THE BIOLOGY OF THE WESTERN KING PRAWN *PENAEUS LATISULCATUS* KISHINOUYE 1900 IN SOUTH AUSTRALIA

by

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SUMMARY

Large populations of the migratory penaeid prawn *Penaeus latisulcatus* Kishinouye 1900, inhabit the waters of the South Australian gulfs and of Shark Bay, Western Australia. Although the species undergoes the typical penaeid life cycle it is unusual in respect to the salinity of the nursery areas occupied by the juvenile prawns. The juveniles of other penaeid species inhabit low salinity estuaries. In Shark Bay and the South Australian gulfs no such estuaries exist and in fact a "negative estuary" situation occurs. The juveniles of *P. latisulcatus* therefore live in hypersaline waters, but in most other respects these nursery areas are similar to those of other species.

A fishery for *P. latisulcatus* is operated in Spencer Gulf and from the available statistics on catch per unit effort in this fishery an index of recruitment has been calculated after first making allowance for other factors that may influence the catch per unit effort. A negative correlation exists between the annual recruitment index and the effective rainfall over northern Spencer Gulf. This supports the hypothesis that reduced salinities (after heavy rainfall) are detrimental to the survival of juvenile *P. latisulcatus*.

Laboratory studies have shown that the survival of juvenile *P. latisulcatus* in high salinities is better than that of other penaeid prawns. In low salinities however, fewer juvenile *P. latisulcatus* survive than do juveniles of other species. *P. latisulcatus* therefore appear to be better adapted to high than to low salinities. Studies on the osmotic and ionic regulation of *P. latisulcatus* have shown that the physiological basis for the

apparent adaptation to high salinities is likely to be the marked degree of ionic regulation in the haemolymph in high salinities. In low salinities the degree of regulation of calcium in the haemolymph of juvenile *P. latisulcatus* falls sharply and this may account for the poor survival rate of this species in low salinities.

DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University and to the best of my knowledge contains no material previously published or written by any other person, except where due acknowledgement is made in the text of the thesis. Submitted in partial fulfilment of the requirements for the award of the degree of Master of Science, University of Adelaide.

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Date:

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CHAPTER ONE

INTRODUCTION

The penaeid prawns are considered to be the most primitive of the decapod crustaceans, and are of marine origin (Kubo, 1949). Although some species are stenohaline and non-migratory, completing their entire life cycle in the sea, adaptation to other salinities has occurred and juveniles of various species of migratory penaeid prawns inhabit a wide range of salinities. The majority of the penaeid prawns are migratory, the newly-hatched larvae moving into shallow inshore "nursery areas" where they settle and grow to juveniles before returning to the sea to mature. It has often been asserted that low-salinity estuarine waters are essential to the life cycles of the migratory penaeids. Venkataramiah, Lakshmi and Gunter (1974) state that "the low-salinity estuaries are essential to many species and they are certainly conducive to the normal development of the young stages." It will be established in this study that *Penaeus latisulcatus* Kishinouye (1900) is quite unusual amongst the penaeid prawns since in Australian waters the juveniles of this species inhabit hypersaline waters. Large populations of *P. latisulcatus* occur in Shark Bay, Western Australia and in Spencer and St. Vincent Gulfs in South Australia, where the juveniles do not have access to low salinity estuarine water since most of the protected coastal waters are hypersaline. Specimens of *P. latisulcatus* have occasionally been reported from the east coast of Australia where the protected coastal waters are usually low-salinity estuaries, but no permanent populations of this species occur there. Similarly, the many species of penaeid prawns found in association with the estuaries of the east coast of

Australia are not found in the waters of Western Australia and South Australia. This suggests that the distribution of the penaeid prawns may be determined by the salinity of the inshore nursery areas.

From field studies Gunter (1961a, b) and Gunter, Christmas and Killebrew (1964) have argued that salinity is the major determinant of the distribution of the three commercially important penaeid prawns in the Gulf of Mexico. The conclusions drawn from field studies have been criticized by Zein-Eldin and Aldrich (1965) on the basis that factors such as temperature, light, substrate, food supply, shelter and pollution also affect prawn distribution and some of these factors frequently vary with salinity. It will be shown, however that the nursery areas inhabited by juvenile *P. latisulcatus* are similar in many respects to those occupied by other penaeid prawns with the major exception that waters in the *P. latisulcatus* nursery areas are usually hypersaline.

The effect of salinity on determining the distribution of penaeid prawns may act via the effect of salinity on the survival of juvenile prawns. If the presence of hypersaline water is a major determinant of the distribution of *P. latisulcatus* then the effects of reduced salinities in the nursery areas might be expected to be detrimental to this species. However, if salinity *per se* has no effect on the survival of the penaeid prawns, reduced salinities might enhance the survival of juvenile *P. latisulcatus* if it made the nursery areas unfavourable for predators or competitors. Furthermore, reductions in salinity are usually accompanied by an influx of nutrients into the nursery areas (Ruello, 1973), so *P. latisulcatus* might do better under these conditions.

Extensive research in the Gulf of Mexico has shown that there is no correlation between the abundance of adult prawns and the abundance of larvae produced by these adults. No correlations exist between the abundance of larvae and the abundance of later stages, but the abundance of juveniles and adults are correlated (Neal, 1975). This suggests that the abundance of adult prawns is determined by the survival of juvenile prawns in the nursery areas. The effects of salinity on the survival of juvenile prawns may therefore be seen in the variation of catches of adult prawns with varying salinity. Gunter and Edwards (1969) found a correlation between rainfall and annual catches of prawns in the Gulf of Mexico, and attributed this to better survival in reduced salinities. Ruello (1973) found a similar correlation between rainfall and prawn catch in New South Wales, but he attributed it to the indirect effects of reduced salinity, such as the production of more food due to nutrients washed into the estuaries and the stimulation of seaward migration which is said to enhance the prawns' reproductive potential. In these studies factors of favourable low salinity for prawns, unfavourable salinities for predators and competitors, increased food, and enhanced breeding potential would occur together since the species concerned inhabit low salinity estuaries. In the present study where the juvenile prawns have a hypermarine distribution it might be expected that floods from land bringing nutrients into the nursery areas would result in unfavourable salinity regimes. A study of the effects of reduced salinities on the abundance of *P. latisulcatus* might therefore provide a means of distinguishing between the hypotheses of Gunter (1961a, b) and Gunter, Christmas and Killebrew (1964) that the distribution and abundance of penaeid prawns is determined by salinity and that of Zein-Eldin and Aldrich (1965) and Ruello (1973) that the salinity *per se* does not affect the survival and abundance of the penaeid prawns.

Since natural mortality of the adult prawns occurs due to factors such as predation and aging, a better estimate of the survival of juvenile prawns, than the annual catch of adults, is the recruitment of young prawns to the adult stock. In this study an estimate of the annual recruitment of *P. latisulcatus* to the adult stock in Spencer Gulf S.A. will be made from the available fisheries statistics. It will then be shown that salinity in the nursery areas is determined by effective rainfall. At this stage it will be possible to test the hypothesis that recruitment of *P. latisulcatus* is determined by effective rainfall and hence by salinity. Alternative hypotheses that recruitment is determined by the size of the adult stock (a popular idea among fisheries biologists) or that temperature significantly affects the recruitment can be tested before examining the relationship between effective rainfall and recruitment.

Further support for this hypothesis can come from studies on the salinity tolerance, osmotic regulation and ionic regulation of this species.

The unusual distribution of *P. latisulcatus* in relation to salinity raises the question of whether this species is especially adapted to hypersaline conditions. Adaptation to salinity regimes can be considered in two ways. According to Carpelan (1967) species inhabiting hypersaline water can be viewed as specialized, their specialization being wide tolerance to salinity, but that this is a matter of opinion since wide tolerance makes the species generalized. They are euryhaline in contrast to the highly specialized stenohaline species which are limited to narrow salinity ranges. Lockwood (1962) however, views the marine forms as unspecialized in their osmotic physiology, and proposes that existence in media markedly more or less concentrated than seawater requires physiological adaptation to enable the species to maintain the body water balance in a state compatible with the cellular functions of the most sensitive tissue component. This recognises adaptation as a result of evolutionary change in response to the environment. In view of the generally accepted marine origin of the Crustacea, euryhaline penaeids should be seen as adapted to various salinity regimes by the evolution of wide salinity tolerance. In this study *P. latisulcatus* will be considered as a species which has evolved a tolerance to hypersaline waters and the physiological basis of this adaptation will be investigated.

Dorgelo (1976) points out that the salinity tolerance of a species, while not always being correlated to the distribution of the species in nature, provides an index of the physiological status of a species which reflects the degree of primary adaptation of the species to its physicochemical environment. It is therefore important to determine the range of salinity tolerance of juvenile *P. latisulcatus* The survival of penaeid prawns in various salinity regimes is dependent on their ability to regulate the osmotic and ionic concentrations in the haemolymph, thus exposing the tissues to the least degree of osmotic stress at the cellular level.

Osmotic and ionic regulation is thus the physiological basis of the species' adaptations to various salinity regimes. Of the penaeid prawns so far studied all have been found to regulate the haemolymph hyperosmotic to the external medium in low salinities and hypo-osmotic to the medium in high salinities. The point at which the osmotic concentration of the medium and the haemolymph is equal is called the isosmotic point. Adaptations to various salinities can be reflected in the position of the isosmotic point (Brand and Bayly 1971), the degree of homeostasis maintained in the haemolymph and the range over which homeostasis is maintained. Thus, from a comparison of the osmotic and ionic regulation patterns of the penaeid prawns the extent of any adaptations to hypersaline waters that may be possessed by *P. latisulcatus* may be determined.

Since populations of juvenile *P. latisulcatus* examined in this study inhabit hypersaline waters it may be expected that osmotic and ionic homeostasis will be maintained over a greater range and to a more marked extent in the upper salinity regime, than in species which inhabit lower salinities. It is also possible that the isosmotic point may be higher in *P. latisulcatus* particularly if the mechanisms of cellular osmotic and ionic regulation are better developed in the higher salinities in this species.

MacFarland and Lee (1963) found that better adaptation of penaeid prawns towards one end of the salinity spectrum is accompanied by a decreased tolerance to salinity at the other end of the spectrum. If this is the case with *P. latisulcatus* this may explain why the species has not colonized low salinity estuaries on the east coast of Australia even though the species has been occasionally recorded from there. Conversely, if the prawns found on the east coast of Australia are better adapted to low salinity and therefore not as well adapted to hypersaline waters, this may explain the absence of these species from Western Australia and South Australia.

CHAPTER TWO

TAXONOMY, ZOOGEOGRAPHY AND LIFE HISTORY OF *PENAEUS LATISULCATUS*

2.1 TAXONOMY

Penaeus latisulcatus Kishinouye 1900 is one of 28 species of the subfamily *Penaeinae* found in Australian waters (Dall, 1957). The subfamily comprises 15 genera, eight of which are recorded from Australia, the genus *Penaeus* being the best represented (7 species).

There has been dissention over the spelling of the generic name *Penaeus* Fabricius 1798 (Hall 1955). Alcock (1906), Schmitt (1926) and Hale (1927) refer to the species as *Peneus latisulcatus*. In the reviews of Racek (1955a) and Dall (1957) the valid generic name *Penaeus* has been restored.

The species *P. latisulcatus* was first described by Kishinouye (1900) from Tokyo Bay. A specimen from Penang was described as *P. canaliculatus* Olivier var.? by Lanchester (1901) and one female specimen collected from Thursday Island by de Man (1907) and referred to *P. canaliculatus* Olivier var. *australiensis* were later made synonomous with *P. latisulcatus* by Dall (1957).

In Australia large populations of *P. latisulcatus* occur in South Australian and Western Australian waters. Dall's (1957) description of *P. latisulcatus* was based on specimens from Cockburn Sound, Western Australia, and although it differs in some minor respects from that given by Kubo (1949) the specimens from Cockburn Sound, agree well with the

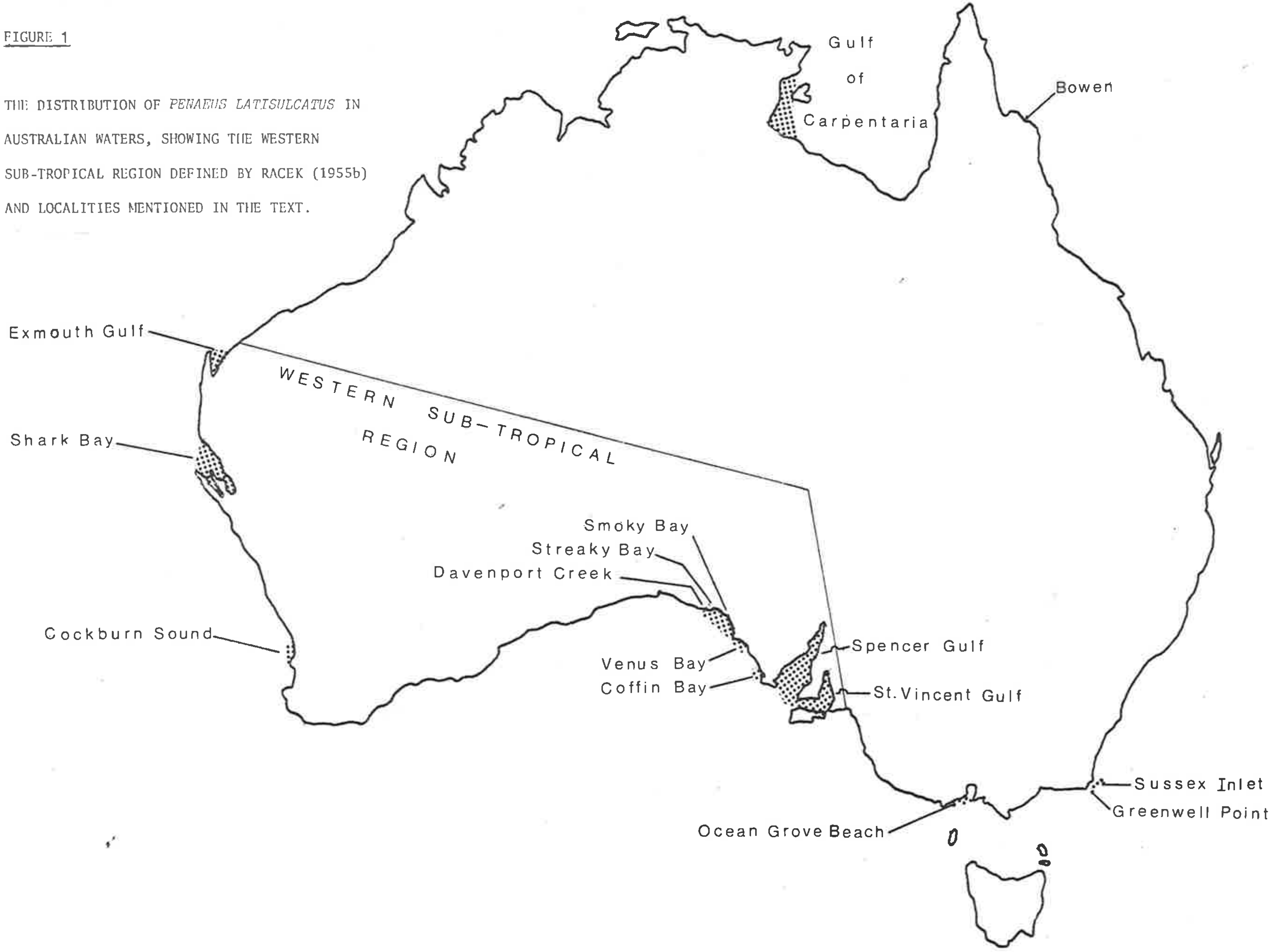
TABLE 1

GENERAL DISTRIBUTION OF *P. LATISULCATUS*

Author	Date	Distribution
Kishinouye K.	1900	Tokyo Bay, Japan
Lanchester W.F.	1901	Pulau Bidan, Penang
De Man J.G.	1907	Thursday Island
"	1911	Batjan, Molluccas, Red Sea
Schmitt W.L.	1926	Kangaroo Island, South Australia
Hale H.M.	1927	South Australian waters
Kubo I.	1949	Korean and Japanese waters
Kow Tham A.H.	1954	Singapore
Racek A.A.	1955a	Sussex Inlet, Greenwell Pt; New South Wales - lists the distribution briefly as Nth Qld, W.A., S.A., Japan, Formosa, Indonesia, Red Sea
Dall W.	1957	Warnbro Sound, Cockburn Sound; W.A.
Racek A.A. and Dall W.	1965	lists the distribution in northern Australia briefly as Joseph Bonaparte Gulf, Gulf of Carpentaria, Princess Charlotte Bay, Townsville, Mackay, Prudhoe Island
Munro I.S.R.	1968a	Western Gulf of Carpentaria
Slack-Smith R.S.	1969b	Shark Bay, Exmouth Gulf, W.A.
Bradbury J.H.	1971	Coffin Bay, South Australia
Kensley B.	1972	South African waters
Gurjanova E.F.	1972	Gulf of Tonkin
Lenanton R.C.	1974	Irwin Inlet, Bow and Kent estuaries, W.A.
Winstanley R.H.	1975	Ocean Grove, Victoria
Zed P.A.	Unpublished records.	Davenport Creek, Venus Bay, Streaky Bay, Smoky Bay; South Australia

FIGURE 1

THE DISTRIBUTION OF *PENAEUS LATISULCATUS* IN AUSTRALIAN WATERS, SHOWING THE WESTERN SUB-TROPICAL REGION DEFINED BY RACEK (1955b) AND LOCALITIES MENTIONED IN THE TEXT.



description and figure (No. 29) from a South Australian population by Hale (1927). There is little doubt then that the populations in Western Australia and South Australia belong to the same species.

2.2 ZOOGEOGRAPHY

Griffin and Yaldwyn (1968) list *P. latisulcatus* as an example of a very widely distributed species. Table 1 shows the distribution and suggests that *P. latisulcatus* may be found in suitable habitats along the east coast of Africa, the Persian Gulf, Arabian Sea and the Bay of Bengal although no records from these localities have been found in the literature to date.

The distribution of *P. latisulcatus* within Australia (Fig. 1) is better known than for other areas. Racek (1955a) postulated that the centre of abundance of the species was along the west coast of Australia, and later (Racek 1955b) he defined a "western sub-tropical region" from Cape Inscription to Kangaroo Island (Fig. 2) where *P. latisulcatus* was the typical form. Racek's (1955a and b) proposals have since been validated by the development of important commercial fisheries for *P. latisulcatus* in Shark Bay and to a lesser extent in Exmouth Gulf, Western Australia (Slack-Smith, 1969b), and in Spencer and St Vincent Gulfs in South Australia (Olsen, 1975). W. Hughes (1972) points out that *P. latisulcatus* accounts for about 1% of the prawn catch from the Gulf of Carpentaria. According to Munro (pers. comm.) *P. latisulcatus* are caught mainly on the western side of the Gulf. Despite extensive exploratory trawling along the coast of the south-east of South Australia no penaeid prawns were recorded (King, pers. comm.).

Winstanley (1975) discussed three possible hypotheses concerning the occurrence of four juvenile *P. latisulcatus* captured off Ocean Grove beach near the entrance to Pt. Phillip Bay in Victoria. The most likely hypothesis is that they were transported from South Australia as larvae or post-larvae by ocean currents which are known to flow eastwards from the South Australian gulf region to Bass Strait (Rochford, 1957). This same explanation may apply to the isolated occurrence of *P. latisulcatus* recorded from Sussex Inlet and Greenwell Point in southern New South Wales by Racek (1955a). Racek (1955b) described the occurrence of this species along the east coast of Australia as rare. The specimen from Bowen, northern Queensland described by Schmitt (1926) as *P. latisulcatus* was later referred to a new species by Dall (1957). Although Dall (1957) was of the opinion that *P. latisulcatus* would probably be found scattered down the east coast of Australia, no records (other than those of Racek (1955a)) of the species exist despite intensive prawn fisheries in Queensland and New South Wales.

It is almost certain that within Australian waters no breeding population of *P. latisulcatus* occurs east of St. Vincent Gulf in southern Australia and east of the Gulf of Carpentaria in northern Australian waters.

2.3 LIFE HISTORY OF PENAEID PRAWNS WITH SPECIAL REFERENCE TO *P. LATISULCATUS*

At the commencement of this study in 1973 very little was known of the life cycle of *Penaeus latisulcatus*. Publications on this species prior to 1973 were concerned with fisheries management (Slack-smith 1969 a, b; Slack-Smith and Stark 1968), and other papers in which reference was made to *P. latisulcatus* were restricted to considerations of the taxonomy and general zoogeographic distribution, and have been cited in the previous sections. Subsequent papers have dealt mainly with fisheries dynamics and management (Penn, 1975 a, c, 1976; Penn and Stalker, 1975; Olsen, 1975; Hancock 1975), migrations (Penn 1975 b; Winstanley, 1975) and measurement of activity (Hindley and Penn, 1975) and have made only passing reference to factors concerning the life cycle. Since a general overview of the life cycle of the species is essential to the understanding of the importance of the juvenile stage in the ecology of this species it will be necessary to discuss the literature concerning life cycles of penaeid prawns. From these studies of other penaeids and the small amount of information available about *P. latisulcatus*, the life cycle of this species can be deduced.

It is known that the penaeid life cycle follows the general pattern of breeding, larval development immigration of post-larvae, juvenile growth phase, emigration of pre-adults and adult stage. The above stages in the general pattern of penaeid life cycles will be discussed and related to the probable life cycle of *P. latisulcatus* in South Australian and Western Australian waters.

2.3.1 Breeding

In a number of species of *Penaeus* including *P. latisulcatus*, the genitalia develop before the gonads ripen (Hall 1962). Mating generally occurs after the prawns migrate offshore where vitellogenesis and spawning takes place. In Penaeidae with closed thelyca, such as *P. latisulcatus* copulation occurs between hard shelled males and newly moulted females. The male deposits spermatophores such that the part containing the semen lies within the paired seminal receptacles of the female. The other portion swells on contact with sea water to form plugs which protect the median thelycal opening (Tuma, 1967). Fertilization of the eggs occurs at the time of spawning and many penaeids are capable of retaining viable sperm for several weeks. It is not known how long *Penaeus latisulcatus* are able to retain viable sperm.

Penaeus species generally reach maturity within one year of hatching and are probably capable of spawning three to five times during their life (Badawi, 1975; Wickins, 1976). Penaeids are among the most fecund of the Natantia and can release 100,000 to 1,000,000 eggs at a single spawning (Hall, 1962; Tuma, 1967).

Tuma (1967) found that there are distinct size groups of adult *Penaeus merguiensis* de Man which engage in mating. Males of 30-36 mm carapace length make up 90% of the males found in association with inseminated females, and 90% of inseminated females are in the size range 32-39 mm carapace length. Badawi (1975) noted that spawning of *Penaeus semisulcatus* de Haan occurred in female prawns of 3 size modes in the size range of 160 to 200 mm total length.

Penn (1975a, 1976) noted that the ovaries of female *P. latisulcatus* underwent rapid development during spring in Western Australia. According to King (1976) the peak ovary development of *P. latisulcatus* in South Australian waters is in October and November.

Correlation between water temperature and spawning has been reported by Lindner and Anderson (1956), Ingle et al (1959), Eldred et al (1961), Cummings (1961) and Idyll et al (1963). It has been shown that intensive spawning activity is generally related to a rise in water temperature.

2.3.2 Larval Development

Ewald (1965) reared larvae of *Penaeus duorarum* Burkenroad whose development is representative of most penaeids (Wickins, 1976), and described 5 naupliar, 3 protozoeal, and 3 mysid stages; however the exact number and duration of each stage varied according to culture conditions. Typically, penaeid nauplii hatch from the eggs 10-15 hours after spawning and subsist on yolk reserves for 2-3 days until active feeding occurs in the first protozoeal stage. The larva moults to the mysis stage after 3-4 days and to a post-larva after a further 3-5 days. During this time it may pass through as many as 11-14 moults. The rate of development is dependent on temperature, food and water quality but in good conditions development to the post-larval stage occurs within 11-21 days (Wickins, 1976).

Fielder, Greenwood and Ryall (1975) described the larval stages of *Penaeus esculentus* Haswell from Queensland, Australia. Four nauplii, 3 zoeal 3 mysid and a post-larval stage were detected. The development from hatching to post-larva was completed in 10 days at a water temperature of approximately 26°C.

The larvae of *P. latisulcatus* have been reared in the laboratory by I. Smith (pers. comm.), but the description of the various stages has not been published. The time taken for development of *P. latisulcatus* through to the post-larval settling stage was approximately 21 days at 20°C in laboratory culture conditions.

Penaeus latisulcatus larvae are reared at a commercial prawn culture enterprise at Pt. Broughton, South Australia. Up to six naupliar stages have been observed. There are three zoeal and 3 mysid stages. (Yasada, pers. comm.).

2.3.3 Immigration

The 'invasion' of estuaries or brackish water habitats is common amongst post-larval penaeids (Wickins, 1976). Hughes (1969a, b) considered the migratory behaviour of *P. duorarum* to be largely determined by tidal flow and salinity but thought it may also be complicated by the influence of endogenous diurnal rhythms (Hughes, 1972). Post-larvae of this species move onshore on flood tides. A decrease in salinity during ebb tides is said to cause the post-larvae to sink to the substrate and burrow to avoid being carried offshore. When the salinity increases on the flood tide the post-larvae become active and are carried ashore.

Racek (1959) and Barber and Lee (1975) considered that ocean currents and wind drifts must be responsible for the inshore migration of *Penaeus plebejus* Hess post-larvae. Jones et al. (1970) also considered ocean currents to be the most likely transport mechanism for *Penaeus duorarum* post-larvae.

