	58.5
	Dec 87	11	1.8	0-4	1.7	229	38.2	10-75	24.0	240	40.0	10-75	24.0
	Feb 88	167	27.8	0-107	41.9	44	7.4	0-16	6.6	211	35.2	0-123	47.0
Castlepoint	Jun 87	1	0.3	0-1	0.5	2	0.5	0-2	1.0	3	0.8	0-2	1.0
	Sep 87	1	0.2	0-1	0.4	30	5.0	0-20	8.2	31	5.2	0-20	8.3
	Dec 87	1	0.2	0-1	0.5	20	4.0	0-10	3.7	21	4.2	0-11	4.2
	Mar 88	10	1.7	0-6	2.1	6	1.0	0-6	2.5	16	2.7	0-11	4.3
Kaikoura	Jul 87	0				0				0			
	Sep 87	0				0				0			
	Dec 87	0				0				0			
	Mar 88	0				0				0			
Banks	Jul 87	0				0				0			
	Sep 87	0				0				0			
	Dec 87	0				0				0			
	Mar 88	0				0				0			
Otago	Jul 87	0				1	0.2	0-1	0.4	1	0.2	0-1	0.4
	Sep 87	0				0				0			
	Dec 87	0				0				0			
	Mar 88	0				0				0			
Foveaux	Jun 87	0				0				0			
	Dec 87	0				0				0			