Penn (1975b) has proposed a tidal transport mechanism for the incoming larvae and post-larvae of *P. latisulcatus* in Shark Bay, W.A. The only behavioural response required by this mechanism is the diurnal vertical migration of the planktonic larvae and post-larvae. Although no such migration has yet been observed for *P. latisulcatus*, such behaviour has been observed for the larvae of *P. duorarum*, *Penaeus aztecus* Ives and *Penaeus setiferus* Linnaeus (Duronslet et al., 1972; Temple and Fischer, 1965) and for larvae of *P. plebejus* (Barber and Lee, 1975). Penn (1975b) has shown that during that part of the year when larvae and post-larvae are present in Shark Bay, the predominant tidal flow of water at night is towards the shore. Thus larvae and post-larvae active at night would be transported inshore. The same nett tidal inflow at night occurs in Spencer Gulf (Penn, 1975b) so the mechanism can explain the ingress of *P. latisulcatus* larvae and postlarvae in Spencer Gulf.

2.3.4 Juvenile Stage

After the inshore migration of the postlarval stages, penaeid prawns spend some time as juveniles in inshore nursery areas. Munro (1975) found that juvenile *P. merguiensis* were present in the nursery areas during all months of the year but appeared most abundant during summer. He deduced that those that do not grow to the size at which emigration to the deeper waters occurs, overwinter in the nursery areas and become the first "adolescents" to leave these areas the following summer. Collier, Gunter, Ingle and Viosca (1959) found that as winter approaches larger juveniles of *P. setiferus* move to offshore waters but the smaller juveniles remain in the nursery areas. Their growth is retarded by lower winter temperatures but with the advent of warmer conditions in spring the small juveniles resume a rapid growth rate and move to the offshore waters. Loesch (1965) also found that juvenile *P. setiferus* and *P. aztecus* overwinter in the nursery areas. Aldrich, Wood and Baxter (1968) have laboratory evidence supporting the hypothesis that most juvenile *P. aztecus* hibernate in the burrowed state for winter in the north-west Gulf of Mexico. Juvenile *P. aztecus* were found to burrow at temperatures below 17°C and to become inactive below 12°C. Emergence from the substrate occurred as the temperature rose to 18°C. Other studies have shown that juvenile *Penaeus indicus* Milne Edwards are present in the inshore nursery areas throughout the year (Mohamed, 1970b) that *Metapenaeus macleayi* Haswell overwinter in their nursery areas (Kirkegaard and Walker 1970b) that in New South Wales waters *Penaeus plebejus* postlarvae enter the nursery areas in autumn and overwinter there to leave the following summer (Racek 1959, Kirkegaard and Walker 1970d), and that Juvenile *Penaeus duorarum* spend from two to at least six months in the nursery areas (Costello and Allen 1970).

King (1976) found that juvenile *Penaeus latisulcatus* spend up to 12 months in the shallow-water nursery areas, but that some larger juveniles (spawned very early in the season and grown rapidly over the summer) might emigrate to the offshore areas before the onset of winter. The summer growth rate of juvenile *P. latisulcatus* was found to be up to 4mm carapace length per month (King 1976). Since the size at which emigration to the offshore waters occurs is about 23mm carapace length for males and about 26mm carapace length for females, juveniles would need to spend about 6 months in the nursery areas before emigrating to offshore waters. Since recruitment to the offshore grounds is completed by April, it is only those prawns spawned in October and early November that would possibly reach 'adolescent' size in the first season. Thus it is likely that most juvenile *P. latisulcatus* overwinter in the nursery areas and emigrate offshore the following summer.

2.3.5 Emigration

Having undergone a period of growth in the nursery areas juvenile penaeid prawns attain a size at which they are termed 'adolescents' or 'sub-adults'. At this stage the development of the genitalia is almost complete and the sexes are readily distinguished.

Tuma (1967) found that male *Penaeus merguiensis* in the Gulf of Carpentaria possess mature gonads when approximately 18.5mm carapace length but the genitalia remain structurally incomplete until a minimum carapace length of 20 mm is reached. Since the majority of males leave the Norman River nursery areas by the time they have reached 22mm carapace length they enter the waters of the Gulf of Carpentaria in a sexually mature state and with structurally complete genitalia. Female *P. merguiensis* do not become sexually mature in the river environment. The majority leave the nursery area by the time they reach a carapace length of 23 mm, and the genitalia become structurally complete when they are about 24 mm carapace length long.

Ruello (1975) found that the mean size of emigrating *Penaeus plebejus* in eastern Australia varied between 19 and 28 mm carapace length, depending on the nursery area and the time at which measurements were made. Pullen and Trent (1969) found that the mean size at emigration of *Penaeus setiferus* varied from 155 mm total length in August to about 90 mm total length in January. In South Australian waters *P. latisulcatus* emigrate to the offshore waters when the males are about 23 mm carapace length and the females about 26 mm carapace length. The peak in this offshore emigration occurs from December to February (King, 1976). Since the peak in ovary development in female *P. latisulcatus* does not occur until October and November (King 1976) young female prawns emigrating from the nursery areas must not have mature gonads.

Penaeus setiferus, after emigrating from estuarine areas, tend to remain near shore or to migrate alongshore unless low temperatures force them offshore (Lindner and Anderson 1956). Pullen and Trent (1969) also found that rapid lowering of water temperature stimulated offshore migration of *P. setiferus*. They related a decrease in size at emigration from August to January to the drop in water temperature from 19°C to 8°C during this time. Peaks of emigration occurred when the temperature and salinity dropped suddenly. It is not known whether the water temperature and salinity have a direct effect on the emigration of *P. latisulcatus*.

P. plebejus move out of New South Wales estuaries in the surface waters of night ebb tides during the darker phase of the lunar cycle (Ruello, 1975). The offshore migration of juvenile *Penaeus latisulcatus* in Shark Bay is confined to ebb tides which occur at night since the juveniles are strictly nocturnal (Penn, 1975b). This offshore emigration is facilitated by the predominance of night ebb tides during the time that emigration occurs (Penn, 1975b).

For most penaeid prawns offshore migrations move individuals from less to more saline waters and circumstantial evidence indicates that most Penaeidae which are unable to reach suitably saline water do not mature (Wickins, 1976). An exception to this is *Metapenaeus bennettae* Racek and Dall which is able to complete its life cycle within estuarine conditions (Dall, 1958).

It has been suggested that the offshore emigration is necessary for the completion of the life cycle of most penaeid prawns because some property of the inshore waters prevents the complete development and maturation of the gonads. This belief has come about because of the failure of penaeid prawns to become sexually mature in aquaculture conditions (Neal, 1975). However, there is evidence that in a small population of *P. latisulcatus* which became land-locked during the construction of salt evaporation pans at Useless Inlet on Shark Bay W.A., maturation, breeding and subsequent development of larvae, juveniles and adults has occurred (Hancock, 1975). A similar incident has occurred at Outer Harbour in South Australia where *P. latisulcatus* became land-locked during reclamation works and developed through one generation (Olsen, 1975). Completion of the life cycle of *P. latisulcatus* is also thought to have occurred in prawn culture ponds at Pt. Broughton, S.A. (Yasada, pers. comm.). It appears then, that migration to offshore waters is not necessary for completion of the life cycle of *P. latisulcatus*.

2.3.6 Adult Stage

After emigration to the offshore waters it has been proposed that *P. plebejus* migrate from more southerly regions to a breeding area just north of Moreton Bay, Queensland (Ruello, 1975). A similar coastal breeding migration has been recorded for many other penaeid species (Allen, 1966).

A southerly movement of tagged *P. latisulcatus* has been noted in Spencer Gulf (King, 1976). Although many thousand of prawns have been tagged in Spencer Gulf, none have been recaptured outside the Gulf (King, 1976). It seems therefore that the populations of *P. latisulcatus* in St. Vincent Gulf, Spencer Gulf and the west coast of South Australia are distinct unless mixing of the larvae from these sources occurs. This is not very likely due to the relatively closed water circulation patterns within the South Australian gulfs (Tronson, 1974; Bullock, 1975; Bye, 1976).

During their life in the offshore waters the male and female *P. latisulcatus* grow to about 40 mm carapace length and 50 mm carapace length respectively. These prawns are mainly of the 1+ age class although some may survive into a third year (i.e. become 2+). It is those larger prawns that form the breeding stock.

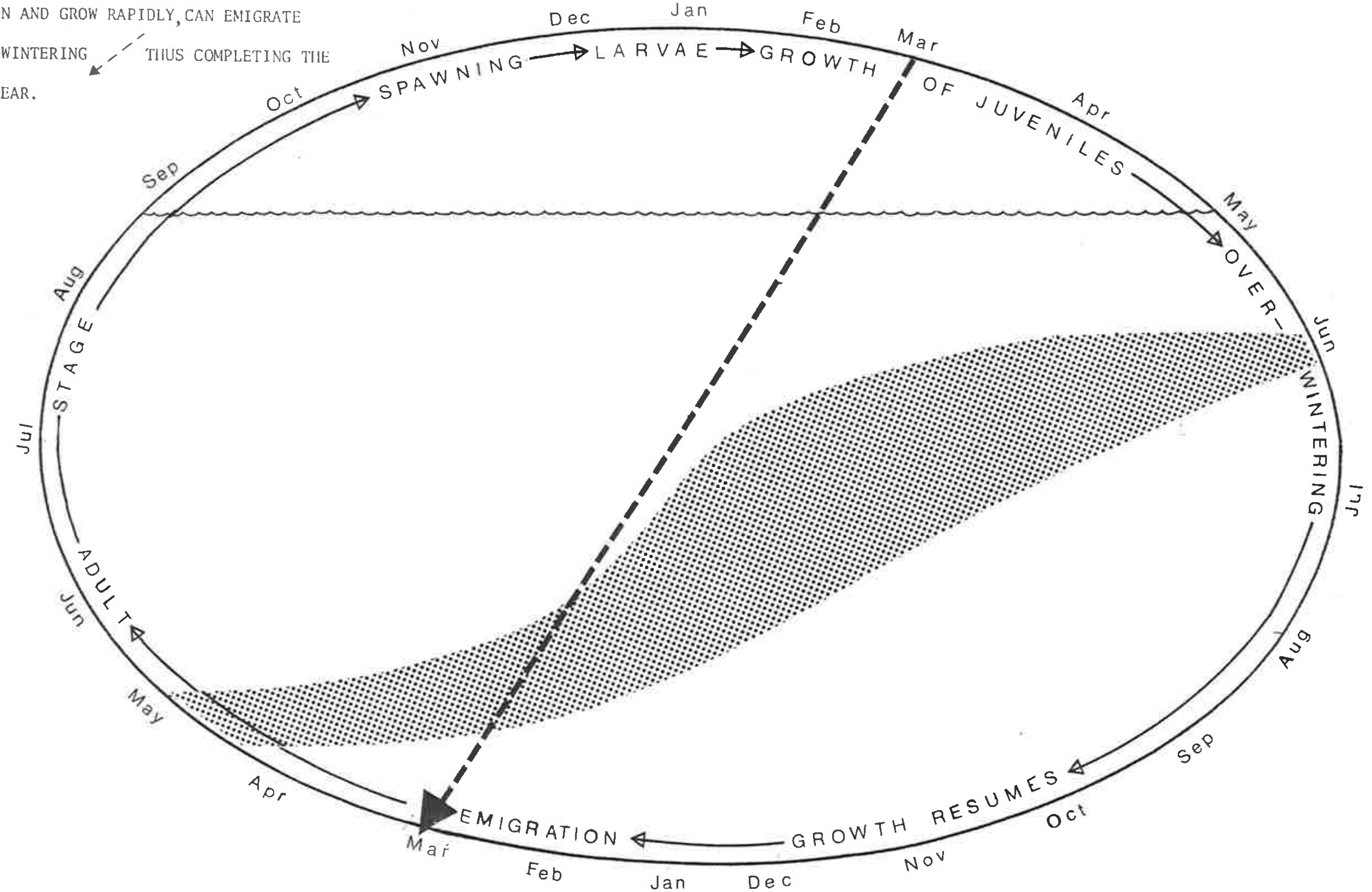
2.3.7 Life cycle of *Penaeus latisulcatus*

From the preceeding discussion it is now possible to present a concise outline of the life cycle of *Penaeus latisulcatus* in South Australian gulf waters (see fig 2).

Most spawning occurs in the offshore waters from November through the early summer months, in the northern waters of the Gulfs. The eggs hatch and the larvae develop through their various stages to postlarvae, probably within 20 to 30 days. During this time they migrate towards the shore. The postlarvae settle in sheltered inshore areas and grow rapidly into juveniles. Most juveniles spend the winter in the inshore nursery areas however some which were spawned very early in the season may emigrate at the end of that summer (broken arrow on fig 3). The following spring and summer rapid growth resumes and the "adolescents" emigrate offshore where they may live till the next spawning season. The life cycle is thus completed in two years although some individuals may complete it in one year, and some may survive into a third year.

FIGURE 2

DIAGRAM OF THE LIFE CYCLE OF *PENAEUS LATISULCATUS* SHOWING HOW SOME PRAWNS WHICH ARE SPAWNED EARLY IN THE SEASON AND GROW RAPIDLY, CAN EMIGRATE WITHOUT OVERWINTERING ↙ THUS COMPLETING THE CYCLE IN 1 YEAR.



CHAPTER THREE

HABITAT AND ENVIRONMENT OF JUVENILE *PENAEUS LATISULCATUS*

3.1 INTRODUCTION

In general the areas occupied by juvenile penaeid prawns are sheltered localities (Dakin 1946, Dall 1958). Postlarval and juvenile stages of *Metapenaeus bennettae* were found to favour warm sheltered localities (Dall 1958). Eldred (1962) found that small juvenile *Penaeus duorarum* prefer very shallow protected and relatively calm areas near shore. Juvenile *P. aztecus* are concentrated in waters ½ to 1 m. deep in Mobile Bay, Alabama, while juvenile *P. setiferus* are found in waters less than ½ m deep. (Loesch, 1965). *P. plebejus* juveniles occur in the littoral areas of Moreton Bay (Young 1975). Gently sloping sand and mud flats are favoured by juvenile *P. semisulcatus* and *Metapenaeus monoceros* Fabricius (Hughes, 1966).

The distribution of juvenile penaeid prawns has been related to substrate type (Williams, 1958), to the distribution of strands of mangroves (Hall 1962) and to hydrological regimes (Gunter, Christmas and Killebrew, 1964). The distribution of juvenile *P. latisulcatus* in South Australian waters will be discussed in relation to these factors.

3.2 GENERAL DISTRIBUTION OF JUVENILE *PENAEUS LATISULCATUS* IN SOUTH AUSTRALIA

When this study commenced in 1973 little was known of the location and nature of the nursery areas of juvenile *P. latisulcatus* in South Australian waters. Juvenile *P. latisulcatus* caught in sheltered shallow waters in St. Vincent and Spencer Gulfs were occasionally sold in Adelaide fish shops as "shrimps" (Hale, 1927), and a brief survey by the South Australian Department of Agriculture and Fisheries showed juvenile *P. latisulcatus* to be abundant in the shallows of the Northern regions of Spencer and St. Vincent Gulfs (Bradbury 1971). Although *P. latisulcatus* were being fished commercially from the west coast of South Australia it was not known whether populations of juveniles occured there, or whether the adults being caught were part of the Spencer Gulf population.

In July 1973 a brief survey of possible nursery areas for *P. latisulcatus* along the west coast of South Australia was made, in conjunction with a survey of mangroves being made by Dr. A.J. Butler. Attempts to trawl prawns were made at Coffin Bay, Venus Bay, Baird Bay, Streaky Bay, Smoky Bay and Denial Bay (fig 3). These localities were selected as they are the only relatively sheltered areas along the west coast (Womersley and Edmonds 1958) and thus the only areas likely to be suitable for juvenile *P. latisulcatus*.

3.2.1 Collection of juvenile prawns

Prawns were collected with a small beam trawl of my own design (fig 5). The 1m x 0.5m frame was constructed from galvanized 1cm diameter steel rod and the skids were made from 2.5 x 0.5cm galvanized flat steel. Strips of 1cm (stretched) shrimp netting cut to the appropriate shape were sewn together to make the net. The top and sides of the mouth of the net were fastened to the steel frame with strong nylon twine as shown (fig 4). A 1.5m length of heavy chain was fastened to the bottom of the frame and laced to the net. The trawl was towed behind a 4m aluminium dinghy powered by a Yamaha 9½ h.p. outboard motor operated at one third throttle.

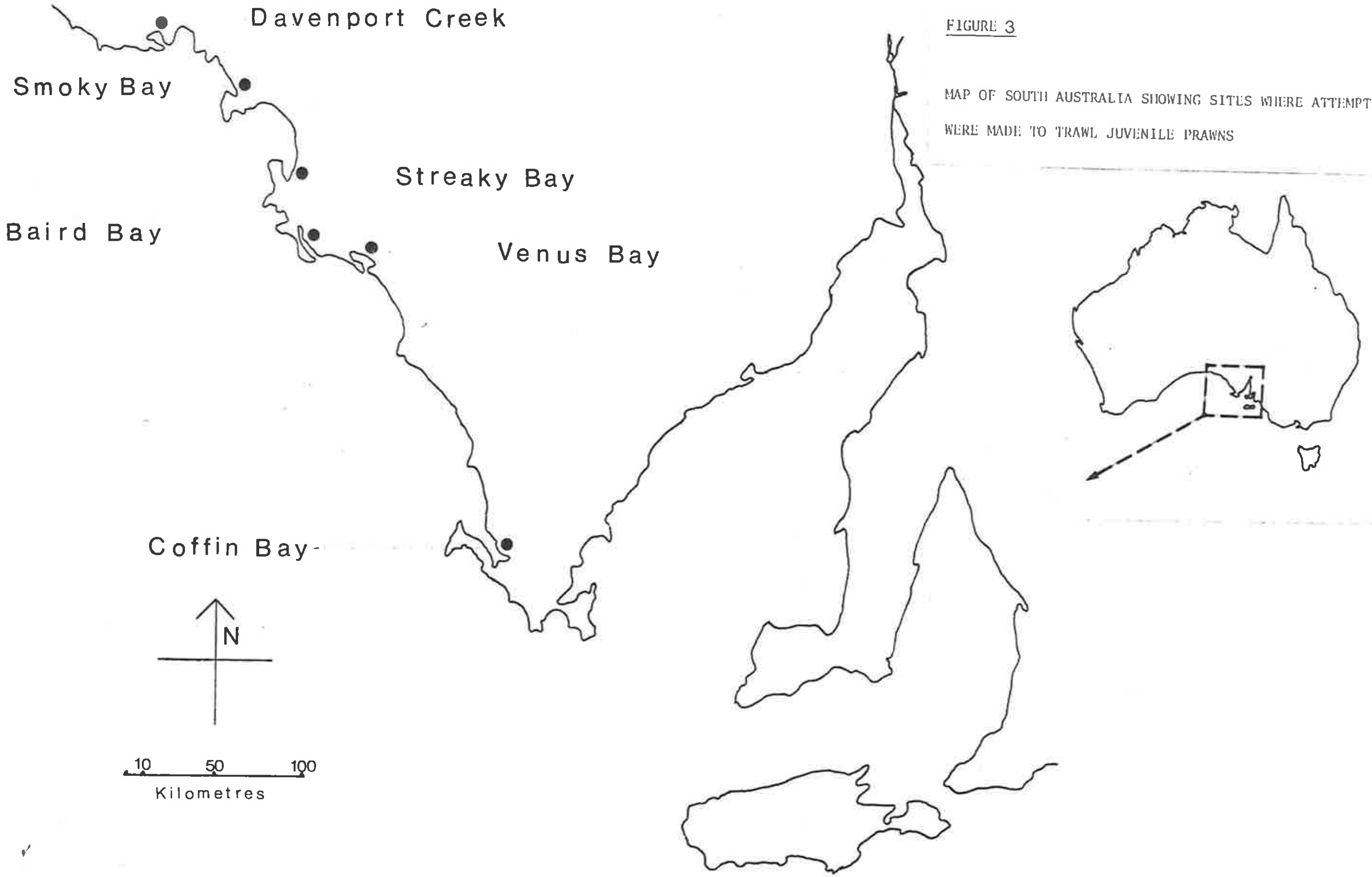
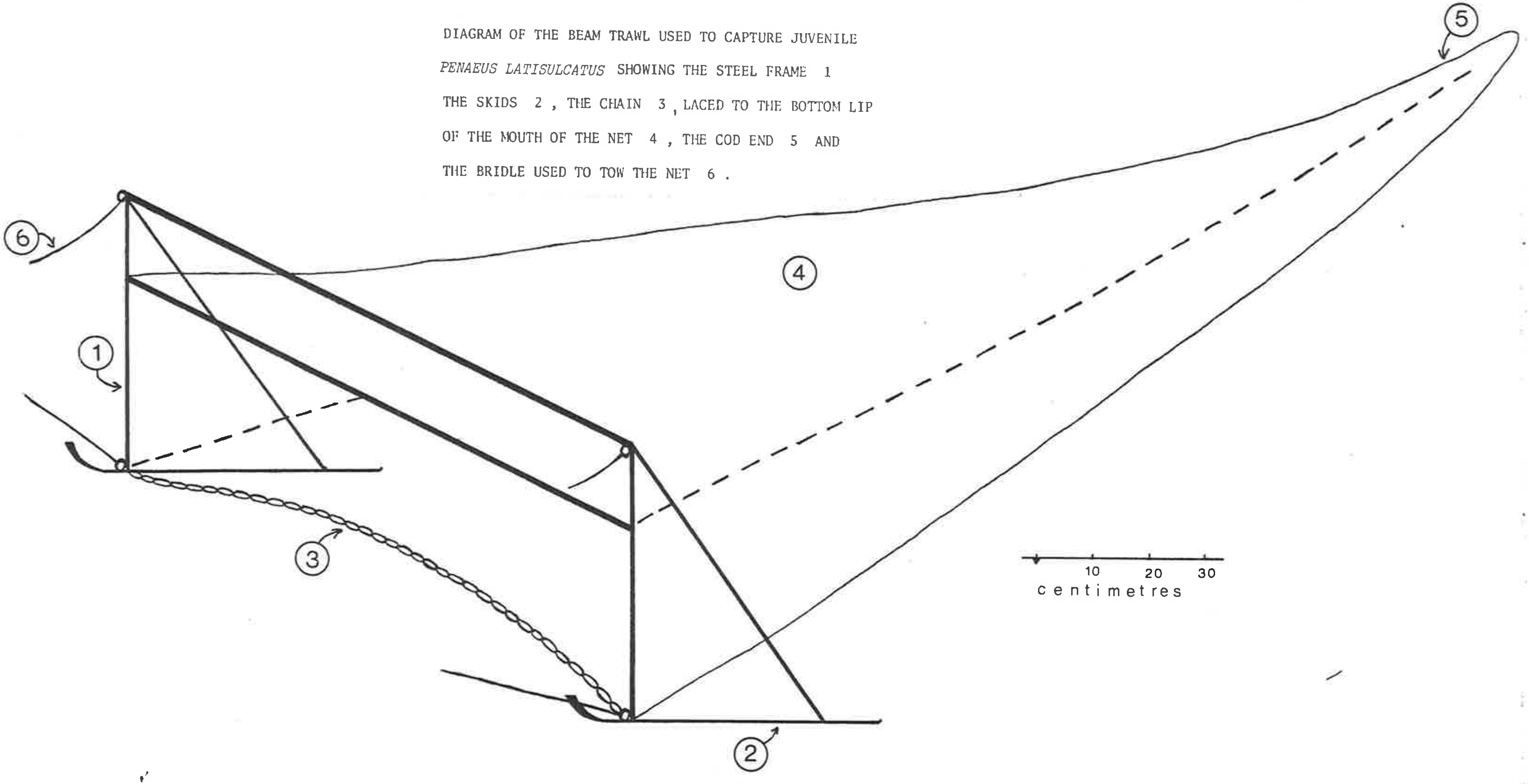


FIGURE 3

MAP OF SOUTH AUSTRALIA SHOWING SITES WHERE ATTEMPTS WERE MADE TO TRAWL JUVENILE PRAWNS

FIGURE 4

DIAGRAM OF THE BEAM TRAWL USED TO CAPTURE JUVENILE *PENAEUS LATISULCATUS* SHOWING THE STEEL FRAME 1 THE SKIDS 2 , THE CHAIN 3 , LACED TO THE BOTTOM LIP OF THE MOUTH OF THE NET 4 , THE COD END 5 AND THE BRIDLE USED TO TOW THE NET 6 .



Juvenile P. *latisulcatus* are nocturnal (M. King, pers. comm.) so all trawls were made at night. After trawling for 10 mins. the trawl was hauled over the stern of the boat and the catch emptied through the cod-end of the net into a shallow sorting tray. The catch was sorted and juvenile prawns retained for subsequent examination.

3.2.2 Results of prawn trawls

At each of the west coast locations the salinity was measured by the 2 method described in section 3.5.2 and the presence or absence of mangroves and seagrass was noted. The results are presented in Table 2. Juvenile prawns were present at Coffin Bay, Venus Bay, Streaky Bay, Smoky Bay and Denial Bay while no prawns were caught at Baird Bay.

3.2.3 Discussion

The trawls show that nursery areas for P. *latisulcatus* do exist in sheltered areas on the west coast of South Australia. No conclusions about the relative importance of these nursery areas can be drawn from the data because of the small number of trawls made and the fact that trawling was conducted on only one night at each of the west coast localities. That juvenile P. *latisulcatus* are abundant in these areas has been confirmed by reports to the S.A. Fisheries Department, by prawn fishermen and other interested persons, but no further trawls in the inshore waters have been made (King, 1976). The distribution of juvenile P. *latisulcatus* in relation to mangroves and seagrasses will be discussed in the next section.

In addition to the west coast area, extensive trawls have been made in the waters adjacent to Torrens Island in St. Vincent Gulf (figs 3, 9)

TABLE 2

SALINITIES AND THE PRESENCE OF MANGROVES, SEAGRASSES AND JUVENILE *P. LATISULCATUS* IN SHELTERED BAYS ON THE WEST COAST OF SOUTH AUSTRALIA

LOCALITY	DATE	SALINITY	MANGROVES	SEAGRASSES	NO. OF TRAWLS	TOTAL NO. OF PRAWNS	PRAWNS PER TRAWL
Coffin Bay	12.7.73	38.2‰	not present	extensive beds of *Zostera sp.* and *Posidonia sp.*	1	3	3
Venus Bay	13.7.73	37.7‰	small grove present	abundant *Zostera sp* and *Posidonia sp.*	4	10	2.5
Baird Bay	14.7.73	45.0‰	not present	very abundant dense beds of *Zostera sp* and *Posidonia sp.*	2	0	0
Streaky Bay	15.7.73	36.1‰	fairly extensive	patches of *Zostera sp.* and *Posidonia sp.*	6	68	11.33
Smoky Bay	16.7.73	36.2‰	fairly extensive	patches of *Zostera sp.* and *Posidonia sp.*	3	52	17.33
Denial Bay	17.7.73	36.05‰	very extensive	patches of *Zostera sp.* and *Posidonia sp.*	2	11	5.5

confirming the presence of large numbers of juvenile *P. latisulcatus* in this area. Large numbers of newly settled postlarvae of *P. latisulcatus* have also been observed on the extensive mud flats at Pt. Gawler and Pt. Clinton in St. Vincent Gulf (fig. 3) from December 1976 until July 1977 by myself and by S. McKillup (pers comm.).

A more extensive survey of the nursery areas of *P. latisulcatus* in South Australian gulf waters is being made by M.G. King of the S.A. Department of Agriculture and Fisheries, who found that sheltered areas to the north of Spencer and St. Vincent Gulfs are more favoured by juvenile *P. latisulcatus* than the more exposed southerly areas (fig.6) (King 1976).

It can be seen from fig. 5 that the nursery areas for *P. latisulcatus* in South Australia most lie within regions where the 10m bathymetric contour is from 5 to 10km more offshore. The nursery areas correspond closely with what Womersly and Edmonds (1958, map 1 p.220) call "coastlines of slight wave action with sandy of muddy flats or beaches." Typically the shore topography comprises very gently shelving flats above and below low tide level, descending gradually into deeper water or abruptly into channels 4m or more deep. (Womersly and Edmonds 1958).

3.3 BIOLOGICAL ENVIRONMENT

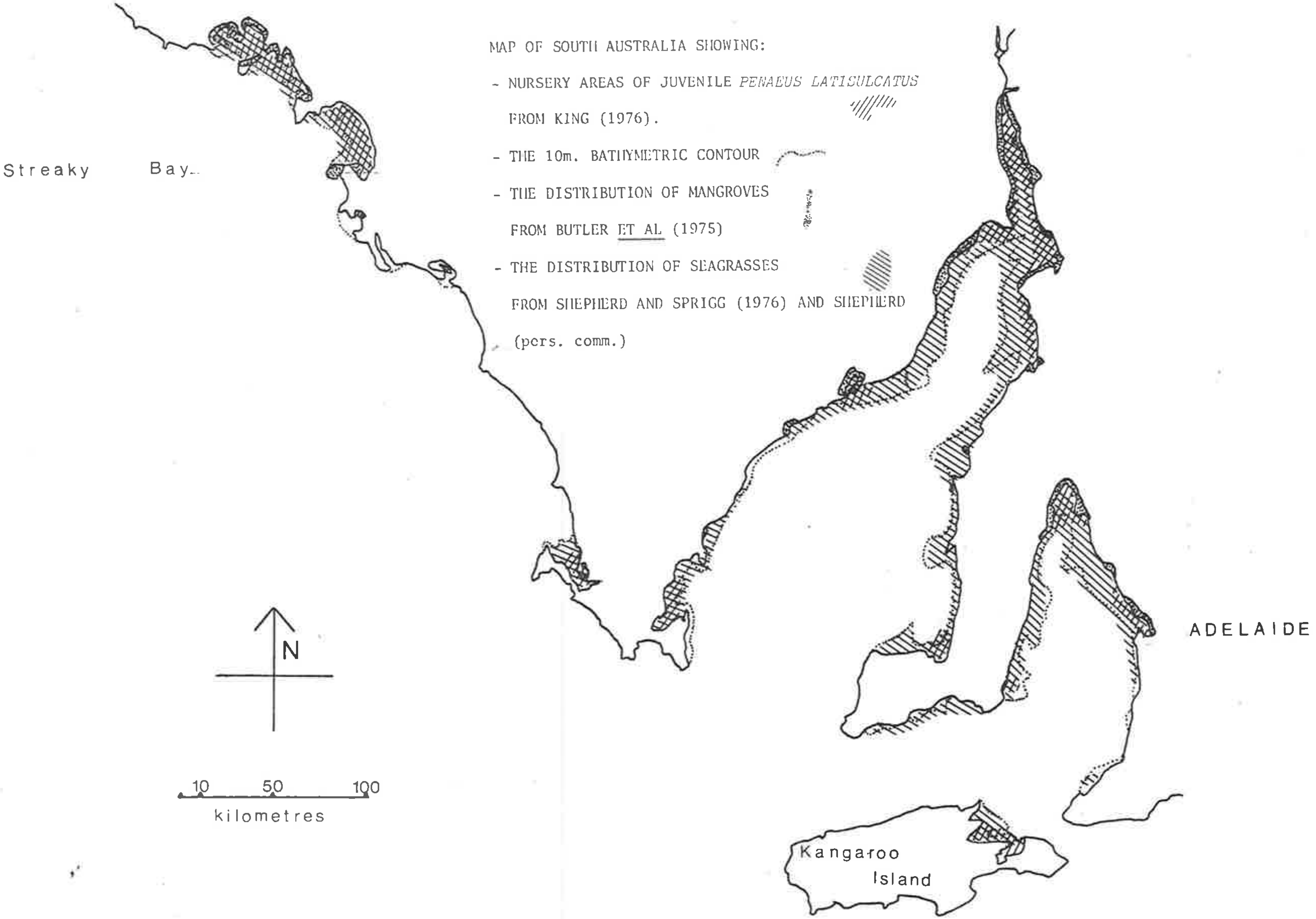
3.3.1 Introduction

Hall (1962) suggested that stands of mangrove trees were an essential part of the habitat of juvenile penaeid prawns. Hughes (1966) found that the juveniles of four species of penaeid prawns, *Penaeus monodon* Fabricius, *P. semisulcatus P. indicus* and *Metapenaeus monoceros*, were

FIGURE 5

MAP OF SOUTH AUSTRALIA SHOWING:

- NURSERY AREAS OF JUVENILE *PENAEUS LATISULCATUS* FROM KING (1976). ▨
- THE 10m. BATHYMETRIC CONTOUR ⋯
- THE DISTRIBUTION OF MANGROVES FROM BUTLER ET AL (1975) ⁝
- THE DISTRIBUTION OF SEAGRASSES FROM SHEPHERD AND SPRIGG (1976) AND SHEPHERD (pers. comm.) ▨



usually associated with mangroves, chiefly *Avicennia marina*. Two species, *P. semisulcatus* and *M.monoceros* however, were also found on littoral sand flats far removed from mangroves. Loesch (1965) found juvenile *P. aztecus* more abundant in "attached vegetation" than on bare sand. Australian studies show that mangroves fringe the littoral areas in which juvenile *P. merguiensis* occur in the Gulf of Carpentaria (Munro 1968) and in which juvenile *P. plebejus* occur in Moreton Bay (Young, 1975). In Moreton Bay, Young (1975) also found that more *P. plebejus* were caught over seagrass beds than on bare sand substrates.

The nursery areas of *P. latisulcatus* in Shark Bay are extensive and occur mainly along the sheltered shallow flats on the eastern and southern shores (fig. 7) (Slack-Smith 1969b). The well developed bank along the eastern shore which forms the main nursery area covers 1000 sq km and is an average of 8 km wide. The extensive intertidal flats shelve gently into this bank which extends gradually out to a depth of about 5m. (Davies 1970). Mangrove thickets of *Avicennia marina* are developed along the east coast of Shark Bay (Logan and Cebulski, 1970; Davies, 1970) and the main nursery areas of *P. latisulcatus* are fringed by these mangroves on the landward side and by the Wooramel seagrass bank (fig. 7) on the seaward side. The major seagrasses growing on this bank are *Posidonia australis* and *Amphibolis antarctica* (Davies, 1970). The wide intertidal and sublittoral flats mostly devoid of seagrass extend seaward from the high water mark until the seagrasses form extensive meadows. *P. latisulcatus* juveniles are found predominantly on the bare sand flats (Slack-Smith, 1969b).

3.3.2 Biological environment of juvenile *Penaeus latisulcatus* in South Australia.

King (1976) found the nursery areas of *P. latisulcatus* in South

Australian gulf waters to be usually associated with the mangrove *Avicennia marina* although there are some areas where large numbers of juveniles occur but mangroves are not present. The nursery areas are however, invariably associated with seagrass beds usually dominated by *Posidonia australis* and *Amphibolis antarctica*. These findings are consistent with the results of my trawling presented in the previous section, which showed that juvenile *P. latisulcatus* were present in Coffin Bay, Venus Bay, Streaky Bay, Smoky Bay and Denial Bay and that seagrasses were present in each of these bays, and that mangroves were present in all but Coffin Bay. The distribution of mangroves in South Australia has been mapped by Butler, Deepers, McKillup and Thomas (1977) and is shown in Figure 6 along with the distribution of juvenile *P. latisulcatus* (King 1976) and the distribution of seagrasses (Shepherd and Sprigg, 1976 and Shepherd pers. comm). Womersley and Thomas (1976) have described these coastlines as sand and mud flats usually backed by mangrove woodlands, with *Zostera macronata* patches in the lower eulittoral areas, *Heterozostera tasmanica* growing more extensively below this and in the sublittoral area *Posidonia australis* forming extensive meadows. According to Womersley and Thomas (1976) *Posidonia australis* is the most important primary producing plant in these areas.

From collections of juvenile prawns made in the waters around Torrens Island, some observations on the distribution of juvenile *P. latisulcatus* within the seagrass-mangrove system can be made. Throughout 1973 to 1976 juvenile prawns for experimental use were trawled by the method described in section 3.2.1 and although no formal catch data were kept it was noted that the majority of prawns were trawled from areas of bare sand rather than over patches of seagrass, and that prawns were most abundant in depths of ½ to 1m. Mangroves are present around most of the perimeter of Torrens Island and occur extensively on the eastern shore of Barker's Reach, especially to the north. Thus in both South Australian and Western Australian waters the nursery areas for juvenile *P. latisulcatus* are usually bounded on the landward side by stands of the mangrove *Avicennia marina* and on the seaward side by seagrass beds. However, the importance of these flora as determinants of the distribution of juvenile *P. latisulcatus* is difficult to assess.

3.3.3 Discussion

The importance of mangroves to the prawn and scale-fish fisheries of Florida has been stressed by Heald and Odum (1972). Animals inhabiting the estuarine system are dependent on an input of energy in the form of vascular plant detritus from decaying mangrove leaves. Penaeid prawns are amongst the relatively few species which are critical links in the mangrove detrital food chain (Heald and Odum, 1972). It is not only the mangrove leaf detritus that is thought to be an important food item, but the rich epiflora of fungi and bacteria which develops on the decaying leaves, that is ingested by the detrital feeders. Dall (1968) has suggested that many Australian penaeid prawns are primarily detrital feeders. Moriarty (1976) has shown that *Metapenaeus bennettae* is capable of digesting and assimilating bacteria and algae that are ingested along with detrital material. Moriarty (1977) has further described the prawns *M. Bennettae, Penaeus plebejus, P. esculentus* and *P. merguiensis* as opportunistic omnivores, not fitting into any strict trophic category but mainly feeding on micro-organisms and on other animals that feed on micro-organisms.

The role of mangroves and seagrasses in the ecology of juvenile *P. latisulcatus* seems to be that of a primary source of organic detritus. It is this detritus and its associated decompositional epibiota of algae, fungi, bacteria, protozoa and nematodes, which is thought to be the major food of juvenile prawns. The sand and mud flats support a rich flora of microscopic algae, and a prolific but inconspicuous fauna. It is on the shallower flats, before the seagrasses develop into dense extensive meadows that most juvenile *P. latisulcatus* seem to occur.

Butler, Deepers, McKillup and Thomas (1975) are of the opinion that the contribution to the organic detrital food chain may be substantially greater from seagrasses than from mangroves in South Australian waters. This is because the seagrasses are more extensive and have a longer growing season than the mangroves. This same situation has been found to be the case in Westernport Bay, Victoria (an environment similar to that of the South Australian Gulfs), where seagrasses provide a much greater proportion to the organic detritus than do mangroves (Attiwill and Clough, 1975). Young (1975) is of the opinion that mangroves are not as important in the ecology of juvenile *Penaeus plebejus* in Moreton Bay, as are seagrasses although the detritus produced by mangrove leaf fall may be of some importance.

Shelter from predators has been suggested as another resource offered to juvenile penaeid prawns by both mangrove and seagrass environments (Hoese 1960 , Parker 1970). This may apply to those species which inhabit the actual seagrass beds or which live amongst the pneumatophores of mangroves. Most juvenile *P. latisulcatus*, however, have been trawled from the more barren region between the mangroves and the seagrass beds. These sand and mud flats offer little protection from predators. One of the major predators of juvenile *P. latisulcatus* in South Australian waters appears to be the fiddler ray *Trygonorhina fasciata gaunerius* Whitley. Several fiddler rays caught near Barkers Reach during 1976 had stomachs filled exclusively with juvenile *P. latisulcatus* (Browning, pers comm). The fiddler ray is very common in South Australian waters and is often seen on the sand and mud flats in relatively shallow water (Scott, Glover and Southcott, 1974), and so predation by this species may be quite high.

3.4 SUBSTRATES AND SEDIMENTARY ENVIRONMENT

Williams (1958) pointed out the importance of substrate type as a factor in the distribution of penaeid prawns. In a series of laboratory experiments he found that *Penaeus duorarum* preferred a sand-shellgrit mixed substrate while *P. aztecus* and *P. setiferus* were found most often on sandy mud, muddy sand or loose peat substrates. Hughes (1966) found that *P. indicus* preferred a muddy rather than a sandy substrate.

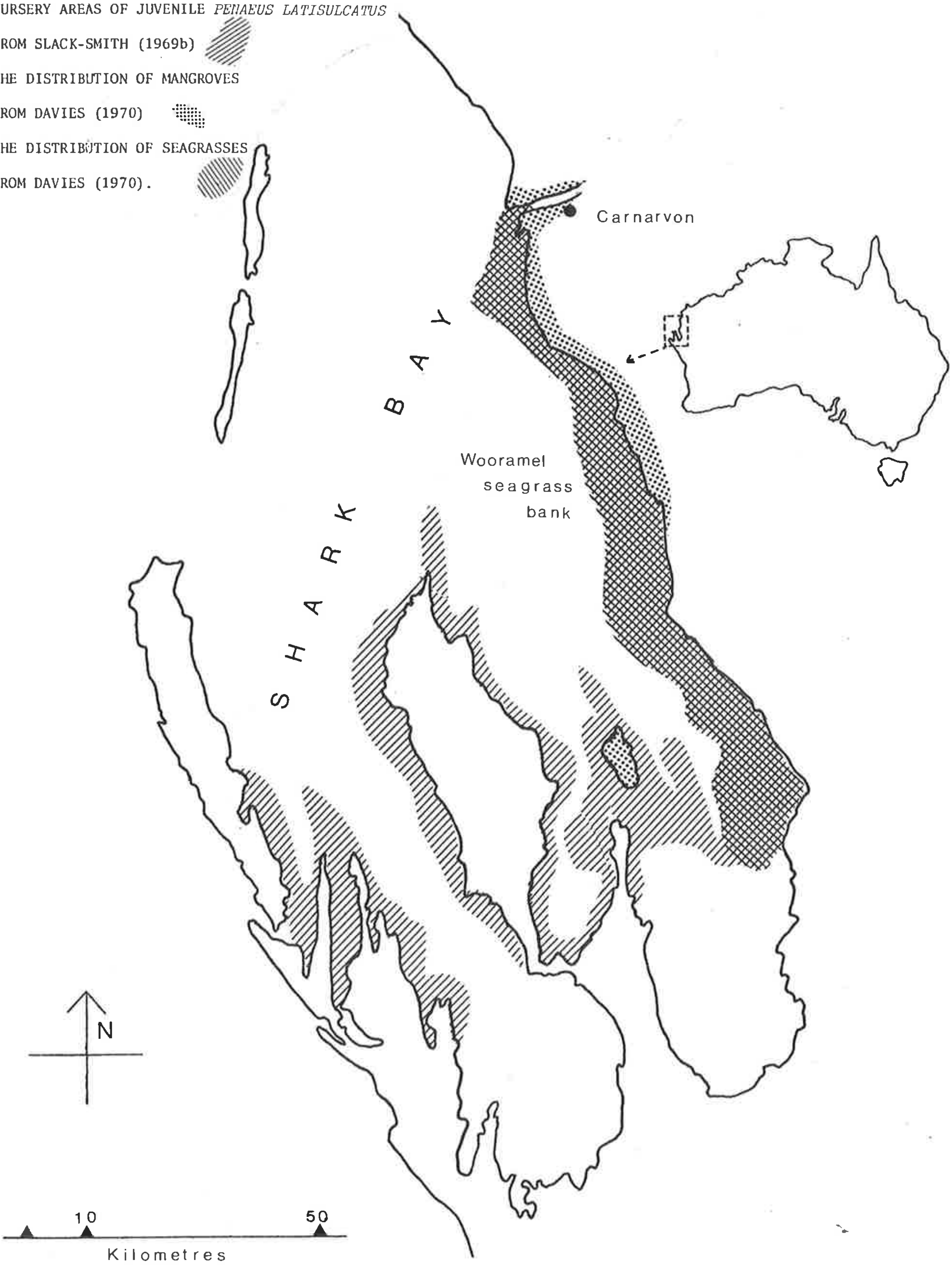
While conducting trials for a daylight sampling device for juvenile *P. latisulcatus* in Shark Bay, Penn and Stalker (1975) caught more juveniles on a fine silty sand substrate than on coarse sand. The sediments of the Wooramel seagrass bank forming the major nursery areas for juvenile *P. latisulcatus* in Shark Bay (fig.6) are described by Davies (1970). The sediments are mainly biogenic carbonates but include admixtures of terrigenous detrital quartz grains. In the sublittoral environment, skeletal fragments of encrusting foraminiferans and coralline algae characterize the sediments, which may contain up to 30% by weight of fine silt-sized skeletal fragments of magnesium-calcite composition (Davies, 1970).

The sedimentary environment of the shallow banks in the northern part of St Vincent Gulf is very similar to that of Shark Bay. Sediments

FIGURE 6

MAP OF SHARK BAY, WESTERN AUSTRALIA, SHOWING:

- NURSERY AREAS OF JUVENILE *PENAEUS LATISULCATUS* FROM SLACK-SMITH (1969b) ▨
- THE DISTRIBUTION OF MANGROVES FROM DAVIES (1970) ░
- THE DISTRIBUTION OF SEAGRASSES FROM DAVIES (1970). ▧



consist largely of carbonate skeletal detritus from encrusting coralline algae, bryozoans and foraminiferans, together with aragonite and quartz grains (Shepherd and Sprigg, 1976). Although no extensive research has been carried out on sediments of Spencer Gulf it is likely that sediment types would be very similar to those in St. Vincent Gulf. This is supported by the fact that the carbonate-rich sediments of the mangrove communities in northern Spencer and St. Vincent Gulfs have been categorized together as "gulf type" sediments by Butler et al. (1977).

3.5 HYDROLOGICAL ENVIRONMENT

3.5.1 Introduction

The vast majority of penaeid prawn species are marine except that during the younger stages they migrate to creeks, backwaters and estuaries of varying salinities (Panikkar, 1968). The importance of estuarine ecosystems to juvenile stages of penaeid prawns has been well attested (Newell and Barber, 1975; Young, 1975). In the Gulf of Mexico, juvenile *Penaeus duorarum*, *P. aztecus* and *P. setiferus* are all found in estuarine areas (Hoese, 1960; Loesch, 1965). Juvenile *P. monodon*, *P. indicus*, *Metapenaeus dobsoni* Miers, *M. affinis* Milne Edwards, *M. monoceros* and *M. breviiornis* Milne Edwards are all found in estuarine and brackish waters along the Indian coast (Mohamed, 1970a, b; George, 1970a, b, c, d). In Australian waters juveniles of *Penaeus merguiensis*, *P. plebejus*, *Metapenaeus bennettae* and *M. macleayi* inhabit estuarine waters (Dall, 1958; Racek, 1959).

Many authors have noted that juvenile penaeid prawns appear to be more abundant in low rather than higher salinity waters. For example George (*op. cit*) and Mohamed (*op. cit.*) found that juvenile prawns in Indian waters were prevalent in estuaries and brackish waters of "reduced salinity", and Lindner and Cook (1970) found juvenile *P. setiferus* in estuaries of "moderate to low salinities." Racek (1959) found *P. plebejus* and *Metapenaeus macleayi* in low salinity estuaries. However, relatively few authors have determined the actual salinities of the waters inhabited by juvenile prawns. Cook and Lindner (1970) found juvenile *P. aztecus* most abundant in salinities from 10 to 20‰. Dall (1958) found that small *Metapenaeus bennettae* occurred in salinities less than 20‰, and Ruello (1973) found *M. macleayi* more abundant in salinities less than 20‰.

The role of salinity in determining estuarine nursery areas for juvenile penaeid prawns has been investigated in more detail in the Gulf of Mexico but the results and their interpretation have been somewhat contradictory. Gunter (1950) found that 54% of juvenile *P. setiferus* were caught at salinities less than 15‰ and that *P. aztecus* and *P. duorarum* (not differentiated as separate species) were more abundant at salinities between 15 to 20‰. Gunter and Hildebrand (1954) noted that the very young *P. setiferus* go into waters of very low salinities and are quite common at salinities of 5‰ and less. They found a direct relationship between salinity and size since the juvenile prawns progressively move back towards the sea as they grow larger. Thus the larger prawns are not found in these very low salinities. Gunter (1961) is of the opinion that the optimum salinity for growth of *P. setiferus* is below 10‰ but that "small shrimp are not killed or precluded from higher salinity as if it were poison; they simply do not do well in it." Hoese (1960) is at disagreement with Gunter (1950) and Hildebrand and Gunter (1953) concluding that "salinity in broad ranges is inconsequential to young shrimp". His data however, are not comprehensive and record only several hundred *P. setiferus* from waters between 19 and 26‰ salinity along the gulf beach of Texas. Furthermore they relate to a region that is not the nursery area of *P. setiferus*. The nursery areas are in the bays, inlets and lagoons, as Gunter (1961 a) points out and it is likely that the prawns Hoese (1960) recorded had just left these nursery areas on their seaward migration. Another study which proposes that salinity is not an important factor is that of Parker (1970) who studied the distribution of juvenile *P. aztecus* in one estuarine system (Galveston Bay, Texas), and from his analysis of the data concluded that salinity was not important in the distribution of this species, although the data do suggest that there were more prawns in waters of lower salinities.

Gunter, Christmas and Killibrew (1964) studied the relationship between salinity and the distribution of juvenile *P. setiferus*, *P. aztecus* and *P. duorarum*. Combining the results of three wide-ranging surveys of all estuarine areas, inlets and coastal lagoons along the Texas coast they found that the lower salinity limit to the distribution of *P. setiferus* was 0.42‰ and that the juveniles were most abundant in waters of salinity less than 10‰ . The lower salinity limit of *P. aztecus* was found to be 0.8‰ and juveniles of this species were most abundant at salinities between 10 and 20‰ . *P. duorarum* were never found in waters of salinity less than 2.5‰, and over 95% were found in waters of 18‰ and higher.

In relation to the Australian species of penaeids, Kirkegaard (1975) proposes a classification of life cycles into three types: wholly estuarine, wholly marine and mixed cycles. *Metapenaeus bennettae* is the only species restricted to a wholly estuarine life cycle. The mixed cycle is typical of penaeid prawns and is represented by *Penaeus esculentus*, *P. plebejus*, *P. merguiensis* and *Metapenaeus macleayi*. *Penaeus semisulcatus* and *P. latisulcatus* are described as having wholly marine life cycles although *P. latisulcatus* is said to have a wholly marine cycle in some areas, such as Shark Bay, and a mixed cycle in other areas. The mixed cycle is presumed to hold for juvenile *P. latisulcatus* that have been found in some estuaries in southern Western Australia. However, the salinity of the water in which they were found is not given (Lenanton 1974) and although Penn (1975a) refers to these areas as "low salinity estuaries" he gives some indication that salinities in these areas may become hypersaline during the summer. In proposing a wholly marine life cycle for *P. latisulcatus*, Kirkegaard (1975) makes no mention of the salinity of the habitats occupied by juvenile *P. latisulcatus* in South Australian and Western Australian waters.