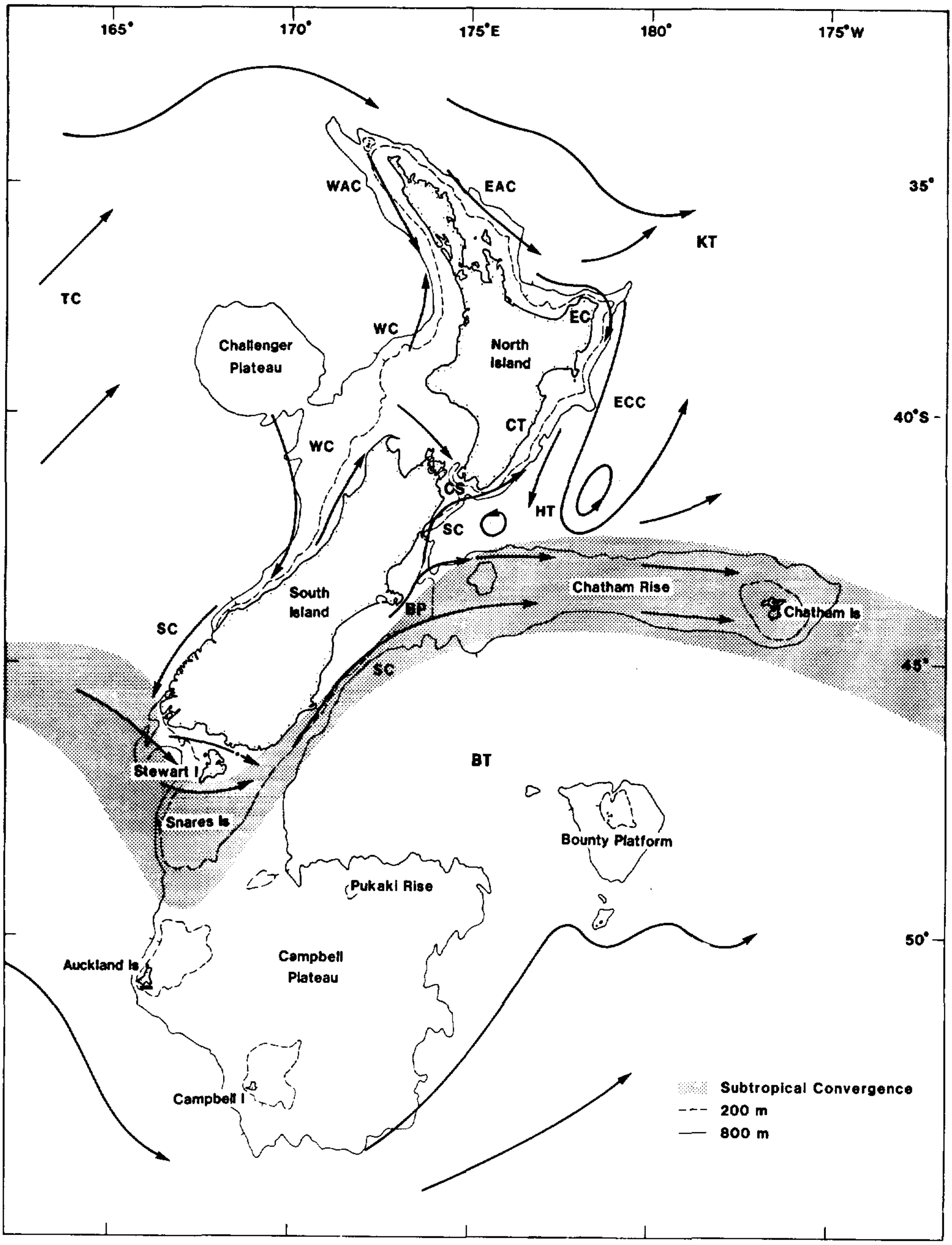

Figure 1. New Zealand region, showing major surface currents (based on Heath 1985, Fig 2), other oceanographic features, and localities mentioned in text in relation to the oceanography. Bathymetry in metres. BP, Banks Peninsula; BT, Bounty Trough; CS, Cook Strait; CT, Cape Turnagain; EAC, East Auckland Current; EC, East Cape; ECC, East Cape Current; HT, Hikurangi Trough; KT, Kermadec Trench; SC, Southland Current; TC, Tasman Current; WAC, West Auckland Current; WC, Westland Current.