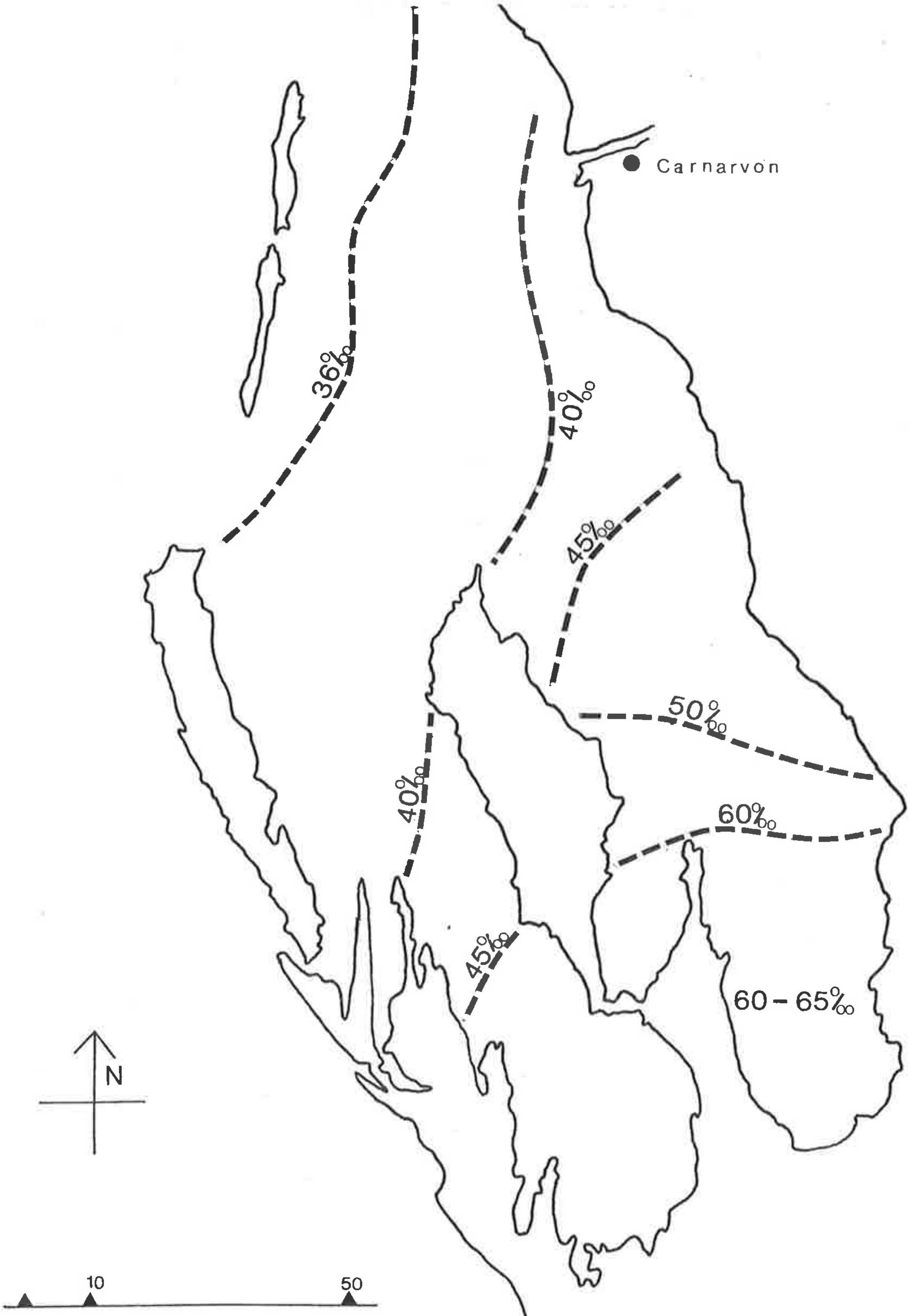
The major nursery areas of *P. latisulcatus* in Western Australia are in Shark Bay where juvenile stages up to 25mm carapace length are found along the extensive hypersaline shallow banks of the eastern and southern shores of the embayment (Slack-Smith, 1969b)(see fig. 6). Juveniles are found throughout the year, with the greatest apparent abundance occurring in summer when salinities would be the highest. Isohalines of summer salinities in Shark Bay during 1965 (from Logan and Cebulski, 1970) are shown in Figure 7 and it can be seen that the salinities over the major prawn nursery areas range between 40‰ and 60‰. The region covered by this salinity range is referred to as metahaline by Logan and Cebulski (1970) in contrast to the highly hypersaline area to the south, and the oceanic region in the northwest.

FIGURE 7

SUMMER ISOHALINES IN SHARK BAY, WESTERN AUSTRALIA

FROM LOGAN AND CEBULSKI (1970)

SALINITIES IN ‰



3.5.2 Salinities in *Penaeus latisulcatus* nursery areas in South Australia.

In South Australian waters the major nursery areas of juvenile *P. latisulcatus* occur at the heads of St. Vincent and Spencer Gulfs (King, 1976). Chlorinities of coastal waters in South Australia have been determined by Thomas and Edmonds (1956) who found that especially in the gulfs, salinities are strongly influenced by high local evaporation, low rainfall and small surface run off, resulting in high salinities at the heads of the two gulfs. Summer salinities at Pt. Augusta, at the head of Spencer Gulf are up to 48.5‰, while at Port Wakefield, at the head of St. Vincent Gulf they reach up to 47‰. Summer isohalines in Spencer and St. Vincent Gulfs (from Bullock, 1975 and Bye, 1976) are shown on the map (fig. 8).

Although indicating the trend of increasing salinity towards the heads of the gulfs, the isohalines shown in Fig. 8 lack resolution in the shallower coastal bays and backwaters that are the major nursery areas for juvenile *P. latisulcatus*. A considerable amount of data on salinities of inshore waters, mainly Barkers' Reach in St. Vincent Gulf (fig. 9) have been collected from various sources and from my own determinations.

In a previous study (Zed, 1972) salinities of the waters adjacent to Torrens Island, a region known to be an importance nursery area for juvenile *P. latisulcatus* in St. Vincent Gulf (M. King, pers. comm.) were measured. This study was expanded by Neverauskus (1977) and Leonavisius (unpublished) who selected the nine stations shown on fig. 9 at which salinities were measured during 1974 and 1975. In order that the data be comparable, subsequent salinity determinations made by me in this region were made

FIGURE 8

ISOHALINES IN SAINT VINCENT GULF (FROM BYE, 1976) AND IN SPENCER GULF (FROM BULLOCK, 1975). SALINITIES IN ‰

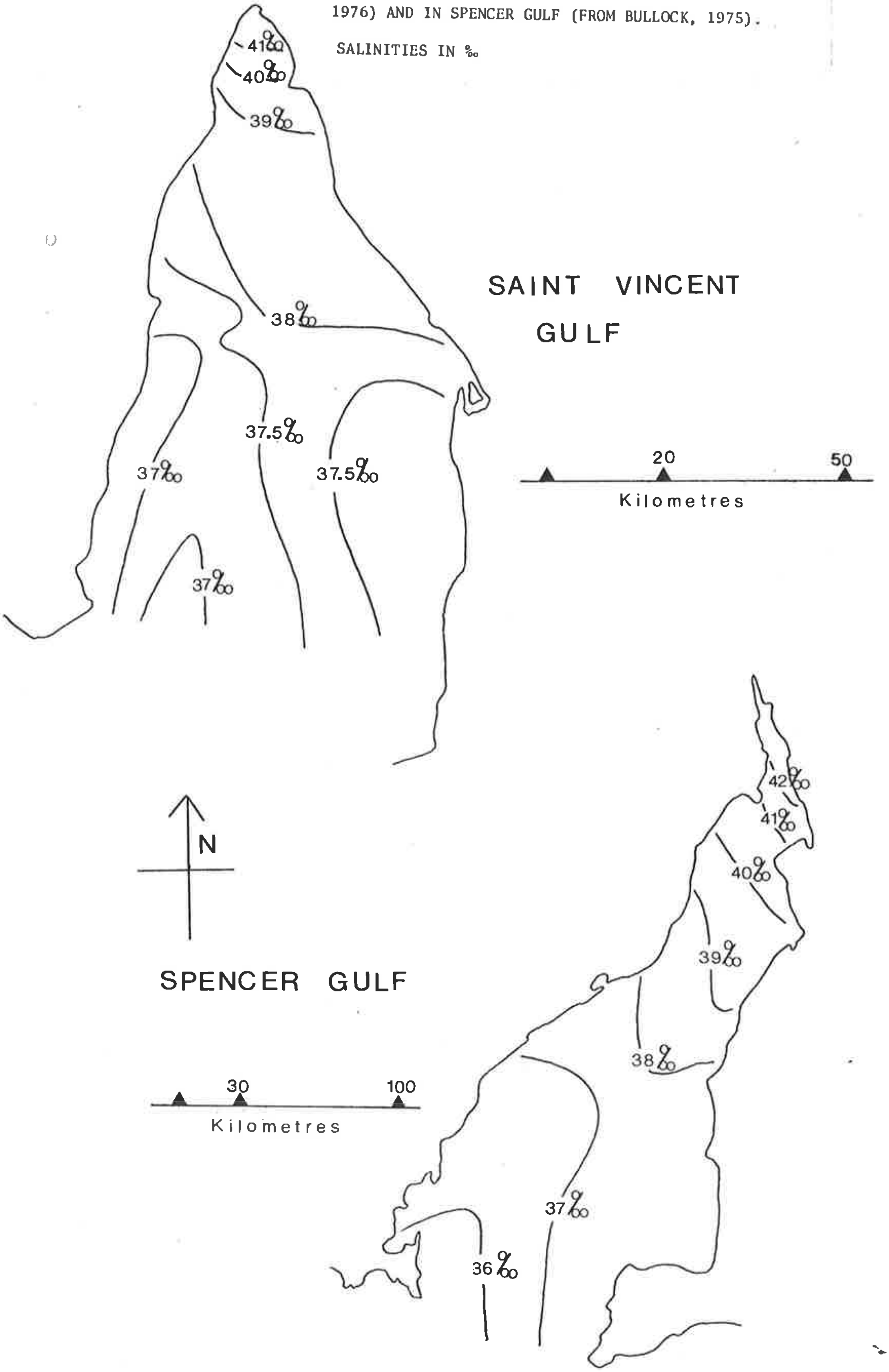
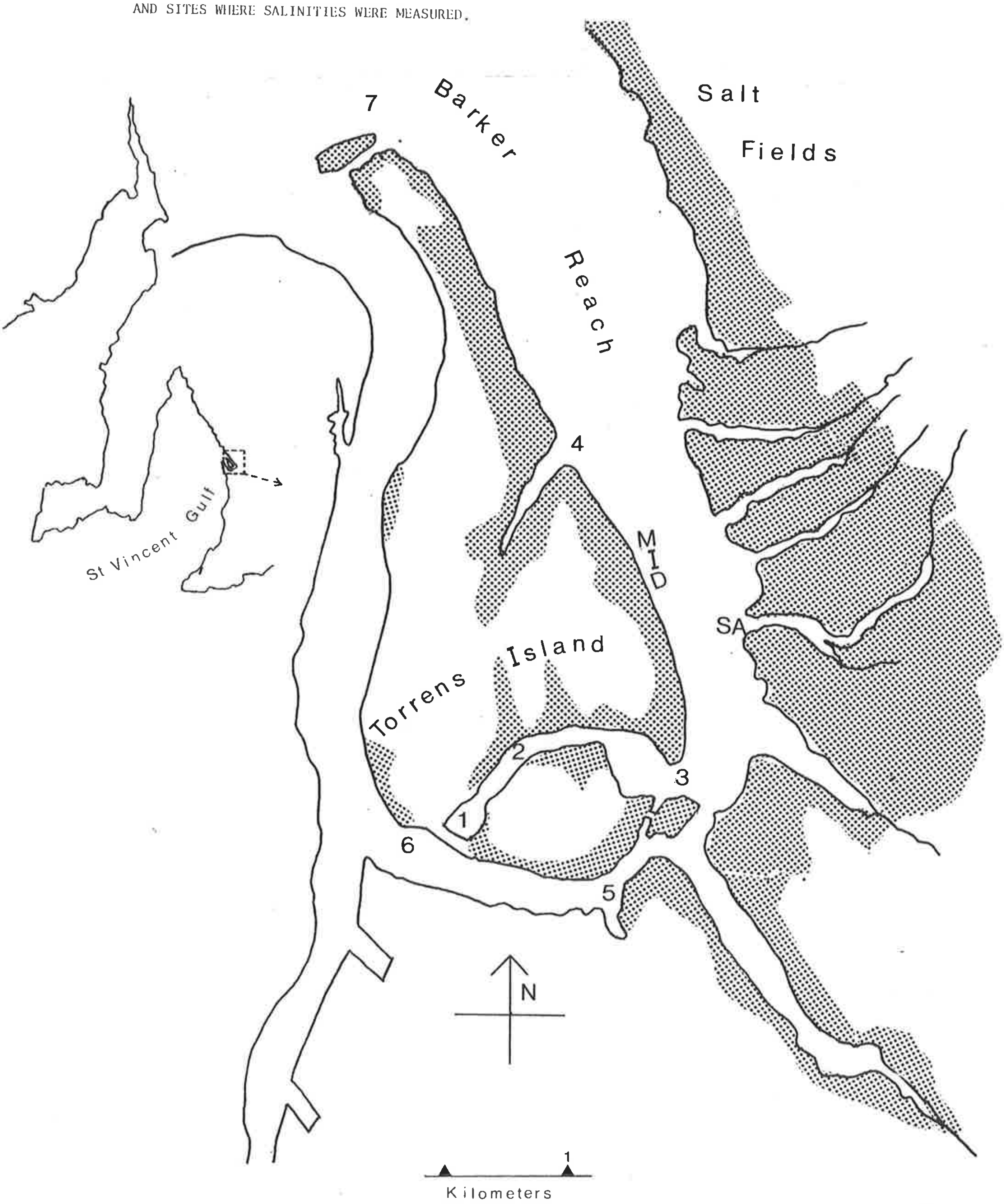


FIGURE 9

MAP OF TORRENS ISLAND SHOWING MANGROVES ▨

AND SITES WHERE SALINITIES WERE MEASURED.



at some or all of these nine stations.

Salinities of surface and bottom waters ranging in depth from 0.5 to about 2.5m were measured *in situ* with a Hamon Autolab model 602 portable temperature - salinity bridge calibrated against seawater of known salinity (I.A.P.O. Standard Seawater Service, Charlottenland Slot, Denmark, Salinity 35.000‰), and are presented in appendix A. Salinity data from other acknowledged sources are also presented there. From this data Table 3 showing summer salinities in the waters adjacent to Torrens Island has been prepared. On several occasions salinities were measured at Pt. Broughton, an important prawn nursery area in Spencer Gulf, and the data are listed in Table 4.

Table 3 shows that summer salinities in the sheltered waters of Barker's Reach (fig. 9) which is an important prawn nursery area may be up to 41.9‰, whereas the summer isohaline at this position in St. Vincent Gulf (fig. 8) is shown as 37‰. The salinities 37.8‰ and 37.3‰ measured at station 7 in January 1973 and April 1974 may be characteristic for this station since it is situated at the seaward extremity of Torrens Island, or they may be lower than normal due to the heavy rainfall in 1973 and 1974 (see section 5.4.2). Similarly at Pt. Broughton winter salinities of 43.3‰ have been measured whereas the summer isohaline through Pt. Broughton is shown as 40‰.

These discrepancies exist because isohalines are based on salinity readings taken offshore in deeper water. In the sheltered inshore regions where juvenile prawns are found salinities may therefore be several parts per thousand higher than are indicated by the isohalines.

The salinity data in appendix A indicate that salinities may fall to

TABLE 3

SUMMER SALINITIES OF WATERS ADJACENT TO TORRENS ISLAND

Stations as shown on fig 10, salinities in ‰

DATE	1	2	3	MID	4	5	6	7	S.A.
19.3.72	39.1								
19.1.73								38.0	
17.4.74								37.9	
15.1.75	39.5	39.2	39.3	40.6	40.3	39.6	39.5		41.9
31.1.75								40.1	
11.2.75	39.0	39.2	39.8	40.4	40.7	39.5	39.4		41.9

TABLE 4

SALINITIES AT PT. BROUGHTON

DATE	SALINITY ‰
11.6.76	43.1
19.7.76	42.9
2.8.76	43.3
7.9.76	43.0
14.10.76	40.5

low levels (e.g. 27.5‰ in upper Spencer Gulf during September 1973 and 18‰ in Barkers' Reach during October, 1974). Although such decreases in salinity may be important in the ecology of juvenile *P. latisulcatus*, the low salinities occur in a localized manner and are transient.

3.5.3 The atypical distribution of juvenile *P. latisulcatus* in relation to salinity.

The distribution of juvenile *P. latisulcatus* in relation to salinity is markedly different from that of other penaeid prawns. The juveniles of most other species inhabit estuaries where the salinities are considerably less than sea water (35‰) and in some cases have been recorded from almost fresh water. Conversely waters in the nursery areas for juvenile *P. latisulcatus* are usually never less saline than 35‰. In the Shark Bay nursery area salinities vary geographically from 40‰ to 60‰ and in Spencer and St. Vincent Gulfs from 36 to 48‰ or more. In the Gulf of Carpentaria salinities reach 40‰ and according to Munro (pers. comm.) one might expect the nursery areas of *P. latisulcatus* to be hypersaline. No data are available for salinities in other localities where *P. latisulcatus* are found except for the Red Sea where salinities higher than 40‰ occur.

The annual range of salinities in Shark Bay is about 5‰ (Logan and Cebulski 1970) and in South Australian coastal waters the range is a maximum of about 4‰ near the heads of Spencer and St. Vincent Gulfs (Thomas and Edmonds 1956). Thus the general hydrological environment of juvenile *Penaeus latisulcatus* in South Australia and Western Australia is hypersaline, and in the terms of Kirkegaard (1975), the life cycle of *P. latisulcatus* should perhaps be classified as "mixed hypersaline" rather than wholly marine. This would be in reasonable agreement with Kinne's (1964) use of the term "hypersaline" to describe waters between 40 - 80 ‰

The atypical distribution of juvenile *P. latisulcatus* in relation to salinity may have important implications for the migration, salinity tolerance and osmotic regulation of this species. The migratory mechanism described by Hughes (1969b, 1972) depends upon the response of postlarval and juvenile prawns in the Gulf of Mexico to salinity changes on ebb and flood tides. If such a mechanism was to explain the immigration of postlarval *P. latisulcatus* into the nursery areas in Shark Bay and the South Australian Gulfs the responses to salinity changes on ebb and flood tides would have to be reversed, since these waters are hypersaline to the incoming tidal waters. The migratory mechanism for *P. latisulcatus* in Shark Bay, described by Penn (1975) does not require any behavioural response to salinity changes and may therefore be of more general application. It might be expected that in adapting to a hypersaline environment the tolerance of juvenile *P. latisulcatus* to high salinities has become greater than that of other penaeid prawns. *P. latisulcatus* may also lack the ability to survive at the low salinities tolerated by other penaeid prawns, since they are generally found in waters at least as saline as normal seawater (35‰). Carpelan (1967) however, stresses that animals adapted to hypersalinity are generally also tolerant of low salinities and that in view of this, euryhalinity is probably a conservative evolutionary character. *P. latisulcatus* may be to some extent euryhaline but further adaptation to high salinities may have occurred to a greater extent than adaptation to low salinities. If this were so it could explain why no large populations of *P. latisulcatus* occur along the east coast of Australia where the sheltered inshore areas are generally hyposaline estuaries, although isolated records of individuals have been reported from Victoria, New South Wales and Queensland water.

CHAPTER FOUR

THE SOUTH AUSTRALIAN PRAWN FISHERY AND THE DERIVATION OF RECRUITMENT TO THE FISHERY

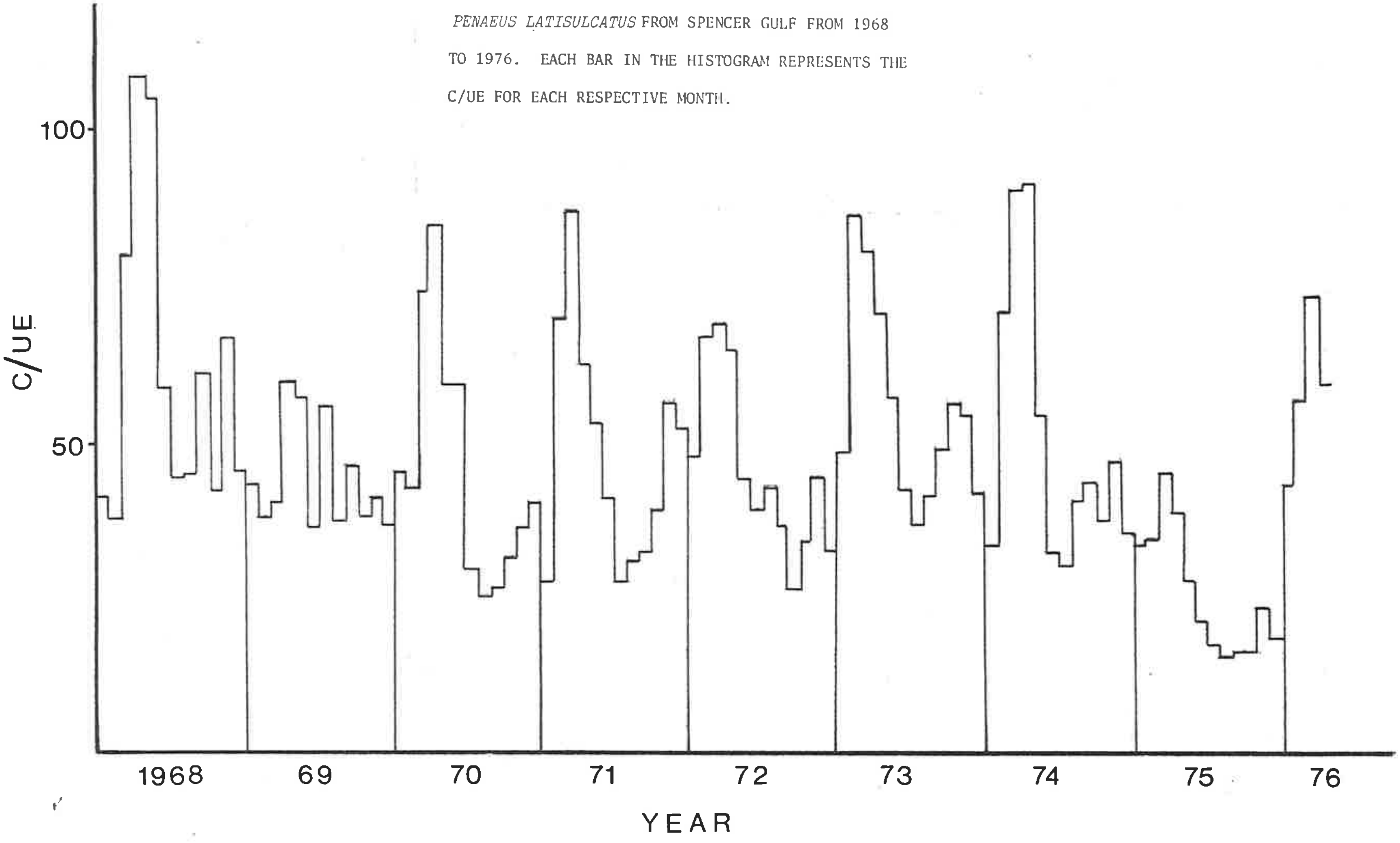
4.1 INTRODUCTION

In September 1967 a fishery based on one species of penaeid prawn, *Penaeus latisulcatus* was commenced in South Australia and by early 1968 was well established, especially in Spencer Gulf. Under the management policy of the Fisheries Branch of the South Australian Department of Agriculture and Fisheries prawn fishermen must be licensed and are restricted to trawl within certain zones. They are required to submit daily logs detailing catches, duration of fishing and fishing localities. In addition monthly summaries detailing the actual landings as recorded by the processing factory are also required. The accuracy of estimates of daily catch made by the fisherman can be checked against the actual landings. Thus a large amount of data on catches and fishing effort is now available. (Appendix B). This data will be examined with the aim of making estimates of recruitment to the fished stocks for each year.

An examination of the data from the Spencer Gulf prawn fishery reveals marked seasonal fluctuations in the catch per unit of standard fishing effort (Kg/hr trawled). The catch rate is high at the beginning of the year, declining to a low level during winter, then rising again during spring (fig 10). Fluctuations in the St. Vincent Gulf fishery are less obvious because the fishing is less intense and because fishermen often avoid trawling areas where newly recruited prawns are caught, or they return small prawns to the sea. In the West Coast fishery, fishing is often sporadic and in the early years the grounds were not well known. Thus only data from the Spencer Gulf fishery will be considered in the following discussion.

FIGURE 10

THE CATCH PER UNIT EFFORT IN KG/HR, OF *PENAEUS LATISULCATUS* FROM SPENCER GULF FROM 1968 TO 1976. EACH BAR IN THE HISTOGRAM REPRESENTS THE C/UE FOR EACH RESPECTIVE MONTH.



For stocks of commercially fished species such as prawns the C/UE is a useful index of the size of the stock (Ricker, 1958; Royce, 1968; Cushing, 1975). One can assume that each standard unit of fishing effort (in the case of the South Australian prawn fishery this is 1hr trawled) captures a fraction 'q' of the stock being fished. This can be summarized by the formula

$$C/UE = qD$$

where: C/UE is the catch per unit effort
q is the catchability coefficient
D is the stock density .

Clearly, variations in C/UE can be due either to variation in the catchability coefficient 'q' or to variations in the stock density 'D'. Changes in these factors will be investigated in the following two sections.

4.2 CHANGES IN THE CATCHABILITY COEFFICIENT 'q'

In most investigations of the population dynamics of exploited prawn populations it has been assumed that the catchability coefficient remains constant throughout the period of the investigation (Iversen, 1962; Costello and Allen, 1970; Kutkuhn 1966; Berry, 1969, 1971). Thus the C/UE is used as a direct index of the population size. However, Penn (1976) stresses that variations in the catchability of penaeid prawns are probably the greatest problem in producing valid population parameters for fisheries predominantly exploiting a single year class (such as the fishery for *Penaeus latisulcatus).*

Variation of catchability in a commercial fishery may result from changes in the intensity of effort applied to the fished stock (Garrod, 1964; White, 1975) or from changes in an individual prawn's vulnerability to the fishing gear.

4.21 Changes related to fishing intensity

To test the possibility of any association between C/UE and effort the data were first analysed to see if they were normally distributed (Appendix C). The C/UE data were distributed in a skewed manner and the effort data were irregularly distributed. Consequently a non-parametric RUNS test (Sokal and Rohlf, 1973) was performed on the data. When the month to month trend in the catch per unit effort was the same as that for the fishing effort, this was scored as a '+'. When the trends were opposite a '-' was scored. There were no neutral trends in the data. The number of '+' and '-' are recorded below:

number of '+' (N_1)	58
number of '-' (N_2)	37
number of RUNS (R)	52

Using the transformation:

$$Z = \frac{R - \left[\dfrac{2N_1N_2}{N_1 + N_2} + 1\right]}{\sqrt{\dfrac{2N_1N_2(2N_1N_2-N_1-N_2)}{(N_1+N_2)^2\ (N_1+N_2-1)}}}$$

(Siegel, 1956), Z was found to be 1.26 with a probability of 0.21 The critical value of Z at 5% level is 1.96. There is thus no significant correlation between the C/UE and the fishing effort in the Spencer Gulf fishery. This can be seen from Figure 11. Penn (1976) also found that the catchability of *P. latisulcatus* is more likely to be affected by changes in the vulnerability of the prawns to the fishing gear rather than by changes in the fishing intensity.

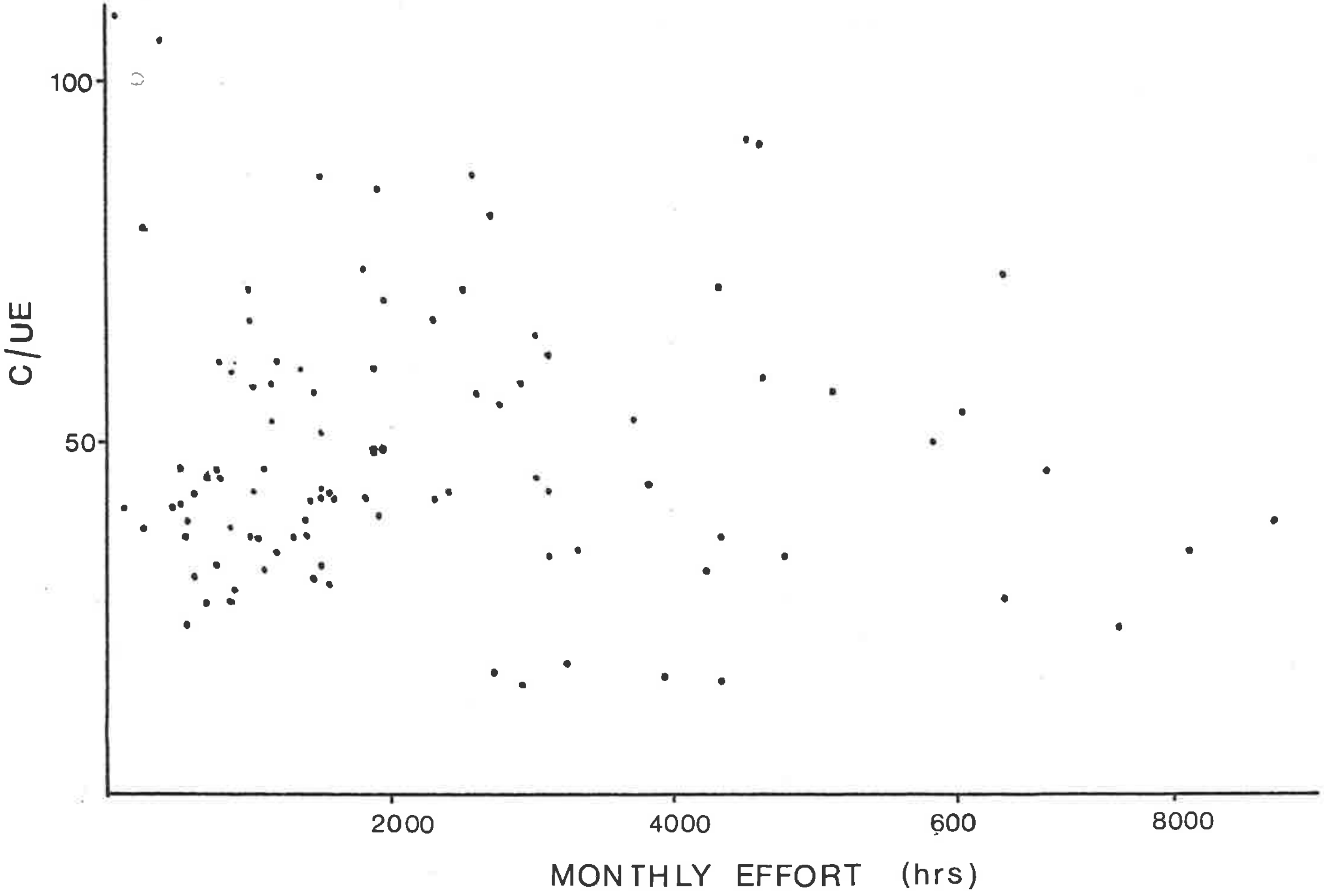
4.2.2 Factors affecting the vulnerability of prawns

Changes in a prawn's vulnerability to the fishing gear occur due to behavioural and physiological changes affecting the activity of the prawn, which may be related to certain environmental stimuli. The nocturnal activity of penaeid prawns has been well documented (Fuss and Ogren, 1966; Hindley, 1975; Hindley and Penn, 1975; Hughes, 1969a,b 1972) and one would expect the catchability of penaeid prawns to be greatest during the hours of darkness. White (1975) has demonstrated such short term variations in the catchability of the tiger prawn *Penaeus esculentus* over a 24 hr. cycle. Penn (1975a) has demonstrated the same variation in *Penaeus latisulcatus*. Since *P. latisulcatus* is fished only at night in Spencer Gulf, short term variation in catchability due to day/night cycles do not exist in the data.

Many workers have attempted to relate the behaviour of penaeid prawns to lunar cycles (Racek, 1959). White (1975) suggests a relationship between catchability of *P. esculentus*, and lunar cycles, with the biggest catches occurring at new moon and low catches occurring near and at full moon. In the South Australian prawn fishery fishermen consider trawling at the time of full moon unprofitable.
Since the data presented are derived from totals of catch and effort over one month, possible variations due to lunar cycles are lost from the data.

FIGURE 11

SCATTER DIAGRAM OF CATCH PER UNIT EFFORT AND FISHING EFFORT IN THE SPENCER GULF PRAWN FISHERY.



It has been suggested by Penn (1975a, 1976) that the vulnerability of *P. latisulcatus* to the trawling gear is related to water temperature since temperature is known to affect the activity of penaeid prawns (Fuss and Ogren, 1966). Long term variations in the catchability of *P. esculentus* attributed to fluctuations in water temperature have been demonstrated by White (1975). Williams (1969) has been able to demonstrate a relationship between the summation of coastal air temperatures and the total catch of three species of prawns, *Penaeus duorarum, P. aztecus* and *P. setiferus*. Good catches are associated with warm years and it is suggested that this could be a direct result of water temperature on the catchability of these species. Morgan (1974) found the catchability of the western rock lobster *Panulirus cygnus* to be positively correlated with water temperature. The catchability coefficient for *P. latisulcatus* in Cockburn Sound, Western Australia, has been calculated by Penn (1976). He found that catchability increased during the spring and suggested that the rise in water temperatures during this period was responsible for the increased catchability. It is possible that the increase in C/UE observed during the spring months before the major recruitment commences in the Spencer Gulf prawn fishery is due to increased catchability of the prawns resulting from increases in water temperature. Mean weekly water temperatures in northern Spencer Gulf are listed in Appendix D and show that water temperatures increase from a minimum of approximately 12°C in winter to a maximum of approximately 24 or 25°C in summer.

4.2.3 The relationship between water temperature and catchability

4.2.3.1 Introduction

It appears that in any further considerations of the catch per unit effort data it will be necessary to take into account the probable effects of water temperature on the catchability of the prawns. Catchability of prawns is related to activity (Penn 1975a, 1976) and so an experiment to determine the effects of temperature on the activity of *P. latisulcatus* was carried out, and the results of this experiment were later used to describe the catchability of prawns in the fishery.

4.2.3.2 Materials and methods

The method of collection of prawns is described in section 3.21. Twenty adult prawns were collected from the Pt. Broughton Prawn Culture Centre and returned to the laboratory. Ten prawns were held in each of two aquaria at constant temperature (19^{o}C) and salinity (38 to 39%), for one week. The substrate, filtration and aeration and dimensions of the aquaria are described in section 6.2.1. Constant temperature was maintained by placing each aquarium in a large thermostatically controlled constant temperature cabinet. Each aquarium was lit for 12 hours each day by an 8w "daylite" fluorescent lamp, corresponding approximately to the natural period of daylight. The prawns were fed *ad. lib* commercial pellet type fish food on the third evening. On the seventh night the activity of the prawns was recorded as the mean proportion of prawns above the substrate. The prawns were counted ten times at random between the hours of 9.00 p.m. and 10.00 p.m. Since even very short exposure to white light is known to significantly reduce the activity of *P. latisulcatus* (Hindley and Penn 1975), observations were made using an underwater divers torch fitted with a red optical filter. The prawns were fed after counting.

The temperature in aquarium A was then raised to 20.5^{o}C and after four days the activity was recorded as described above, the prawns were fed again and the temperature was raised to 25.0°C. After a further four days activity was again recorded. Concurrently the temperature of aquarium B was lowered to 17°C, and activity at this temperature recorded. The temperature was further lowered to 13°C. Because some of the prawns in aquarium B died during the experiment the number of observations made in the 9.00 p.m. to 10.00 p.m. period was increased to bring the total "possible" counts to approximately 100.

It had been planned to raise and lower the temperatures of the respective aquaria by successive 2°C increments every four days, however, due to malfunctions in the constant temperature cabinets this was not possible and a final breakdown in the apparatus meant that the experiment had to be terminated after the second set of activity counts.

4.2.3.3. Results

The results obtained from this limited experiment are presented in Table 5. They clearly indicate a trend of increasing activity as the temperature increases. The regression of activity against the natural logarithm of temperature of the form:

$$a = b \ln T - c$$

was calculated and found to be:

$$\text{activity} = 0.68 \ln T - 1.31.$$

The standard error of the regression coefficient 'b' was found to be 0.0596, that of 'c', 0.1725 and the coefficient of determination 'r2'

TABLE 5

ACTIVITY OF *P. LATISULCATUS* AT VARIOUS WATER TEMPERATURES

AQUARIUM	WATER TEMP. °C	NUMBER OF PRAWNS IN AQUARIUM	NUMBER OF OBSERVATIONS MADE	NUMBER OF PRAWNS ACTIVE EACH OBSERVATION	MEAN PROPORTION OF ACTIVE PRAWNS
A	25	10	10	9,9,9,8,10,9,9, 9,9,10	0.910
A	20.5	10	10	8,9,7,7,7,5,7, 8,8,9	0.750
A	19	10	10	7,8,6,7,8,7,6,7, 6,7	0.660
B	19	10	10	8,6,6,7,6,6,6,5, 6,6	0.660
B	17	8	12	4,6,5,4,4,5,3,5, 5,5,3,4	0.563
B	13	6	17	2,3,4,2,4,3,2,2, 3,3,2,2,3,4,2,3,2	0.451

to be 0.6735. The significance of the regression coefficient is tested as:

$$t_{(67)} = \frac{0.68}{0.0596} = 11.2966.$$

The critical value of $t_{(67)}$ at the 0.001 level of significance is 3.460, so the regression is significant at this level.

4.2.3.4 Discussion

Although the data were not extensive the regression of activity on ln water temperature is highly significant (at the 0.1% level) accounting for 67% of the variability of the data. Analysing the data of Fuss and Ogren (1966) in the same way a regression of activity of *Penaeus duorarum* on ln water temperature produced the equation $a = 0.71 \ln T - 1.43$, a relationship very similar to that for *P. latisulcatus*. The range of mean monthly water temperatures in upper Spencer Gulf is from approximately 12.5°C to approximately 25.5°C (Appendix D and this range is almost covered by that of the experimental temperatures. Since activity was measured as the proportion of unburrowed prawns at each experimental temperature, this can be related to the fishery situation. Unburrowed prawns are obviously vulnerable to a net being trawled across the substrate whereas deeply burrowed prawns are not vulnerable to the net. The catchability will therefore be assumed to be directly proportional to the activity and thus

$$q = \alpha a = \alpha (0.68 \ln T - 1.31).$$

where α is a constant of proportionality, the value of which cannot be determined from the existing data. The validity of this expression as a description of catchability of *P. latisulcatus* in the Spencer Gulf fishery can be investigated after allowance has been made for the effects of growth on the C/UE figures and estimates of mortality have been made.

4.3 CHANGES IN THE STOCK DENSITY 'D'

Changes in the stock density D can be assigned to the four variables migration, growth, mortality and recruitment. Tagging experiments conducted by King (pers. comm.) suggest that the Spencer Gulf fishery is a closed system. Prawns tagged in the northern part of the Gulf generally move in a southerly direction. However, out of many thousands of prawns tagged and released in Spencer Gulf, none have been recovered outside of the Gulf, although a high percentage of the tagged prawns have been recovered in the gulf. Since the C/UE data is from the whole of the Spencer Gulf fishery the effects of migration of prawns within the gulf can therefore be neglected. The effects of the remaining three factors will now be discussed.

4.3.1 Growth

The C/UE data are expressed in terms of Kg of prawns trawled per hour of trawling. A given number of prawns caught at the beginning of the year will weigh less than the same number caught at the end of the year. Thus the catch rates are biased throughout the year by the continued growth of individual prawns.

Preliminary estimates of growth rates have been calculated for *Penaeus merguiensis*, *P. esculentus* and *P. plebejus* by Lucas (1975). The rates were all very similar, being rapid for the first few months, then leveling out for the remainder of the year. Some data are available on the size distribution of prawns from month to month in Spencer Gulf (King, 1976). The mean size of prawns from Spencer Gulf from month to month has been derived from the size frequency data of King (1976) and is shown in Table 6.

In order to convert these mean carapace lengths to weights, a length weight relationship for *P. latisulcatus* was derived. A total of 200 prawns were obtained from a commercial prawn fisherman at Pt. Adelaide at various times during 1973 to avoid seasonal bias (Fontaine and Neal, 1971). The carapace length of each prawn was measured to the nearest mm. and the wet weight to the nearest 0.1 gm was determined (Appendix E). A linear regression between log carapace length and log wet weight for male and female prawns combined was calculated and the relationship was found to be

$$\text{Log wt} = -2.1308 + 2.2804 \log CL$$

confidence limits at the -5% level were found to be:

$$-2.1308 \pm 0.1296$$

$$+2.2804 \pm 0.0800$$

coefficient of determination (r^2) = 0.9490

Although Fontaine and Neal (1971) found small differences in the length/weight ratios of male and female penaeid prawns the small sample size in this case does not permit the calculation of separate length - weight relationships for male and female *P. latisulcatus*. However, from the distribution of carapace lengths and weights (fig 12) and the high coefficient of determination of the combined sample it is likely that there is no major difference in the length-weight relationship for males and females. The same relationship between carapace length and weight is assumed to apply in Spencer Gulf. Thus the size data transformed to weights is shown in Table 7. Since the

TABLE 6

MEAN CARAPACE LENGTH OF *P. LATISULCATUS* IN SPENCER GULF

Mean Carapace length (nearest 0.1 mm)

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
♂ Mean Cl.mm	25.7	26.9	27.9	31.6	32.7	34.2	33.3	34.3	34.6	34.3	33.4	28.6
♀ Mean Cl.mm	28.0	29.4	30.4	34.3	36.8	36.2	38.7	39.9	41.3	38.7	38.4	32.7
Mean Cl.mm	26.9	28.2	29.2	32.9	34.8	35.2	36.0	37.1	37.9	36.7	35.9	30.7

TABLE 7

MEAN NET WEIGHTS OF *P. LATISULCATUS* IN SPENCER GULF

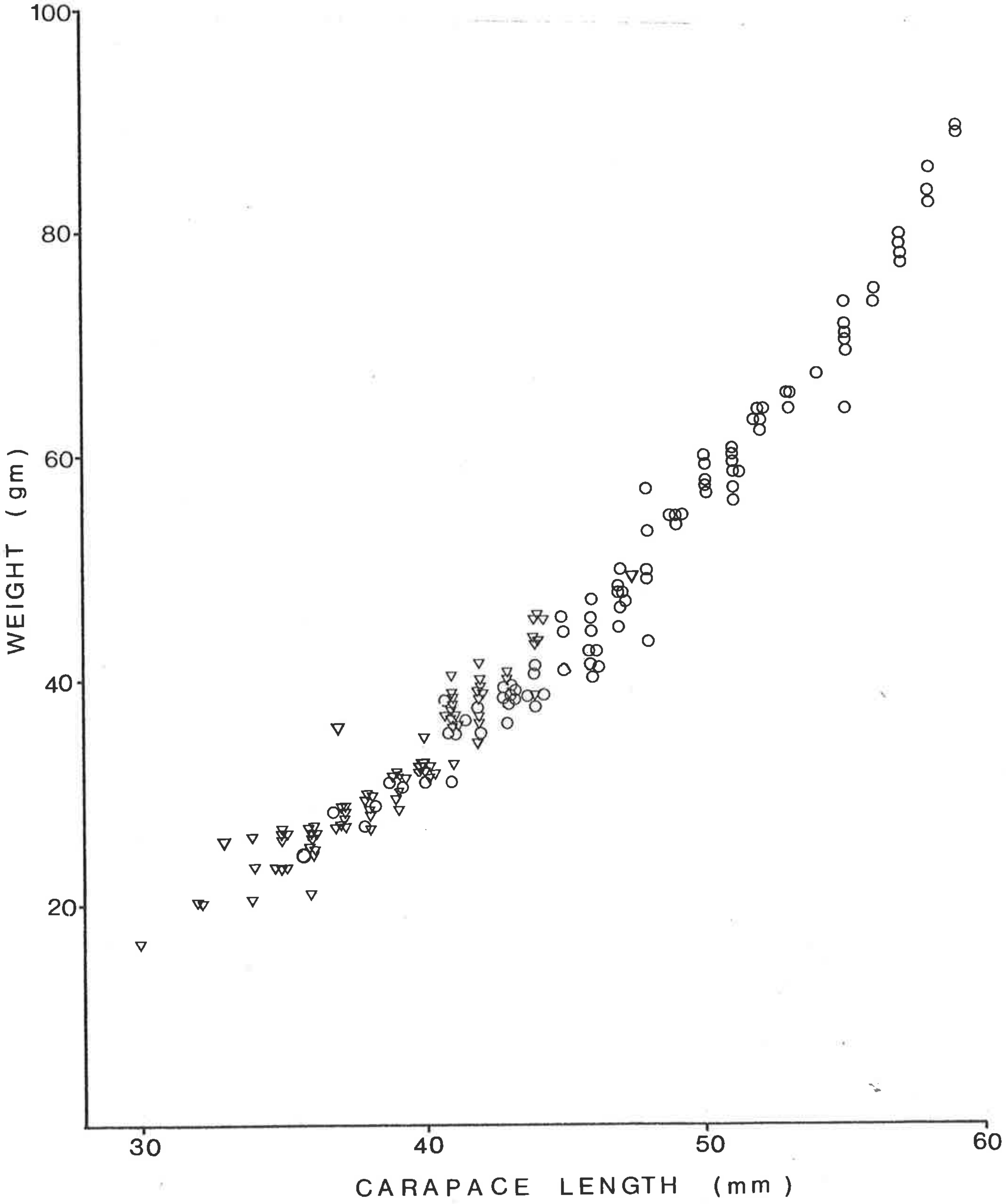
Mean weight (nearest 0.1 gm)

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
♂ Mean Wt gm	12.2	13.5	14.6	19.5	21.0	23.3	21.9	23.5	23.9	23.7	22.1	15.5
♀ Mean Wt gm	14.8	16.5	17.8	23.5	27.5	26.5	30.9	33.1	35.8	31.3	30.3	21.0
Mean Wt gm	13.5	15.0	16.2	21.5	24.3	24.9	26.4	28.8	29.8	27.5	26.2	18.3

FIGURE 12

NET WEIGHTS OF *PENAEUS LATISULCATUS* PLOTTED AGAINST THEIR CARAPACE LENGTHS.

- MALES ▽
- FEMALES ○



sex ratio is 1:1, the mean of the male and female weights is the mean weight of an individual prawn in each month.

It is now possible to convert the catch per unit effort figures from Kg/hr trawled to numbers/hr. trawled using the mean weights of prawns from month to month. This conversion makes the assumption that the mean monthly weights remain the same from year to year. This assumption is not strictly correct since King (pers. comm.) has evidence that while growth rates are similar from year to year the phasing may be out of time by a few weeks. Without empirically derived size distributions for each year the strict conversion of weights to numbers cannot be made. However, for the purposes of this investigation the conversion using the assumption that the size distributions are similar from year to year seems reasonable as it makes allowance for the growth of prawns from month to month. No accuracy is lost since the weight caught per hour each month is divided by the same mean weight each year to obtain the numbers caught per hr. The advantage is that for no loss in accuracy the effects of growth during the year can be largely eliminated from the data.

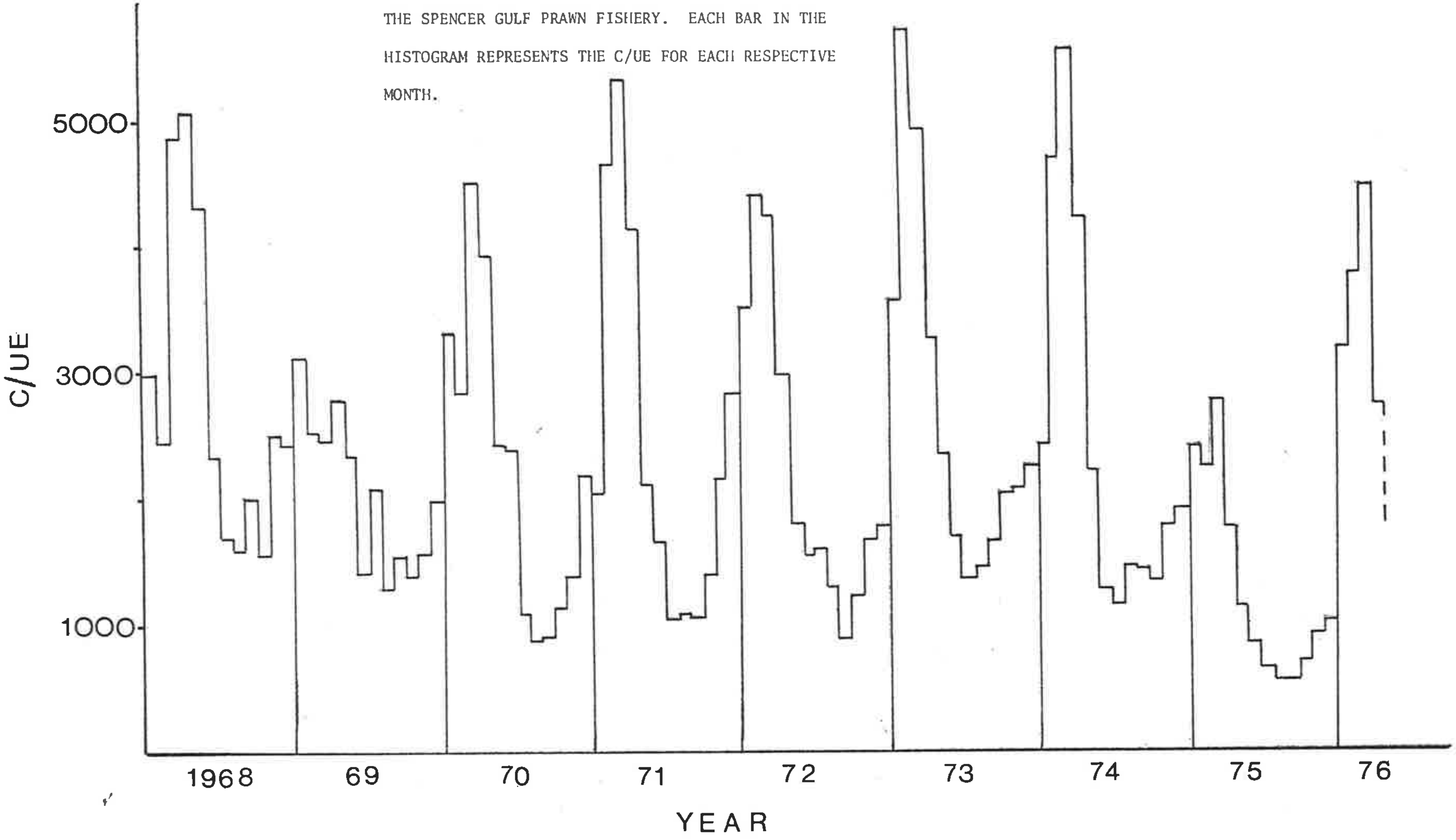
The catch per unit effort data, transformed to numbers caught per hour trawled according to the above reasoning are set out in appendix F, and are shown in Figure 13. The large peaks in catch per unit effort at the beginning of each season, the sharp decrease to low levels in winter and the rising values of catch per unit effort in spring are made more apparent in this data.

4.3.2 Mortality

Estimates of the instantaneous total mortality of prawns in the Spencer

FIGURE 13

CATCH PER UNIT EFFORT IN NUMBERS PER HOUR IN THE SPENCER GULF PRAWN FISHERY. EACH BAR IN THE HISTOGRAM REPRESENTS THE C/UE FOR EACH RESPECTIVE MONTH.



Gulf fishery for each year can be made by solving the exponential mortality equation:

$N_t = N_o e^{-Zt}$ (Ricker, 1958) where:

N_o is the number of prawns at time o

N_t is the number of prawns at time t

t is the lapsed time

Z is the instantaneous total mortality coefficient .

Catch per unit effort (C/UE) will henceforward be abbreviated to C.

Since $C = qD$ where D is the density of prawns

and $N = AD$ where A is the area fished

therefore $C = q \times \frac{N}{A}$

therefore $N = \frac{1}{q} \times A \times C$

The instantaneous mortality equation can thus be expressed as

$\frac{1}{q_t} \times A_t \times C_t = \frac{1}{q_o} \times A_o \times C_o \times e^{-Zt}$ where the subscripts t and o denote the values of catchability 'q', area fished "A' and catch per unit effort 'C' at times t and o respectively.