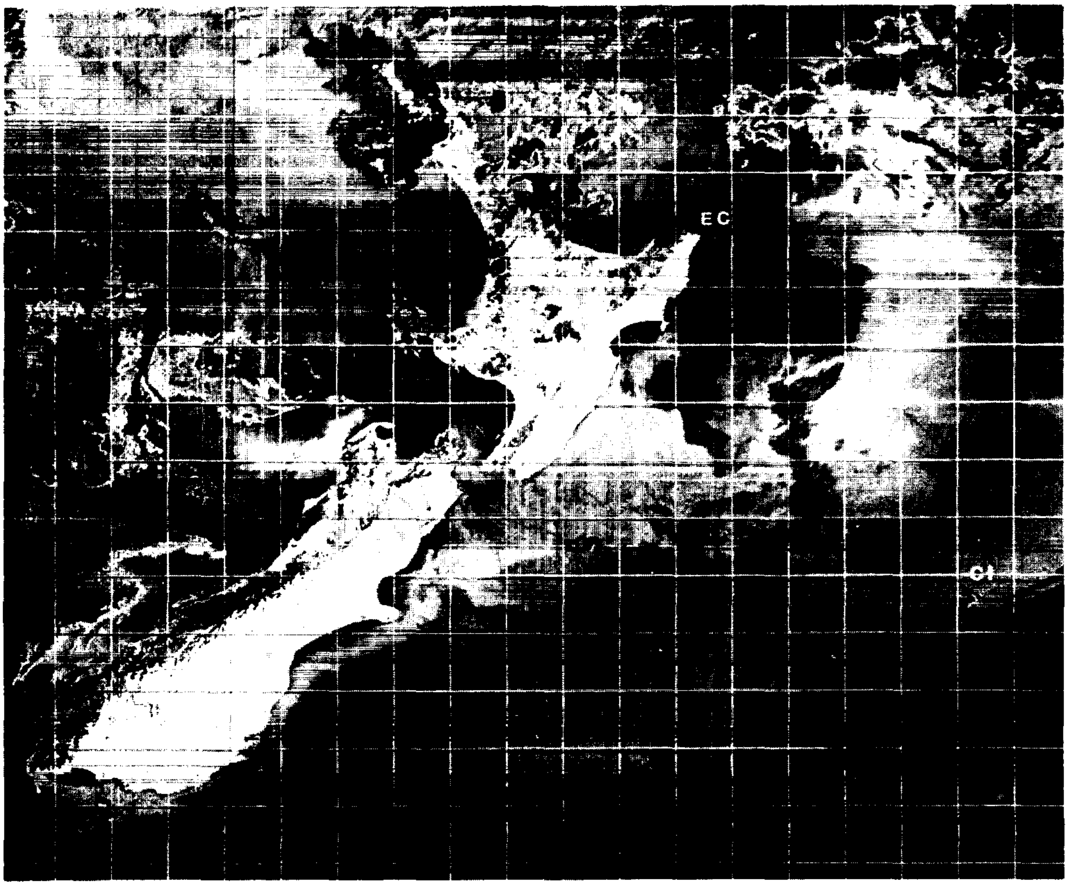

Figure 2. Sea surface temperature image for New Zealand, 14 November 1985, showing flow of warm East Cape Current water (dark) south from East Cape, and presence of mixed East Cape Current – Southland Current Water further south off the North Island (light). Cold Southland Current Water off the East Coast of the South Island also shows as dark in this image. Data received by N.Z. Meteorological Service and the image processed and kindly provided by E.J. Barnes, DSIR Physical Sciences. Black is cloud cover; EC, East Cape; CI, Chatham Islands.