Since we are considering the fishery in Spencer Gulf as a closed system the area fished is considered constant so A_t and A_o can be cancelled from each side of the equation leaving:

$$\frac{1}{q_t} C_t = \frac{1}{q_o} C_o e^{-Zt}$$

or

$$C_t = \frac{q_t}{q_o} C_o e^{-Zt}$$

The factor $\frac{q_t}{q_o}$ cannot be cancelled from the equation unless $q_t = q_o$. Most of the previous investigations of the dynamics of exploited prawn populations have assumed that catchability remains constant or in other words that $q_t = q_o$ (Iverson, 1962; Costello and Allen 1970; Kutkuhn, 1966; Berry, 1969, 1971). However it can be seen from the discussion in section 4.2.3 that the catchability coefficient 'q' is not constant and that allowance must be made for the effects of water temperature on it. Therefore, to solve the exponential mortality equation for "Z" C_o and C_t are chosen at time 'o' in the beginning of the season and time 't' later in the season before the next recruitment when water temperature is the same as at time 'o'. Under these circumstances q_o and q_t are assumed to be equal and thus $\frac{q_t}{q_o} = 1$ and the mortality equation becomes

$C_t = C_o\ e^{-Zt}$ and can be solved for "Z'

For example the mortality rate in 1968 is calculated thus:

$$C_t = C_o e^{-Zt}$$

therefore $$e^{-Zt} = \frac{C_t}{C_o}$$

therefore $$-Zt = \ln C_t - \ln C_o$$

therefore $$Z = \frac{1}{t}\ (\ln C_o - \ln C_t).$$

Choosing C_o as the catch per unit effort during April and C_t as that during November, when the water temperatures were similar (table 9), the instantaneous total mortality 'Z' in 1968 is found to be:

$$Z = \frac{1}{7}\ (\ln 5095.6 - \ln 2534.4)$$
$$= 0.0998 \text{ per month, or } 0.0249 \text{ per week.}$$

Similarly, mortality rates for the years 1969 through to 1975 have been calculated and are presented in Table 8.

For all years except 1972 and 1975, mortality was estimated over the period April to November, since water temperatures were similar (approximately 20°C) during these two months (Appendix D). During 1972 and 1975 similar water temperatures of about 21°C occurred in March and November (Appendix D) so mortalities were estimated over the period March to November for these two years.

The expression of mortality as rates (per month or per week) assumes that mortality is constant throughout the season. Mortality is not likely to remain constant, however, the estimates are valid if the period April to November or March to November, as the case may be, is considered as one unit of time. Expressing the mortality as monthly or weekly rates thus gives a value of Z which is the average monthly or weekly value over this period. The values of Z obtained for the Spencer Gulf population of *P. latisulcatus* are all reasonably consistent with those obtained by (Penn 1975, 1976) who found from tagging experiments the range of weekly mortalities from 0.029 to 0.043 to be a realistic indication of the range of 'Z' values likely to occur in an exploited population of adult *P. latisulcatus*.

4.3.3 Recruitment

4.3.3.1 Models of catch per unit effort in the Spencer Gulf prawn fishery.

Since recruitment of *P. latisulcatus* is an annual event having its

TABLE 8

MORTALITY RATES OF *PENAEUS LATISULCATUS* IN THE SPENCER GULF FISHERY

YEAR	Total instantaneous mortality rate ('Z') PER MONTH	PER WEEK
1968	0.0998	0.0250
1969	0.0828	0.0207
1970	0.1502	0.0398
1971	0.0933	0.0233
* 1972	0.0925	0.0231
1973	0.1264	0.0316
1974	0.1228	0.0307
* 1975	0.1424	0.0356

* Calculated over the period March to November

peak in the early months of the year (King, 1976) changes in the catch per unit effort during any year should be due largely to mortality of prawns and to the effects of water temperature on the catchability. (Possible effects of other factors on the catch per unit effort have been discussed and accounted for in the previous sections). In order to test this hypothesis a model of the catch per unit effort of *P. latisulcatus* in Spencer Gulf assuming constant catchability, and a model which allows the catchability to vary according to the observed water temperatures in Northern Spencer Gulf will be compared to the observed data on catch per unit effort.

Both models are based on the assumption that the prawn population follows an exponential decline due to mortality at the rates derived in section 4.3.2. These rates were estimated from two values of the catch per unit effort chosen at times of each year when the water temperature was similar.

This does not imply prior acceptance of the temperature compensated model since if temperature has no effect on C/UE, then C_o and C_t chosen at any two times (including times when temp. is equal) will provide a valid estimate of the mortality. However, if temperature does affect catchability then C_o and C_t chosen at different temperatures will provide over estimates or under estimates of the true mortality. Since the same mortality rates must be used in both models, derivation of the rate from C_o and C_t when temperatures are equal must be used since this will be consistent with both models.

The predicted values of catch per unit effort for the constant catchability model are obtained by evaluating the equation:

$$C_t = \frac{q_t}{q_o} C_o e^{-Zt}$$

assuming that $q_t = q_o$

and that therefore $\frac{q_t}{q_o} = 1$

therefore $C_t = C_o e^{-Zt}$

Values predicted by the temperature compensated model are obtained from the expression:

$$a = 0.68 \ln T - 1.31$$

relating the activity of *P. latisulcatus* to water temperature which was experimentally derived in section 4.23. It was proposed that this expression could be used to describe the catchability of prawns if catchability was directly proportional to activity.

Thus: $q = \propto a$

therefore $q = \propto(0.68 \ln T - 1.31)$

therefore $\frac{q_t}{q_o} = \frac{\propto(0.68 \ln T_t - 1.31)}{\propto(0.68 \ln T_o - 1.31)}$

therefore $\frac{q_t}{q_o} = \frac{0.68 \ln T_t - 1.31}{0.68 \ln T_o - 1.31}$

From the data on mean weekly seawater temperatures in northern Spencer Gulf (Appendix D), the mean monthly seawater temperatures have been calculated and are presented in Table D2. These temperatures can be substituted into the expression

$$\frac{q_t}{q_o} = \frac{0.68 \ln T_t - 1.31}{0.68 \ln T_o - 1.31}$$

to obtain estimates of the ratio $\frac{q_t}{q_o}$ for each month.

Assuming that the population is at its peak and that there is little further recruitment, time o each year is now chosen as the month in which the observed catch per unit effort is highest. The subsequent predicted catch per unit effort C_oe^{-Zt} (based on the constant catchability model), estimates of the ratio $\frac{q_t}{q_o}$, and the product $\frac{q_t}{q_o} C_oe^{-Zt}$ (the temperature compensated model) are shown in Appendix F. From these and Figures 14 to 21 it can be seen that the values predicted by the temperature compensated variable catchability model fit the observed data much better than do those predicted by the constant catchability model. Values predicted by the latter model are generally substantially higher than the observed catch per unit effort, particularly in the winter months. Those predicted by the former model, while generally a little higher than the observed data in the winter months, are much closer to the observed catch per unit effort.

The sums of squares of the difference between the observed data and the data predicted by both models, and the percentage reduction in the sums of squares brought about by the inclusion of variable catchability has been calculated and is shown in Appendix F.

Unfortunately the statistical significance in reduction of the sums of squares of the difference between observed data and values predicted by the models cannot be tested, since the statistical theory required to treat this particular type of data has not been developed (P. Leppard, pers. comm.).

However, the percentage reduction in the "error" sums of squares is quite high in most years, the highest being 90.03% in 1972 and the

FIGURES 14 TO 21

HISTOGRAMS SHOWING:

- THE OBSERVED CATCH PER UNIT EFFORT IN NUMBERS PER HOUR IN THE SPENCER GULF FISHERY FOR *PENAEUS LATISULCATUS* ▨
- THE CATCH PER UNIT EFFORT PREDICTED BY THE CONSTANT CATCHABILITY MODEL —
- THE CATCH PER UNIT EFFORT PREDICTED BY THE TEMPERATURE DEPENDENT VARIABLE CATCHABILITY MODEL. ━

FIG. 14

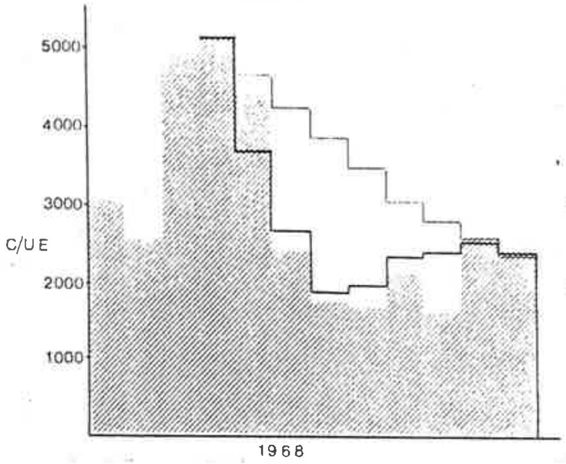


FIG. 15

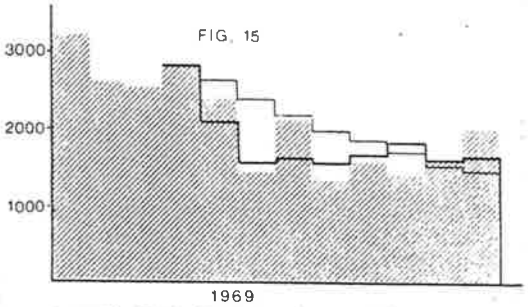


FIG. 16

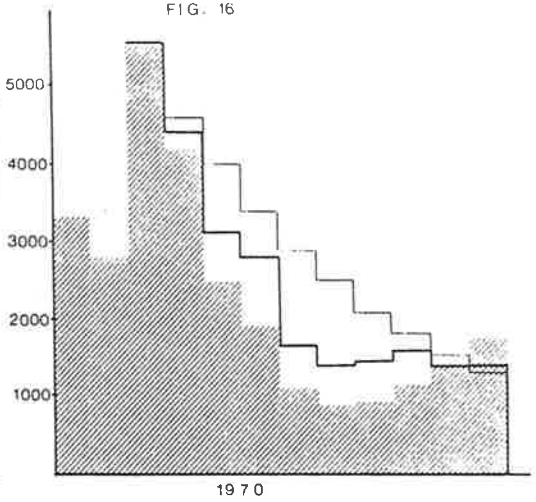


FIG. 17

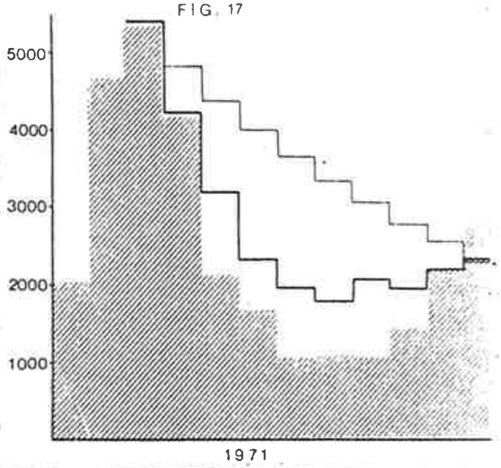


FIG. 18

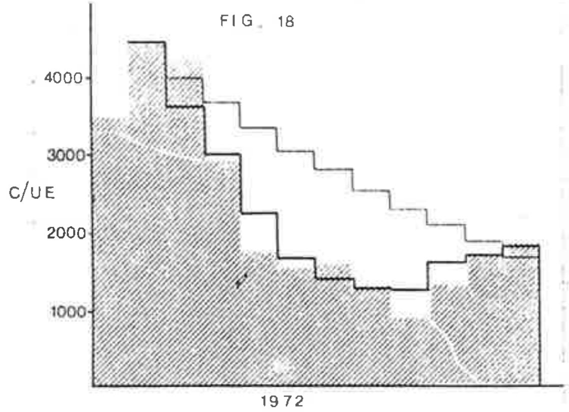


FIG. 19

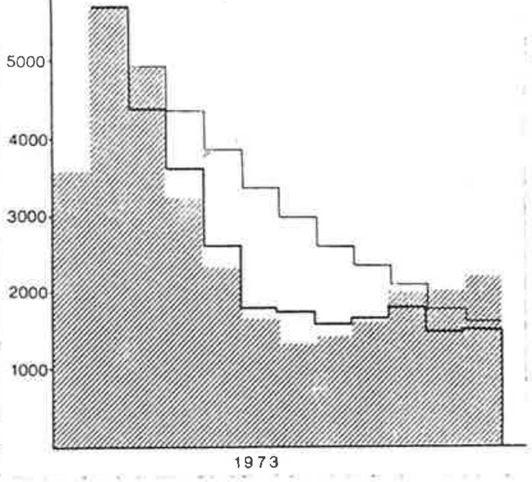


FIG. 20

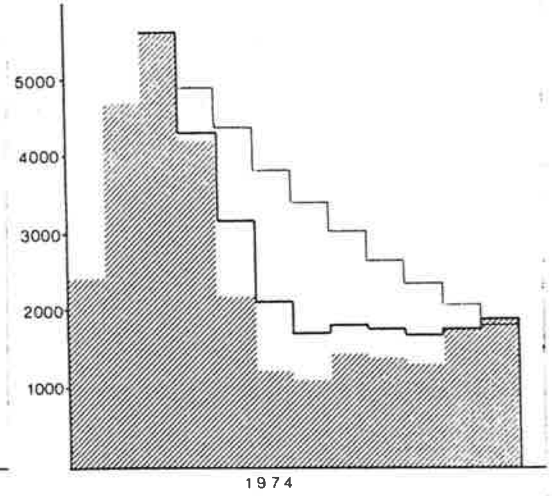
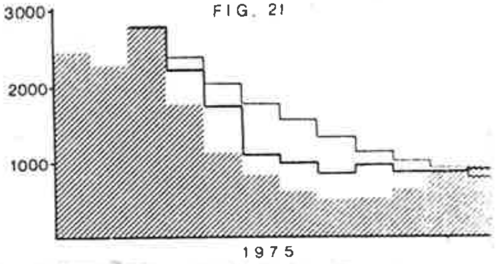


FIG. 21



lowest being 55.74% in 1969. The mean reduction is a quite substantial 80.32%, and the reduction combining data from all years is 85.40%. It is therefore most likely that the temperature-mediated variable catchability model sufficiently accounts for the variation in observed catch per unit effort throughout each year, although no estimate of statistical significance of the goodness of fit of this model can be made.

4.3.3.2 Estimates of recruitment

Having established a model which sufficiently accounts for the variation in catch per unit effort of *P. latisulcatus* in Spencer Gulf throughout each year, it can now be concluded that the sharp increase in C/UE observed at the beginning of each year is due mainly to the recruitment of prawns into the fishable stock. Recruitment is thus the difference between the number of prawns at the peak of the population and the residual number at the end of the previous season. From Appendix F (observed catch per unit effort) and from Figures 14 to 22 it can be seen that the peak in catch per unit effort varies from year to year. This variation reflects variation in recruitment from year to year.

It is possible to estimate an index of recruitment in Spencer Gulf for each year from the expression:

$$R = N_{peak} - N_{residual}$$

where N_{peak} is the number of prawns at the peak of the population

$N_{residual}$ is the residual number of prawns at the end of the previous season.

R is the number of prawns recruited.

$N_{residual}$ will be taken as the number of prawns remaining at the previous November, since recruitment generally increases from a low level in December (King 1976) and reaches its peak in March or April. N_{peak} occurs when the observed catch per unit effort is highest. Thus:

$$R = N_{peak} - N_{Nov.}$$

and since $N = \frac{1}{q} \times A \times C$ (Ricker 1958)

$$R = \frac{1}{q_{peak}} \times A \times C_{peak} - \frac{1}{q_{nov.}} \times A \times C_{nov.}$$

In the previous section it was established that the expression $q = \alpha(0.68 \ln T - 1.31)$ was an acceptable estimate of the catchability

therefore $R = \frac{1}{\alpha(0.68 \ln T_{peak} - 1.31)} \times A \times C_{peak} - \frac{1}{\alpha(0.68 \ln T_{nov.} - 1.31)} \times A \times C_{no}$

therefore $R\frac{\alpha}{A} = \frac{C_{peak}}{0.68 \ln T_{peak} - 1.31} - \frac{C_{nov}}{0.68 \ln T_{nov} - 1.31}$

Since α is assumed to be constant and A is the area of Spencer Gulf $\frac{\alpha}{A}$ is a constant and $R\frac{\alpha}{A}$ is therefore an index of recruitment. This index will be referred to as R_{Ω}.

The index R_{Ω} has been calculated for each year and is presented in Table 9.

TABLE 9

RECRUITMENT INDEX FOR *P. LATISULCATUS* IN SPENCER GULF

Year	Recruitment index R_Ω
1968	3806.3 - 5225.6 *
1969	417.3
1970	3746.0
1971	4443.3
1972	2322.0
1973	4241.1
1974	3778.8
1975	1173.8
1976	4307.0

*The range of probable recruitment for 1968 is estimated from the mean of all available November C/UE values since no data for catch per unit effort in November of 1967 are available

(Mean of Nov. catch per unit effort data = 1763.1 ± 508.7)

The mean recruitment from 1969 to 1976 is 3053 and the standard deviation is 1557, just over 50% of the mean. These results show that the recruitment varies widely from year to year.

Recruitment was high in 1971, '73 and '76 and probably also in 1968, the range of probable recruitment for this year being 3806 to 5225 based on the mean value of the November catch per unit effort since data are not available for the C/UE in November of 1967. Recruitment was very low in 1969, being less than 10% of the highest value, and again in 1975. Intermediate values were estimated for 1970, '72 and '74. Possible reasons for the variation in recruitment from year to year will be discussed in the following chapter.

CHAPTER FIVE

THE EFFECT OF RAINFALL ON THE RECRUITMENT OF *P. LATISULCATUS* INTO THE SPENCER GULF FISHERY

5.1 INTRODUCTION

It has been customary among fisheries biologists to relate the recruitment to a fishery to the size of the adult stock, on the assumption that it is the abundance of mature spawners which is often of outstanding importance in the determination of the number of progeny that become recruits to the useable stock (Ricker, 1958). However the importance of the effect of environmental factors on the survival of pre-recruitment stages of various fished stocks to the subsequent recruitment has also been recognised by Ricker (1958), and by Cushing (1975). According to Ricker (1958) fluctuations in recruitment from year to year often show significant correlation with one or more measured physical characteristics of the environment. Cushing (1975) cites several examples of relationships between scale fish recruitments and various environmental factors such as seawater temperatures, salinities and wind strength and direction. Cushing (1975) is of the opinion that the link between climate and recruitment is mediated through the match or mismatch of larval production to that of their food, rather than via a direct effect of climate on the survival of pre-recruitment stages.

It is my hypothesis that environmental factors, in particular salinity, have a direct and significant effect on the survival of juvenile *P. latisulcatus* in the nursery areas in Spencer Gulf, and thus have a major role in determining the subsequent recruitment.

In this section three possible major determinants of recruitment will be investigated. First, the hypothesis commonly held by fisheries biologists that recruitment is largely determined by the size of the adult stock will be discussed. Secondly, water temperature may significantly affect recruitment (Williams 1969). The third hypothesis is that salinity is the major determinant of recruitment of *P. latisulcatus*. Because of the difficulty in obtaining comprehensive measurements of salinity over a wide area and a sufficient time scale, this last hypothesis will require the development of a relationship between salinity and the effective rainfall and the testing of correlation between recruitment and effective rainfall.

It is possible that all three hypotheses can to a certain extent explain the variation in recruitment of *P. latisulcatus* from year to year. However, treatment of the data as an analysis of variance or a multiple regression would not be appropriate since there are only eight years for which good estimates of the recruitment of *P. latisulcatus* are available. Ricker (1958) and Cushing (1975) point out the dangers in applying multiple regression analysis to short series of data. Each of the hypotheses will therefore be discussed separately, but neither is simple regression the appropriate analysis since the independent variable (size of the adult stock, water temperature, effective rainfall) is not under the control of the experimenter (Sokal and Rohlf, 1973). Possible correlations between the above three variables and recruitment to the Spencer Gulf prawn fishery will be examined. Cushing (1975) warns against the indiscriminate search for significant correlations between recruitment and environmental factors, stating that if one looks extensively enough a statistically significant correlation is sure to be found, but its biological relevance may be difficult to assess. This is because the factor found to correlate significantly with recruitment may have no role in determining recruitment but is itself correlated to some other variable that does determine recruitment but which was overlooked by the investigator. For this reason I have chosen to examine only possible correlations for which there is an *a priori* biological reason to suspect a causal relationship between the independent variable and the recruitment, or to treat the data in a manner similar to that of other investigators who have found biologically relevant correlations between prawn population sizes and environmental factors.

5.2 THE RELATIONSHIP OF RECRUITMENT TO THE SIZE OF THE ADULT STOCK

The majority of juvenile *P. latisulcatus* are thought to overwinter in the shallow nursery areas, (King, 1976) so that most recruitment in each year is derived not from the mature spawners of the previous year, but from those of the year preceeding that. Since most spawning occurs from November through the early summer months, any relationship between recruitment and the abundance of mature spawners will be apparent as a relationship between the recruitment of year x and the abundance of prawns in the November of year (x-2). To test this hypothesis, the correlation coefficient between each year's index of recruitment and the appropriate November index of abundance will be calculated as follows:

Recruitment was defined in the previous chapter as:

$$R = N_{peak} - N_{residual}$$

and an index R_{Ω}(where $=\frac{\alpha}{A}$) was estimated.

Thus $$R = N_{peak} - N_{residual}$$

or $$R\frac{\alpha}{A} = N_{peak}\frac{\alpha}{A} - N_{residual}\frac{\alpha}{A}$$

The November abundance must therefore be defined in a comparable manner to the recruitment index.

Since $N_{Nov} = \frac{1}{q} \times A \times C_{Nov}$

and $q_{Nov} = \alpha(0.681\ln T_{Nov} - 1.31)$

Nov $N_{Nov} = \frac{A}{\alpha} \frac{C_{Nov}}{(0.681\ln T_{Nov} - 1.31)}$

therefore $N\frac{\alpha}{A}_{Nov} = \frac{C_{nov}}{(0.68 \ln T_{Nov} - 1.31)}$

(or $N_{\Omega\, Nov}$)

and this is comparable to the recruitment index R or $R\frac{\alpha}{A}$. The index of recruitment R_{Ω} in year x and the index of abundance in November of year x - 2, N_{Ω} are shown in Table 10.

The product-moment correlation coefficient 'r' was calculated according to the procedure of Sokal and Rohlf (1973) for the recruitment years 1970 to 1976. The recruitments of 1968 and 1969 are not included in the calculation since no real estimate of the November index of abundance is available for 1966 and 1967. The correlation coefficient 'r' was found to be 0.2589. The critical value of 'r' at the 95% level of significance for six degrees of freedom is 0.707, so the correlation is not significant.

It seems therefore that the size of the adult stock has little influence on the subsequent recruitment of *P. latisulcatus* in Spencer Gulf. In fact the November index of abundance does not vary greatly from year to year (table 20; mean 2534, S.D. 552) while the recruitment varies

TABLE 10

RECRUITMENT INDEX AND NOVEMBER INDEX OF ABUNDANCE FOR *P. LATISULCATUS* IN SPENCER GULF

YEAR	RECRUITMENT INDEX R_{Ω} FOR YEAR X	NOVEMBER ABUNDANCE INDEX N_{Ω} FOR YEAR X - 2
1968	*3806 - 5225	
1969	417	*1254 - 2272
1970	3746	2068
1971	4443	3407
1972	2322	1852
1973	4241	2992
1974	3778	2238
1975	1174	2793
1976	4308	2390

*Estimates based on the mean November catch per unit effort since there are no data for the year 1967.

widely (mean 3053, S.D. 1557). It is assumed that the number of eggs produced by the mature spawners is correspondingly constant and this is supported by the fact that *P. latisulcatus* has a very high fecundity. The variation in recruitment from year to year may therefore be due to variation in the success of the larval stages or to variation in the survival of the juveniles in the nursery areas. Without estimates of larval abundance it is not possible to differentiate between these alternatives. However in the Gulf of Mexico, significant correlations have been found between juvenile abundance and catches of adults, but not between larval abundance and the abundance of later stages (Neal, 1975).

5.3 THE EFFECT OF TEMPERATURE ON RECRUITMENT

On the assumption that inshore water temperatures closely parallel coastal air temperatures, Williams (1969) reported correlations between the summation of effective day degrees (calculated from daily coastal air temperatues) and catches of penaeid prawns in the Gulf of Mexico. A correlation between the sum of effective day degrees for the calendar year and prawn catches of the same year was significant and was considered by Williams (1969) to be the result of the effect of temperature on activity and thus catchability of the prawns. The effects of temperature on the catchability of *P. latisulcatus* in Spencer Gulf have been discussed and accounted for in the previous chapter.

Williams (1969) also considered that extremes of cold temperature during the winter may have a deleterious effect on the survival of juvenile prawns overwintering in the nursery areas. This hypothesis is supported by the fact that the prawn catches in certain areas of the Gulf of Mexico were also correlated with the sum of effective day degrees for the coldest six months of the preceeding year (Williams 1969), warmer winters being followed by higher catches and *vice versa*.

The life cycle of *P. latisulcatus* outlined in Section 2.3.7 shows that the majority of juvenile prawns would be overwintering in the nursery areas from April to October, the coldest months in the year (Table 9). If low temperatures during this period significantly reduce the survival of juvenile *P. latisulcatus* in the nursery areas this will have a direct effect on the recruitment of young prawns to the fishery in the following summer. This hypothesis can be tested by calculating a correlation coefficient between temperatures over the period April to October and recruitment.

Data on the mean weekly water temperatures in Northern Spencer Gulf are listed in Appendix D. To make the analysis of this data comparable to that of Williams (1969) the effective 'month degrees' for the April to October period each year was calcuated after the method of Andrewartha (1970) as:

$$E = P \times \frac{\text{max. temp. of the month - "effective temp."}}{2}$$

'Month degrees' were calculated since there were insufficient data to calculate day or week degrees. "E" is the effective month degree and "P" is the proportion of the month that water temperatures exceed the "effective temperature". The effective temperature is chosen as 13°C. In the experiment described in section 4.2.3 it was found that less than 50% of the prawns observed were active at this temperature. Zein-Eldin and Aldrich (1965) found that whereas juvenile *Penaeus aztecus* survived temperatures as low as 11°C, their ability to withstand other environmental stress, such as low salinity, was impaired at temperatures below 15°C.

The effective month degrees during April to October for each year from

1967 to 1975 are shown in Table 11. The April to October period has been divided into eight equal "months" of exactly four weeks each to make for easier calculation of the month degrees from the mean weekly temperatures. The sum of the effective month degrees over April to October for each year, and the recruitment of the following summer are shown in Table 12. The Pearson product-movement correlation coefficient 'r' was found to be 0.214. The critical value of 'r' with seven degrees of freedom is 0.666 at the 5% level of significance, so there is no significant correlation between the sum of month degrees over the winter period, and recruitment. This suggests that temperature over the range experienced by juvenile *P. latisulcatus* in the nursery areas has little effect on the survival of juvenile prawns.

5.4 THE INFLUENCE OF RAINFALL AND EVAPORATION ON THE RECRUITMENT OF *PENAEUS LATISULCATUS*

5.4.1 Correlations between rainfall and catches of penaeid prawns

A relationship between rainfall and catches of penaeid prawns was first reported by Hildebrand and Gunter (1953) who found that the annual catch of *Penaeus setiferus* in Texas waters was positively correlated ($r = 0.883$) with the average rainfall over Texas for that year and the previous two years. In a later paper Gunter and Hildebrand (1954) concluded that the simplest and most probable connection of prawn catch with rainfall was through salinity of the coastal bays which is governed by rainfall. This may account for the apparent lag in their previously reported correlation since rainfall may take some time to influence the salinity and since juvenile prawns overwinter in the shallow nursery areas and their

TABLE 11

EFFECTIVE MONTH DEGREES IN NORTHERN SPENCER GULF FROM APRIL TO OCTOBER

YEAR	MONTH							
	(APRIL)							(OCTOBER)
	1	2	3	4	5	6	7	8
1967	4.05	3.20	1.55	0.25	0.11	0.78	2.40	4.60
68	4.05	2.10	2.10	0.18	0.04	0.98	1.85	3.80
69	4.60	2.95	0.83	0.90	1.00	2.05	4.60	4.85
70	3.85	2.45	1.45	0.70	0.05	1.00	2.80	3.30
71	5.65	4.05	0.85	0.50	0.34	0.94	2.85	4.15
72	3.65	2.15	1.30	0.00	0.00	0.23	2.15	4.15
73	4.20	2.40	0.95	1.25	1.55	2.15	5.15	5.95
74	5.15	3.40	1.55	0.13	0.68	1.30	2.25	4.45
75	4.00	3.30	2.80	0.60	1.80	3.45	3.45	3.00

TABLE 12

SUM OF EFFECTIVE MONTH DEGREES AND SUBSEQUENT RECRUITMENT

YEAR	SUM OF EFFECTIVE MONTH DEGREES	SUBSEQUENT RECRUITMENT INDEX
1967	16.94	3806-5226 *
1968	15.10	417
1969	21.78	3746
1970	15.60	4443
1971	19.33	2322
1972	13.63	4241
1973	23.60	3779
1974	18.90	1174
1975	22.40	4307

*not included in the calculation of the correlation coefficient since this is not an accurate estimate of recruitment.

susceptibility to changes in salinity would not become apparent until the following fishing season. Gunter and Edwards (1969) confirmed the correlation between rainfall and catches of *P. setiferus* in Texas waters with a longer series of data. In Indian waters catches of *P. monodon* from the Godarvi estuary region have been positively correlated with river discharge of the previous year (Subrahmanyam, 1966)

Thomson (1956) found that annual catches of penaeid prawns from Lake Illawarra on the east coast of Australia were positively correlated with rainfall of the 12 month period beginning 18 months and ending 6 months before the start of the prawn season. He reported a positive correlation between prawn catches at Stockton Bight near Lake Illawarra and rainfall of the previous year, and a similar correlation exists for prawns near Clarence River, further north on Australia's east coast. Although the species were not named it is likely that in each of the above cases the major component of the catch was *Metapenaeus macleayii*, which is the species most commonly caught in the inshore fisheries of New South Wales and Queensland. Ruello (1972, 1973, 1975) has also reported a positive correlation between rainfall of the previous year and abundance of the school prawn *M. Macleayii* in the Hunter River region on the east coast of Australia.

Before investigating the relationship between rainfall and evaporation and recruitment of *P. latisulcatus* in Spencer Gulf, the way in which these factors influence the salinity of the inshore nursery areas will be discussed, since it is the salinity of these waters which is thought to have a direct effect on the survival of juvenile prawns and thus the subsequent recruitment.

5.4.2 The relationship between rainfall, evaporation and salinity in nursery areas for *P. latisulcatus*

Logistic difficulties have meant that measurements of salinity after periods of heavy rainfall in Spencer Gulf are infrequent. However, salinities have been measured regularly at Torrens Island near Adelaide a region that is an important nursery area for *P. latisulcatus* in St. Vincent Gulf and one that is geographically very similar to prawn nursery areas in Spencer Gulf.

Measurements of salinity made at nine stations (fig 9) in these waters are presented in Appendix A and the data in Table 13 illustrate that rainfall directly affects the salinity of these waters.

Salinities were lower than normal in early September 1973 when the Adelaide rainfall in August and September of 1973 was 210 and 234 mm respectively. The mean August rainfall at Adelaide is 62 mm and the September mean is 51 mm. During 1974 salinities were low while rainfalls were generally about twice as high as the monthly mean during July, August, September and October. Salinities are generally lower in the region closer to Swan Alley Creek (fig 9) which is the outlet for the Little Para River, than towards the open waters of St. Vincent Gulf. However, in 1975 salinities remained at normal levels throughout most of the region (see Appendix A) and monthly rainfalls were a little less than the mean for any particular month. While these findings can not be directly related to the Spencer Gulf fishery statistics they do illustrate that rainfall has a direct effect on the salinity of inshore waters.

Measurements of salinity in northern Spencer Gulf made after periods of heavy rain also show that salinities are significantly lowered.

Data extracted from Appendix A are presented in Table 14. Salinities were measured in situ as described previously at inshore and offshore locations at Chinaman's Creek, and at Pt. Davis on the mouth of the Broughton River (fig 22). At each location the inshore station was about 500m upstream from the mouth of the creek, while the offshore station was about 500 m seaward of the mouth of the creek. At Pt. Germein the salinity was measured at the end of the jetty which is 1.5 km long.

The measurements at Eastern Shoal and Douglas Bank (fig 22) were made by M.G. King. (pers. comm.). Rainfall at Pt. Pirie, Pt. Germein, Baroota and Pt. Augusta during October 1973 was 159 mm, 132, 113 and 70 mm respectively while the mean October rainfall at these places is 32, 31 51 and 23 mm respectively (Commonwealth Bureau of Meteorology). The salinities of 30.5‰ and 27.5‰ are well below the normal range of salinities of approximately 39‰ to 42‰ at these stations (appendix A). The rainfall in May 1974 was again well above average (147, 123, 116 and 123 mm at Pt. Pirie, Pt. Germein, Baroota and Pt. Broughton respectively) and salinities measured at Chinamans Creek and Pt. Davis (fig 23) were correspondingly low (table 14). Rainfall at Pt. Pirie, Pt. Germein, Baroota and Pt. Augusta was high again in October 1976 (110, 119, 137 and 64 mm respectively). Salinities at Chinamans Creek, Pt. Davis and Pt. Germein were correspondingly low. Measurements made by M.G. King (pers. comm.) at Chinamans Creek indicate that the normal range of salinities in the offshore waters is from 41‰ to 46.5‰.

These results support the findings of Bullock (1975) that there is little exchange of the waters in the northern part of Spencer Gulf with those of the southern Gulf and the South Australian Sea (after

TABLE 13

SALINITIES IN THE WATERS AROUND TORRENS ISLAND AFTER PERIODS OF HEAVY RAINS

Salinity ‰

Station / Date	1	2	3	Mid	4	5	6	7	S.A
8.9.73	36.4	36.3	31.9	31.5		33.7			10.3
5.8.74	34.1		34.4						
6.8.74					32.6		34.8	33.2	
8.8.74		35.1				34.5			
12.8.74	35.4	35.4	35.0		34.2	35.2			
13.8.74	35.7	35.6	35.0		35.3	35.5			
14.8.74	34.8	35.1	35.1	34.3	34.3	34.4			31.2
16.8.74	35.1	34.9					19.5		9.5
26.8.74	35.4	35.5	35.5	35.2	35.9	35.5			16.0
4.9.74			35.9	32.5	35.2				23.5
8.10.74	34.6	34.9	32.6	31.5	33.4	34.8			
16.10.74	33.7	34.4	32.4	26.6	26.5	27.7	29.5		0.2
30.10.74	35.4	35.1	34.7	33.4	32.6	34.8	34.8		18.2

TABLE 14

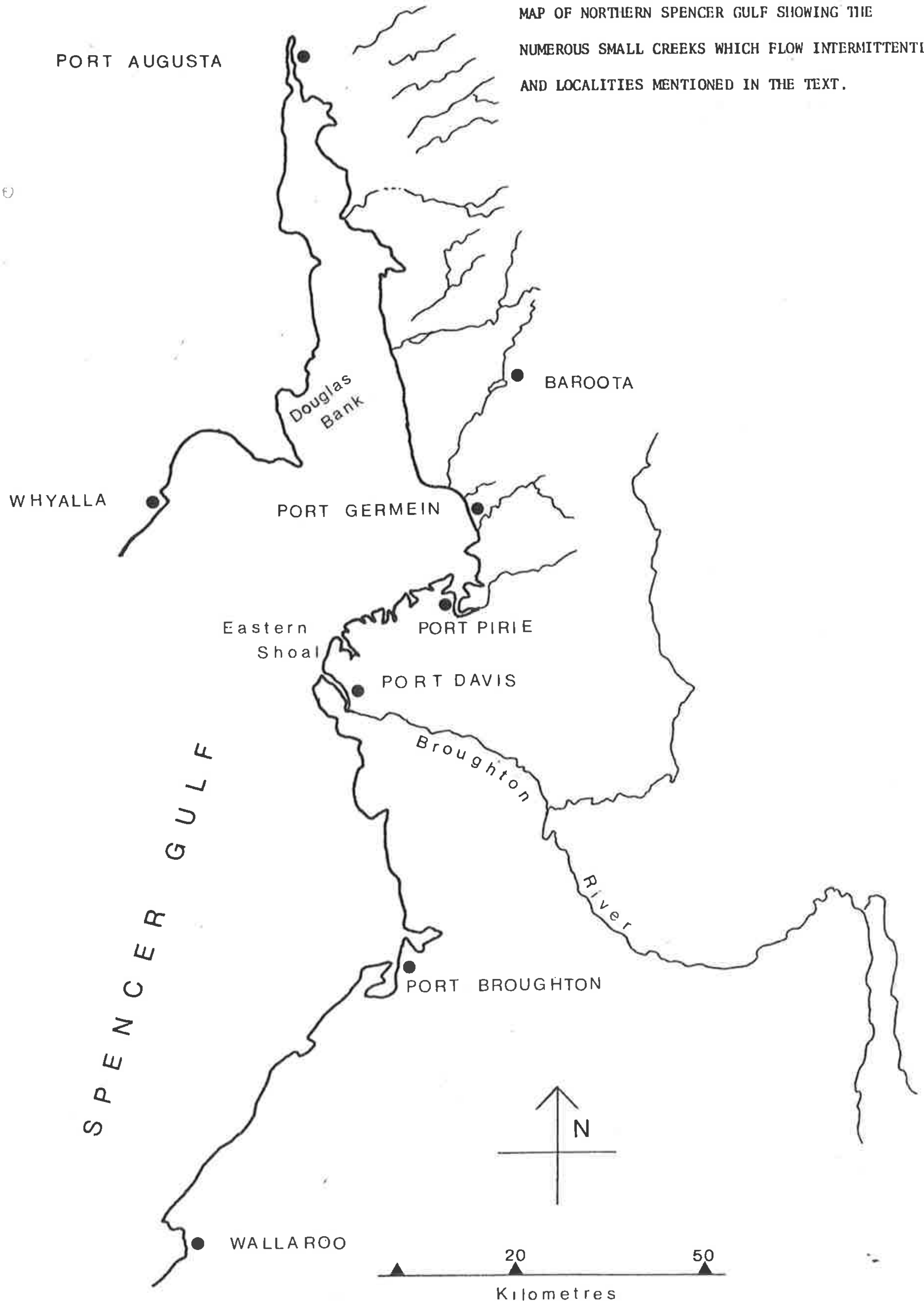
SALINITIES IN NORTHERN SPENCER GULF AFTER PERIODS OF HEAVY RAIN

Salinity ‰

Date	Eastern Shoal	Douglas Bank	Chinaman's Creek		Pt. Davis		Pt. Germein
			Inshore	Offshore	Inshore	Offshore	
17.10.73	30.5	27.5					
20.5.74			32.5	16.9	6.0	30.5	
14.10.76			30.9	12.6		15.9	27.0

FIGURE 22

MAP OF NORTHERN SPENCER GULF SHOWING THE NUMEROUS SMALL CREEKS WHICH FLOW INTERMITTENTLY, AND LOCALITIES MENTIONED IN THE TEXT.

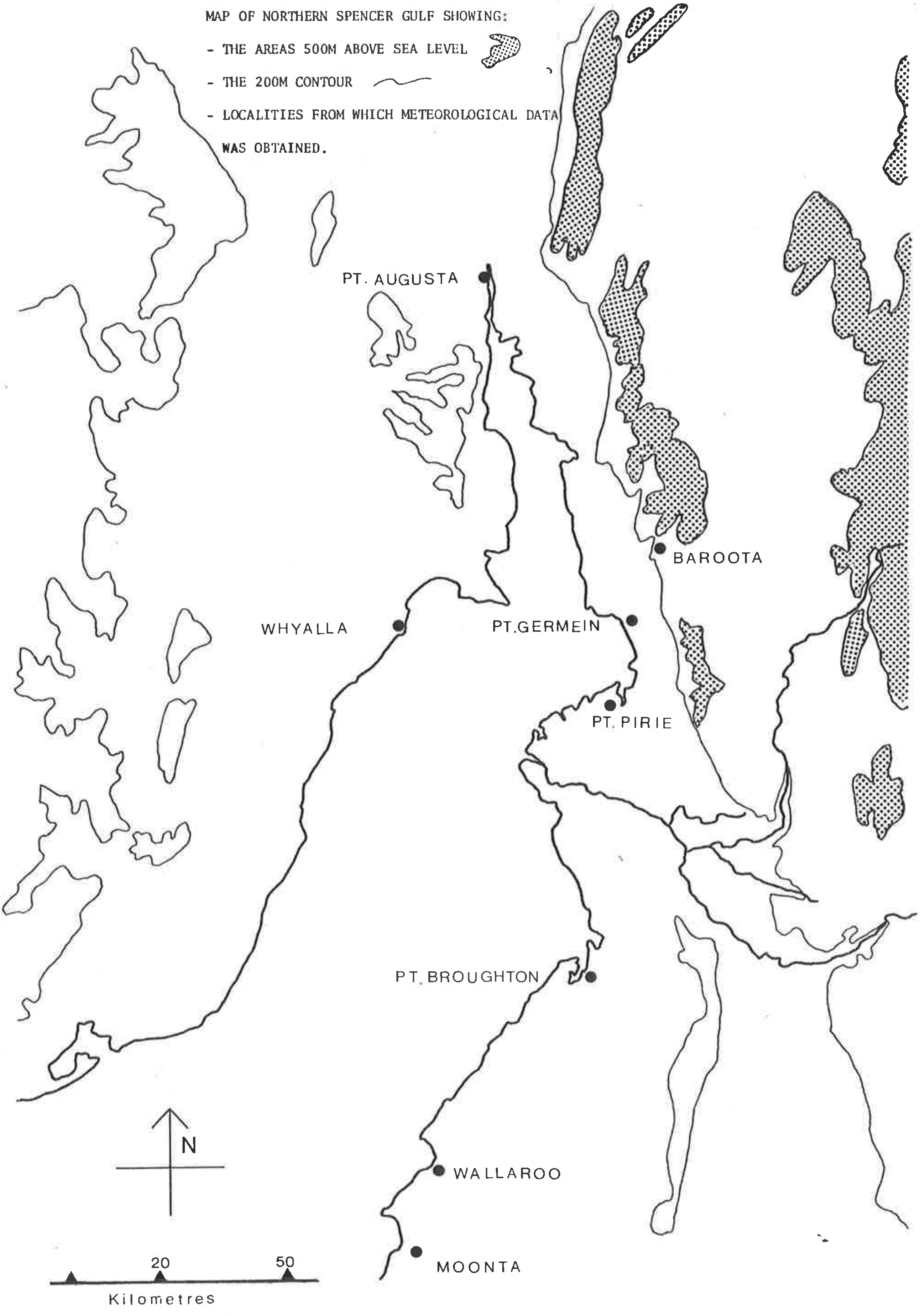


Bye 1976), and the resultant implication that salinities in the northern part of the Gulf must be determined by the balance between evaporation and the influx of fresh water. Holloway (1974) found that eddy diffusion coefficients calculated on the basis of the evaporation/rainfall balance in upper Spencer Gulf were consistent with those determined from dye tracking experiments. According to Green (1974) the reported variations in salinity of upper Spencer Gulf are consistent with the calculated effects of evaporation and rainfall, including run-off from the surrounding hills.

Evaporation from the water surface operates over the whole of Spencer Gulf to increase the salinity. The way in which rainfall reduces the salinity of the gulf waters can be seen from a consideration of the topography of this region. To the east of Spencer Gulf lie the southern spurs of the Flinders Ranges (fig 23). Drainage from the western face of the ranges is towards Spencer Gulf. Numerous creeks feed from the gullies dissecting the southern Flinders Ranges (fig 22) but no permanent streams exist (Chebotarev, 1958). These streams flood however, after prolonged and heavy rain or after extremely intense rainfall. Because the prevailing winds are from the south westerly direction the effect of the southern Flinders is to produce orographic rainfall, and because of the higher relief in the north (fig 23) more runoff for a given rainfall will be produced than in the flatter regions bordering the south of Spencer Gulf.

South of Pt. Pirie the Broughton River is the major source of freshwater runoff into Spencer Gulf, but the flow of this river is only intermittent. It can be seen from Figure 23 that the high relief areas near the north of Spencer Gulf are also a major catchment for the Broughton River.

FIGURE 23



MAP OF NORTHERN SPENCER GULF SHOWING:

- THE AREAS 500M ABOVE SEA LEVEL
- THE 200M CONTOUR
- LOCALITIES FROM WHICH METEOROLOGICAL DATA WAS OBTAINED.

Evaporation from the water surface operates over the whole of Spencer Gulf to increase the salinity. In the southern part of the gulf this is counteracted by mixing with water from the South Australian Sea and by rainfall directly onto the gulf waters. There is very little run-off into Spencer Gulf south of Pt. Broughton. In the more enclosed waters of the northern part of the gulf, the influence of rainfall on the salinity is much stronger since the water is generally shallower, and there is little exchange with waters of the southern part. Run-off from the southern Flinders Ranges to the east of this region also has a strong influence, particularly in the coastal backwaters into which the intermittent streams flood after heavy rains. Since it is the sand and mudflats in these backwaters that are the nursery areas for juvenile *P. latisulcatus* and since the nursery areas are mainly in the north, rainfall over the northern area of Spencer Gulf and the high relief areas to the east must have an important influence on the salinity of the major prawn nursery areas in Spencer Gulf.

5.4.3 Rainfall and evaporation and the recruitment of *P. latisulcatus* in Spencer Gulf

The hypothesis put forward in section 4.1, that recruitment is determined primarily by the effects of salinity on the survival of juvenile prawns can now be investigated by establishing a relationship between rainfall and evaporation over northern Spencer Gulf, and recruitment, since it has been shown in section 4.4.2 that salinity especially in the inshore areas is directly affected by rainfall and evaporation.

Monthly rainfalls from eight localities (fig 23) around the perimeter of northern Spencer Gulf were obtained from the Commonwealth Bureau of Meteorology. This data is presented in appendix G. These localities were chosen because it has been argued in the previous section (4.4.2) that rainfall over the northern part of the gulf induced by the orographic effect of the hills to the east has an important influence on the salinity of the major prawn nursery areas. The mean rainfall over this region has therefore been calculated for each month from the data from these stations (Appendix G). In the Spencer Gulf region, evaporation is measured only at Baroota (Appendix G). Although this station is situated in the hilly region a few kilometers east of the shore, evaporation here is probably representative of that over the general region (I. Hancy, Climatologist, Commonwealth Bureau of Meterology, pers. comm.).

Since the effect of evaporation on salinity is the inverse of that of rainfall the data on rainfall and evaporation will be treated as a single value climatic index of the form $\frac{R}{E^m}$ which has been found to be the most appropriate climatic index in assessing the efficiency of rainfall for defining ecological zones, for agriculture and for soil hydrology (Cornish, 1976). "R" is the monthly rainfall, "E" the monthly evaporation and "m" is a constant. In agricultural applications "m" has been found to be approximately 0.75 and this value has been taken as a standard in applying the index to climatological studies. However, since only relative values of the index from year to year are required for this study the value of "m" will be defined as 1.00 for convenience. Furthermore, according to Cornish (1976) the variability in evaporation in any particular month, from year to year, is very small compared to its mean value, and especially so when compared to the variability of the monthly rainfall. Hence the index $\frac{R}{E}$ will take into account the effects of evaporation on salinity, but any variations will predominantly reflect the influence of rainfall in diluting the shallow waters in the prawn nursery areas. The ratio of the mean rainfall over the region to the evaporation ($\frac{R}{E}$) has been calculated for each month and is presented in Table 15.

From the life cycle of *P. latisulcatus* outlined in Chapter one, it can be seen that the majority of juvenile prawns would be present in the inshore nursery areas from about April to October each year. It is thus during this time that they would be susceptible to changes in salinity in the inshore areas. Consequently I have calculated the sum of the $\frac{R}{E}$ ratio from April to October each year from 1967 to 1975. Table 16 shows the recruitment index for each year and the corresponding April to October $\frac{R}{E}$ ratio of the previous winter.

The correlation coefficient between recruitment and the $\frac{R}{E}$ ratio for April to October of the previous year was calculated according to the method of Sokal and Rohlf (1973) to be - 0.82 and this is significant at the 1% level of significance. The 1968 recruitment estimates were not used in the calculation of the correlation coefficient since the range of probable recruitments for this year were not estimated in the same way as the recruitment index for the following years. Fig 24 shows the recruitment index plotted against the April to October $\frac{R}{E}$ ratio for the previous year, and the calculated line of best fit estimated by the method of least squares (Sokal and Rohlf, 1973). Again the 1968 recruitment was not used in this calculation, however it can be seen from fig 24 that the range of probable recruitments lies close to the value predicted by the line of best fit.