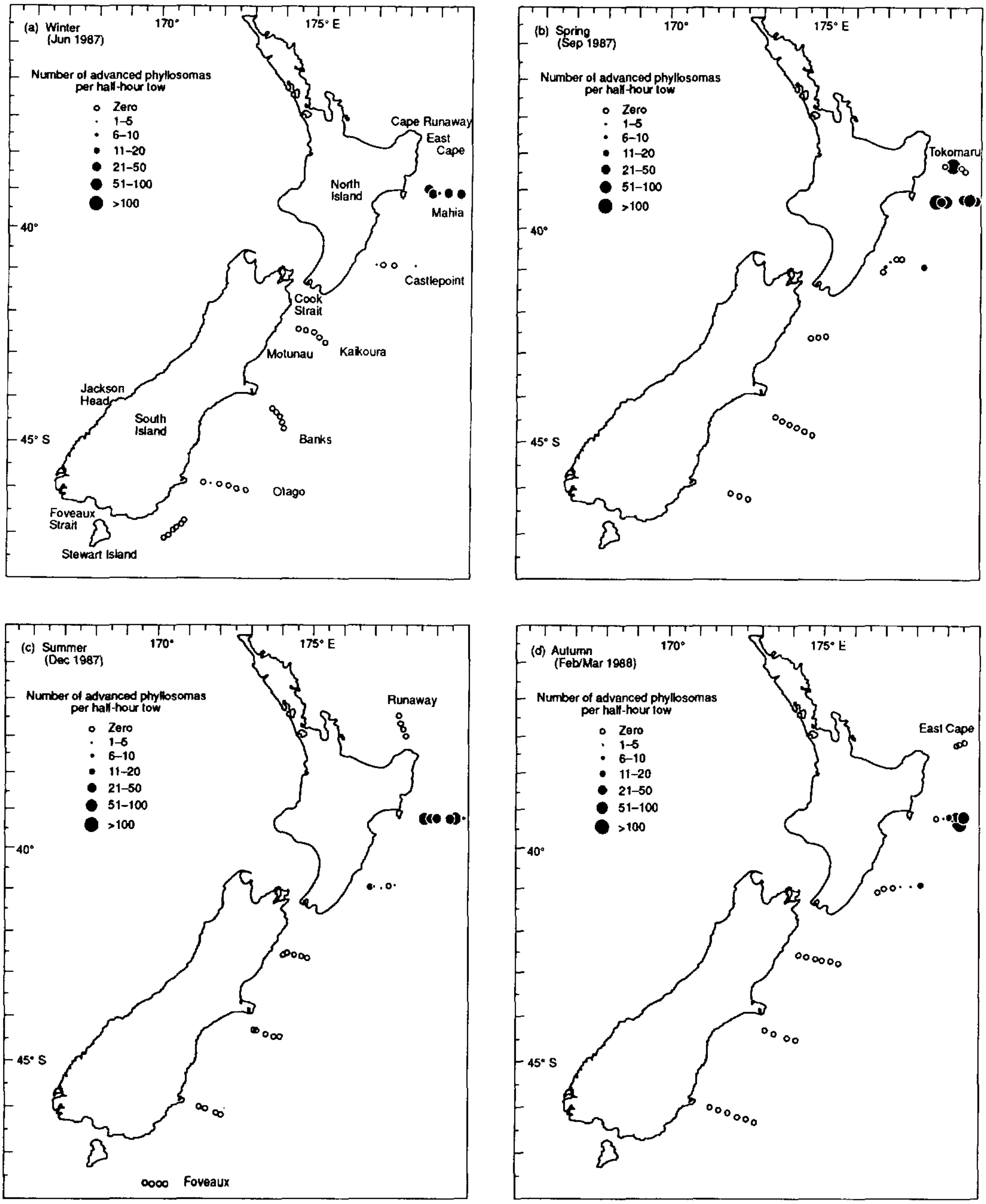

Figure 3. Catches by season of *Jasus edwardsii* phyllosoma larvae in half-hour tows along transects off the east coast of New Zealand, 1987-88. Localities mentioned in text in relation to biological data are given.

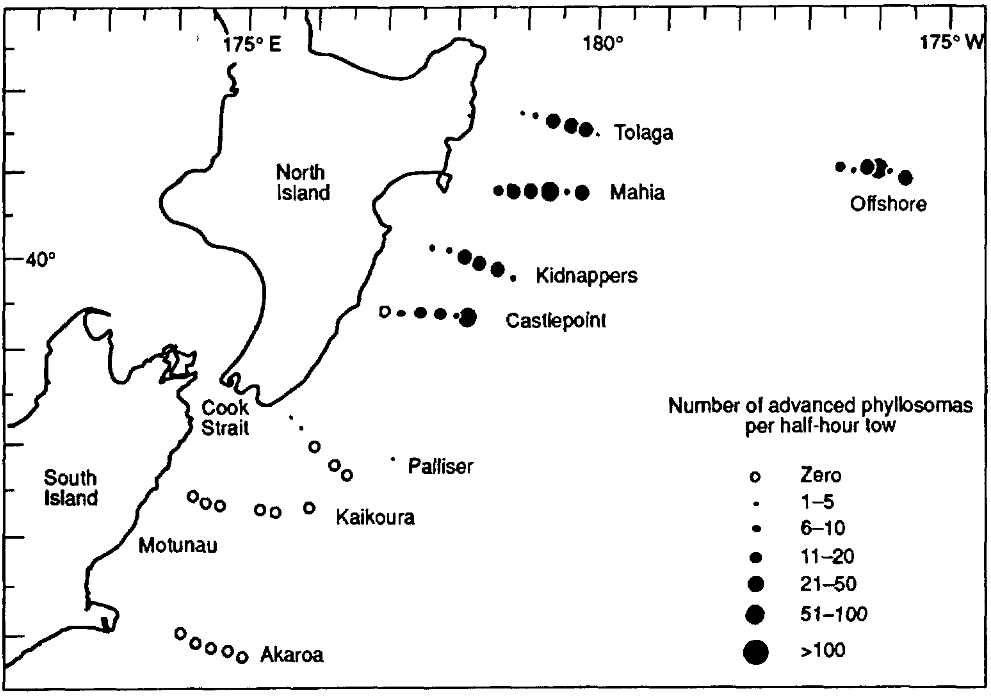

Figure 4. Catches of *Jasus edwardsii* phyllosoma larvae in half-hour tows along transects off the east coast of New Zealand, June 1988.