5.4.4 The relationship between rainfall and catches of *P. latisulcatus* in Shark Bay

The relationship between rainfall and catches of *P. latisulcatus* in Shark Bay was also investigated. Because two species of prawns are

TABLE 15

MONTHLY RAINFALL/EVAPORATION INDEX ($X10^3$) OVER NORTHERN SPENCER GULF

	J	F	M	A	M	J	J	A	S	O	N	D
1967	76.4	204.7	4.4	23.1	141.6	73.2	273.7	333.3	116.4	29.6	0	16.4
1968	139.1	129.8	73.9	204.3	735.6	1129.0	650.8	433.0	100.0	147.8	164.7	47.0
1969	51.9	180.2	110.6	114.5	677.4	347.2	671.2	263.2	515.5	63.3	95.2	46.7
1970	84.8	0	37.4	125.7	259.6	198.3	161.0	392.5	450.3	56.7	164.1	98.6
1971	6.3	7.3	156.8	364.6	410.5	966.1	658.5	369.6	322.3	21.1	216.3	83.9
1972	116.3	126.8	0	111.1	37.6	58.3	359.6	495.4	75.8	76.2	49.6	25.9
1973	68.0	491.2	87.5	185.8	263.2	892.3	493.7	683.7	174.7	461.2	129.9	90.3
1974	280.3	248.8	24.0	686.0	1423.0	260.9	873.4	257.9	416.7	567.1	35.1	10.2
1975	46.2	10.8	107.6	87.6	223.8	23.3	293.2	336.7	337.1	538.5	52.8	62.7

TABLE 16

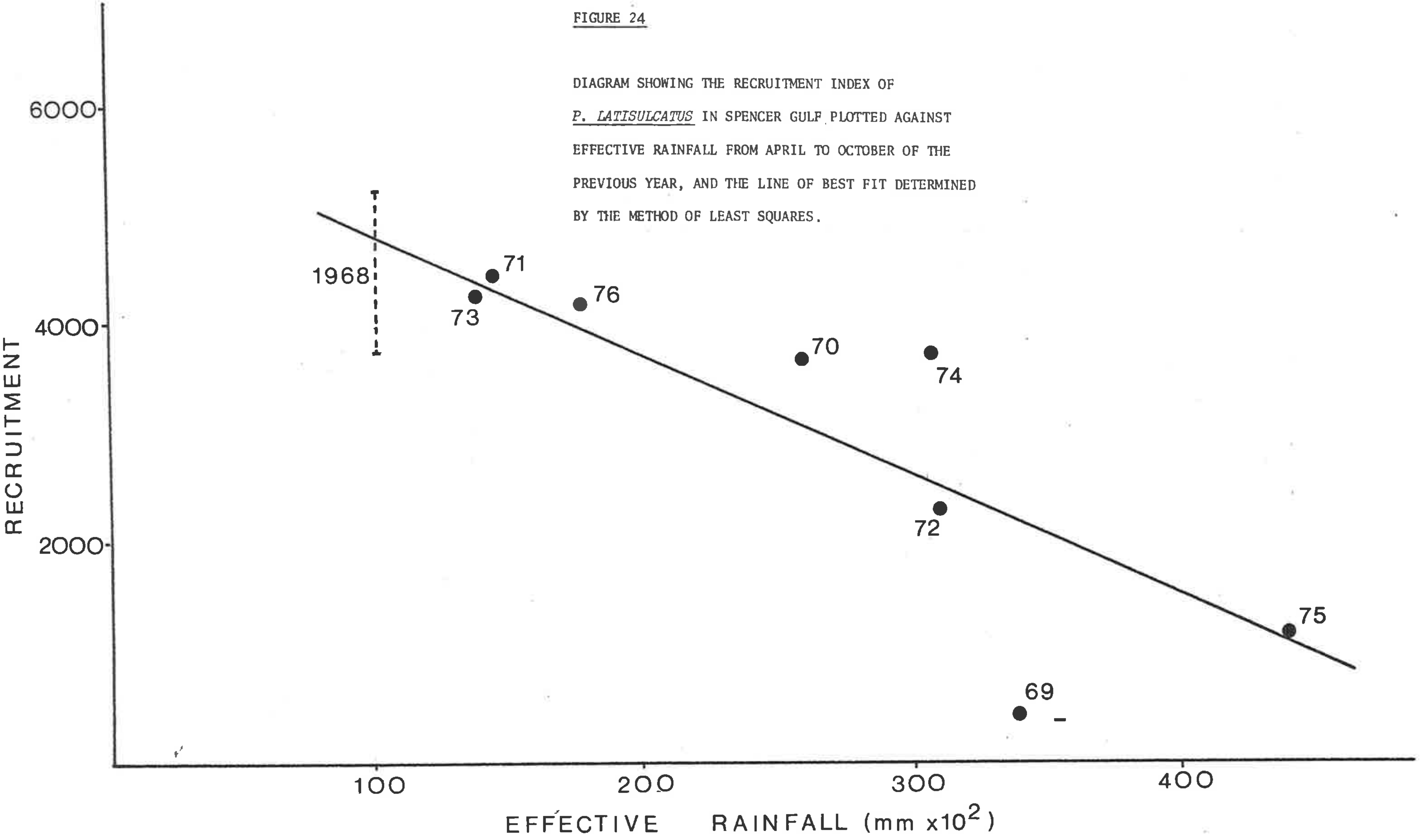
RECRUITMENT INDEX AND EFFECTIVE RAINFALL OF THE PREVIOUS WINTER IN SPENCER GULF

Year	Recruitment index	$\sum_{\text{Oct}}^{\text{Apr}} {}^{R}/_{E}$ $(\times 10^2)$ for previous year
1968	3806-5226*	99.1
1969	417	340.0
1970	3746	264.8
1971	4443	164.4
1972	2322	310.4
1973	4241	121.4
1974	3779	315.5
1975	1174	447.7
1976	4307	184.7

* range of probable recruitment

FIGURE 24

DIAGRAM SHOWING THE RECRUITMENT INDEX OF *P. LATISULCATUS* IN SPENCER GULF PLOTTED AGAINST EFFECTIVE RAINFALL FROM APRIL TO OCTOBER OF THE PREVIOUS YEAR, AND THE LINE OF BEST FIT DETERMINED BY THE METHOD OF LEAST SQUARES.



caught in Shark Bay there is some difficulty in assigning the amount of effort applied to each species and monthly catch per unit effort data for *P. latisulcatus* could not be obtained (Penn. Pers. comm.). An index of recruitment could not be calculated for the Shark Bay fishery in the same way as was done for Spencer Gulf. Annual catch per unit effort has however, been corrected for the estimated effort applied to *P. latisulcatus* and is available from 1962 to 1975.

Evaporation data from Carnarvon on the eastern shore of Shark Bay is incomplete, commencing only in 1967 and then with several subsequent missing observations. Monthly rainfall at Carnarvon has been recorded and is presented in appendix G. The sum of monthly rainfalls from April to October each year was calculated.

Table 17 lists the annual catch per unit effort for *P. latisulcatus* in Shark Bay and the sum of April to October rainfall for the previous year.

From Figure 25 it can be seen that there is no apparent relationship between previous winter rainfall and annual catch per unit effort of *P. latisulcatus* in Shark Bay, even though such a relationship may have been expected if the prawns here react similarly to salinity changes as do the Spencer Gulf prawns. Possible reasons for the lack of any relationship between rainfall and annual C/Ue are that firstly the salinity in Shark Bay may be determined by factors other than rainfall. Evaporation data could not be included in the above analysis because it is incomplete. Logan and Cebalski (1970) noted that the salinity in Shark Bay was about 5‰ less during 1965 than in previous years and attributed this to changes in the pattern of water circulation in the bay. It is to be noted that the total catch (but not the C/Ue) of *P. latisulcatus* in Shark Bay declined in 1966

TABLE 17

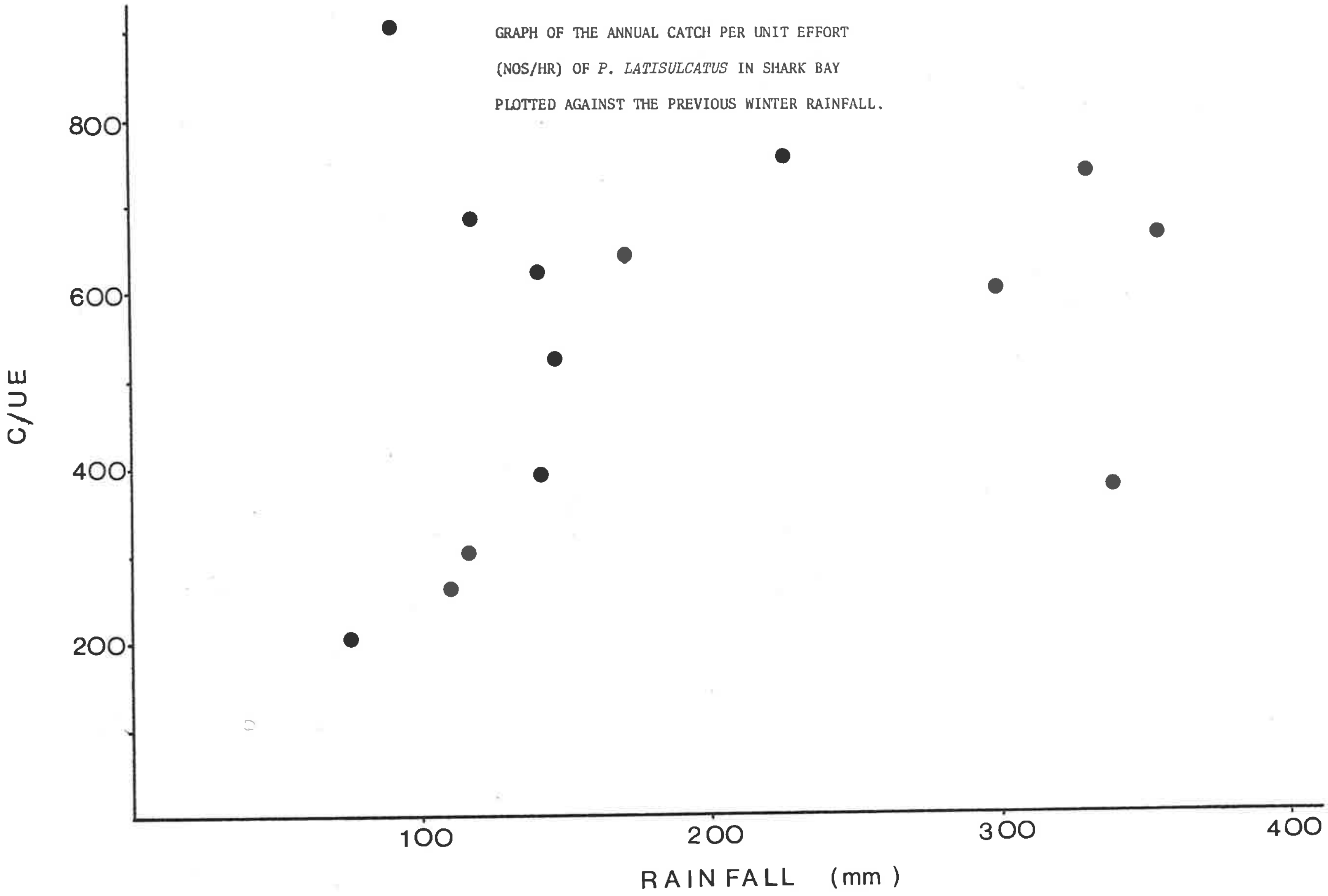
ANNUAL CATCH PER UNIT EFFORT AND WINTER RAINFALL IN SHARK BAY*

YEAR	ANNUAL CATCH/UNIT EFFORT (NOs. PER HR. TRAWLED)	RAINFALL APRIL - OCT. OF THE PREVIOUS YEAR
1962	300	116
63	261	110
64	733	332
65	536	146
66	373	340
67	216	73
68	392	139
69	574	115
70	912	91
71	633	139
72	789	224
73	603	303
74	671	117
75	660	354

*Data from Penn pers. comm.

FIGURE 25

GRAPH OF THE ANNUAL CATCH PER UNIT EFFORT (NOS/HR) OF *P. LATISULCATUS* IN SHARK BAY PLOTTED AGAINST THE PREVIOUS WINTER RAINFALL.



(Slack-Smith 1969b). Secondly there may not be a clear cut relationship between recruitment to the fishery and annual catch per unit effort. This appears to be the case in the Spencer Gulf fishery for *P. latisulcatus* where although there is a trend towards increasing annual C/Ue as the recruitment increases, this trend is not well defined (fig 26).

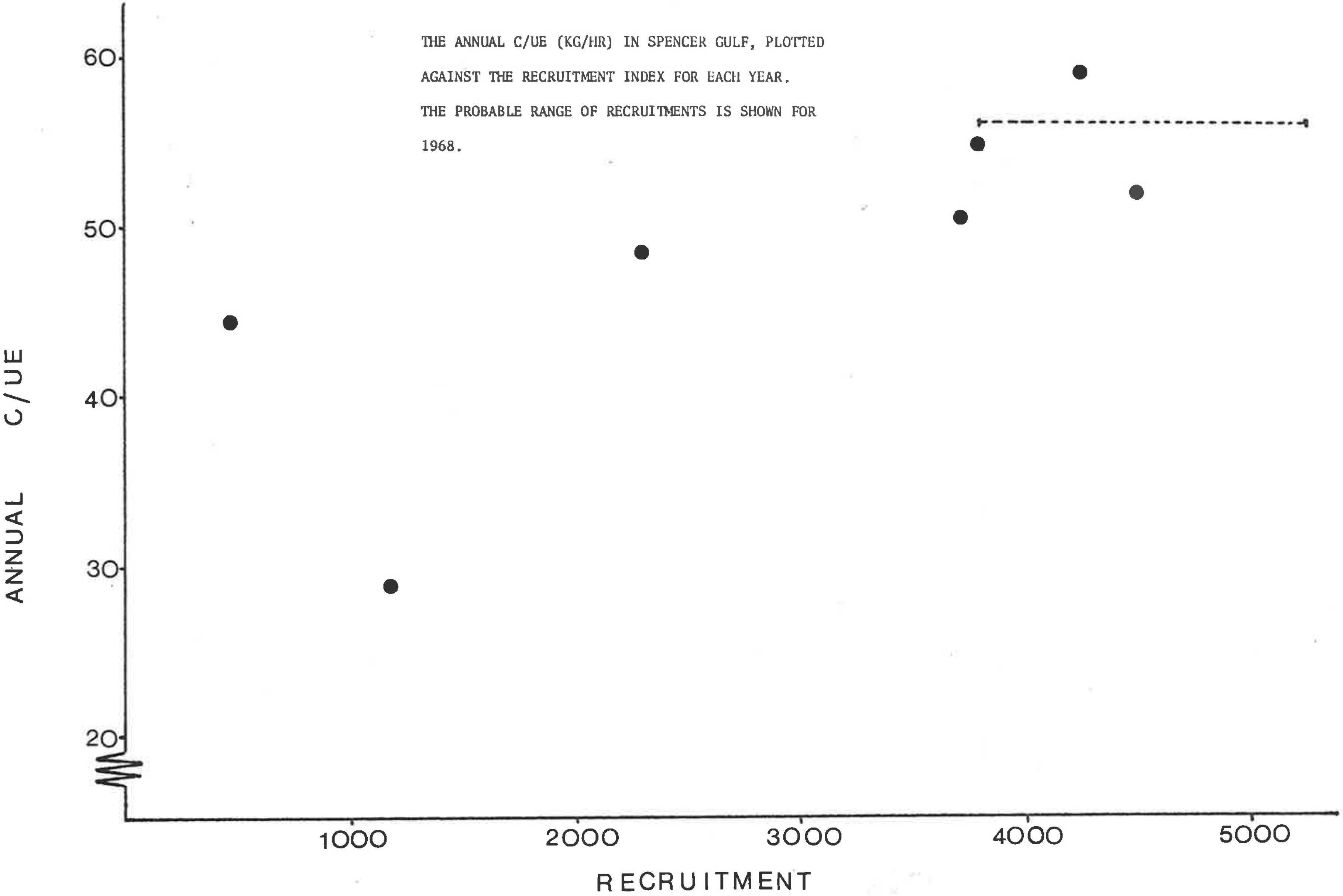
It is still possible that when further refinements are made to the Shark Bay data, and recruitment indices can be calculated, that a relationship between recruitment and rainfall/evaporation or other factors that determine the salinity may be demonstrated.

5.4.5 Discussion

The highly significant negative correlation between effective rainfall and recruitment established in Spencer Gulf is in keeping with the unique hypersaline habitat of juvenile *P. latisulcatus* discussed in the previous chapter. If this species is specially adapted to hypersaline conditions, decreased salinities in the nursery areas caused by high rainfall and low evaporation, might be expected to have an adverse effect on the survival of juvenile *P. latisulcatus*. Gunter and Edwards (1969) found that catches of *P. duorarum* in Texas waters were weakly negatively correlated to rainfall of the previous year, but the correlation was not significant. They postulated that a longer series of data than then available "may show a significant negative correlation between catch and rainfall which would be expected of a shrimp adapted to a dry, high salinity coast." Other correlations between prawn catch and rainfall discussed by previous authors have all been positive, indicating a possible beneficial effect of low salinity. It is to be noted that in each case the natural habitat of the juveniles of the species

FIGURE 26

THE ANNUAL C/UE (KG/HR) IN SPENCER GULF, PLOTTED AGAINST THE RECRUITMENT INDEX FOR EACH YEAR. THE PROBABLE RANGE OF RECRUITMENTS IS SHOWN FOR 1968.



concerned (*P. setiferus*, *P. monodon* and *M. macleayii*) is estuarine. Gunter and his associates (op. cit) believe that salinity directly affects the survival of juvenile prawns and thus the size of subsequent catches. Ruello (1973) however, holds the opinion that the effects of rainfall on *M. macleayii* are less direct. Ruello (1973) observed that seaward movement of *M. macleayii* was enhanced after periods of heavy rainfall. This is said to improve the prawns chances of mating and spawning and thus to partly account for the increased abundance of prawns in the following year. Decreased salinities are also thought to increase the survival of juvenile *M. macleayii* indirectly by making the estuary unfavourable for predators and competitors, and to indirectly promote better growth due to the nutrients washed into the estuary after heavy rains. Such explanations can not be applied to the correlation between recruitment of *P. latisulcatus* and effective rainfall.

It is possible that decreased salinities after heavy rains may cause juvenile *P. latisulcatus* to move seaward and if this was to lead to enhanced reproductive potential, prawn abundance the following year should be high, but this is not the case with *P. latisulcatus*
That the nursery areas of *P. latisulcatus* are made unfavourable to predators and possible competitors, by decreased salinity is possible, however, prawn abundance does not increase as is the case with *M. macleayii* indicating that the decreased salinity must also be detrimental to juvenile *P. latisulcatus*. If influx of nutrients from freshwater run-off increased growth but did not affect survival, then the recruitment of *P. latisulcatus* should be greater after periods of heavy rain.

The simplest explanation is that salinity directly affects the survival of juvenile prawns. In the case of *P. setiferus*, this species inhabits estuarine waters and may survive better at reduced salinities. This could also apply to *M. macleayii* and *P. monodon* whose abundance is also positively correlated to rainfall. *P. latisulcatus* however, inhabits hypersaline nursery areas and a reduced survival at lower salinities would explain the negative correlation between effective rainfall and abundance.

CHAPTER SIX

SALINITY TOLERANCE OF JUVENILE *PENAEUS LATISULCATUS*

6.1 INTRODUCTION

Salinity is the environmental factor most commonly associated with discussions of the distribution and abundance of juvenile penaeid prawns (Gunter, 1950, 1961 a, b; Gunter, Christmas and Killebrew, 1964; Kinne 1964; Parker 1970). It has been suggested that the abundance of juvenile prawns is greatest in low salinities and particularly that large numbers of the smallest animals occur in the lowest salinities (Gunter, 1950). This relationship has often been interpreted to mean that low salinities are necessary for the survival and growth of juvenile penaeid prawns (Neal 1975), and that juvenile prawns do not "do well" in waters of higher salinity. (Gunter 1961 a In Chapter three it was proposed that in accordance with the distribution of juvenile *Penaeus latisulcatus* in hypersaline waters their tolerance to high salinities may be greater than that of other penaeid species and that adaptation to low salinities may not be possessed to as great an extent as in other penaeids which usually inhabit hyposaline estuarine waters. Support for these hypotheses can be drawn from the conclusions of the previous chapter that a negative correlation exists between effective rainfall over northern Spencer Gulf and recruitment of *P. latisulcatus* into the Spencer Gulf fishery, with the most likely explanation for this correlation being that salinity directly affects the survival of juvenile prawns. Reduced salinities appear to cause mortality and hence low recruitments of juvenile *P. latisulcatus* while higher salinities are followed by higher recruitment. There is some variance between those conclusions and the ideas of Dahl (1956), Hedgepeth (1957) and Carpelan (1967) that tolerance to high salinity is usually associated with tolerance to low salinity and that exclusive adaptation to a hypersaline environment would be an adaptation which leads to extinction (Carpelan 1967). Therefore the tolerance of juvenile *P. latisulcatus* to reductions in salinity will be investigated in this chapter. The importance of experimental determinations of the salinity tolerance of aquatic animals as a reflection of the adaptation of species to their physicochemical environment has been stressed by Kinne (1963, 1964, 1971) and Dorgelo (1976).

In the nursery areas juvenile *P. latisulcatus* are usually exposed to salinities greater than about 37‰ and up to 60‰. In some parts of Shark Bay salinities of about 70‰ have been measured but juvenile *P. latisulcatus* are usually not found in these areas (Slack-Smith, 1969b). Salinities as low as 6‰ have been measured in sheltered backwaters known to be nursery areas for juvenile prawns in Spencer Gulf, after periods of heavy rainfall. The range of salinities investigated in these experiments will therefore be from 5‰ to 75‰ in order that the results may be related to conditions actually occurring in the nursery areas.

All the salinity tolerance experiments were of the "direct (or sudden) transfer" type. There were several reasons for this. Firstly the responses of juvenile *P. latisulcatus* to reduced salinity were of major interest. Since the results of the experiments were intended to relate to the reduction in salinity which occurs in the nursery areas after heavy rains and flooding, sudden transfer from the acclimatization medium to the experimental salinity was thought to be the most appropriate way of testing the salinity tolerance of juvenile

P. latisulcatus. Secondly the sudden transfer method allows for the easiest comparison of the tolerances of different species (Dorgelo, 1974, 1976). Thirdly, acclimatization to increasingly higher or lower salinities may extend the range of tolerance but the degree of this extension may depend upon the rate of acclimatization.

It is known that the degree of salinity tolerance of postlarval and juvenile *P. latisulcatus* is affected by temperature and that it is dependent on the salinity and temperature of acclimatization (Williams, 1960, Zein-Eldin and Aldrich, 1965; Wiespape, Aldrich and Strawn, 1972; Venkataramiah, Lakshmi and Gunter, 1974). Since the salinity tolerance of *P. latisulcatus* may also be determined by temperature, all experiments were carried out at a constant temperature as close as possible to the acclimatization temperature. The experimental temperature was either 14°C or 18.5°C. It would have been desireable to acclimate prawns to a particular set of laboratory conditions prior to the experiments but because of inadequate facilities, large numbers of prawns could not be held in the holding aquaria for the long periods of time needed to assure acclimation.

Prawns were therefore considered to be acclimatized to the salinity and temperature of the water from which they were captured, and were held in the laboratory at similar temperature and salinity for at least two days prior to transfer to the experimental aquaria. Prawns captured from waters ranging in salinity from 35.5 to 37‰ were held in the laboratory at 36‰. Those captured from waters ranging in salinity from 40 to 45‰ were held in the laboratory at 42.5‰. Similarly prawns captured at temperatures of 13 to 15°C were held at 14°C and those caught at 17 to 20°C were held at 18.5°C. Temperatures of approximately

14°C and salinities of approximately 36‰ are referred to as winter temperatures and salinities. Those of approximately 18.5°C and 42.5‰ are referred to as summer temperatures and salinities. During the period of this study experiments were carried out on juvenile prawns acclimatized to four temperature-salinity combinations.

Due to the unpredictable climate, especially with respect to the timing of rainfall, the four field acclimations experienced by the prawns before capture can be classified in the following way:

- winter temperature and salinity - May and July 1973
- summer temperature and winter salinity - March, April and October 1974
- winter temperature and summer salinity - July and August 1975, August 1976
- summer temperature and salinity - October and November 1976.

The salinity tolerance of juvenile *P. latisulcatus* may also be dependent on the stage of development. Venkataramiah, Lakshmi and Gunter (1974) found that the post-larvae of *P. aztecus* survived in a wider range of salinities than did the juveniles. The findings of Zein-Eldin and Aldrich (1965) suggest that post-larval *P. duorarum* also survived in a wider range of salinities than did the juveniles. In these experiments only juvenile *P. latisulcatus* ranging in total length from 4 cm to 6 cm were used.

6.2 METHODS

6.2.1 General methods

Juvenile *Penaeus latisulcatus* used in the salinity tolerance experiments were collected from two sources. "Wild" prawns were collected from the vicinity of Torrens Island (fig 9) by the method described in section 3.2.1. Repeated trawls were made until sufficient numbers of prawns were captured; when this was not achieved on one night trawls were made on succeeding nights. A commercial aquaculture enterprise at Pt. Broughton on Spencer Gulf (fig 3) was the source of "cultured" juvenile *P. latisulcatus*. Prawns were collected from outdoor ponds which had been stocked with the hatchery-reared progeny of "wild" gravid female prawns captured offshore. The same beam trawl described in section 3.2.1 was hauled across the pond by hand to catch those prawns.

After recovery from the trawl "wild" and "cultured" prawns were placed into plastic 50 litre bins containing seawater from the site of collection. It was found that mortality during transport to the laboratory was minimized if the bins were filled to only one third of their capacity and if a maximum of 50 prawns were carried in each bin. Time from capture to return to the laboratory was usually about three hours. The temperature and salinity of the water at the collection site was measured with a Hamon Portable Temperature-Salinity Bridge.

In the laboratory the bins containing the juvenile prawns were placed in a constant temperature room which had been pre-set to the expected water temperature. The data on water temperatures in upper Spencer Gulf (Appendix D) allowed the temperature to be pre-set to within

1 or 2°C of the actual water temperature. Aeration was provided and the prawns were left to equilibrate to the laboratory temperature until the following day. Mortality of juvenile prawns to this stage rarely exceeded 20%, and those prawns that died were usually moulting or newly post-moult prawns. The surviving prawns were then placed into "holding" aquaria adjusted to the same salinity as the water from which they were captured. Glass aquaria measuring 60 x 29 x 35.5 cm were used throughout the study for both holding prawns at the acclimatization salinity, and for the experimental salinities. Filtration and aeration were simultaneously provided by an "under-gravel" type filter powered by compressed air. The under-gravel filter was first covered by a layer, 2 or 3 cm deep, of shellgrit. Over this 7 or 8 cm of fine beach sand provided a suitable substrate into which the juvenile prawns could burrow. Fifty prawns per aquarium could be maintained with negligible mortality for one week in these aquaria, but after this the water quality often deteriorated and cannibalism occurred under these conditions. Consequently juvenile prawns were usually not held at this density for more than 3 or 4 days. It was found that up to 20 juvenile *P. latisulcatus* could be held in each aquarium for indefinite periods.

A 24-hour photoperiod divided into 12 hours of light and 12 hours of darkness, occurring approximately at the natural times of day and night, was maintained in the constant temperature room. Thus, the normal nocturnal activity of the juvenile prawns was not disrupted.

The diet of the experimental prawns consisted of dry fish pellets. The juvenile prawns were fed *ad lib.* each second evening and excess food was siphoned from the aquaria the following morning. The pellet food was occasionally supplemented by chopped cockle (*Macomona deltoidalis*), freeze-dried brine shrimp (*Artemia salina*) or chopped fish (*Helotes sexlineatus*) when the prawns were being held for longer periods of time.

6.2.2 Salinity tolerance experiments

Juvenile prawns were transferred directly from the holding aquaria to each experimental aquarium. The experimental aquaria were of the same dimensions and were provided with the same filtration, aeration and substrate as in the holding aquaria. The low salinities were obtained by dilution of natural seawater with tap water. Concentrated seawater of approximately 100‰ was obtained from the salt evaporating ponds near Torrens Island (fig. 9) and was diluted with natural seawater to obtain the salinities of 45‰ and greater. The salinity was measured with a Hamon portable Temperature-Salinity Bridge, but since this apparatus can measure salinities up to only 42‰ , the higher salinities were measured from a 100 ml sample diluted by the addition of a further 100 ml of distilled water. The experimental aquaria were prepared at least one week prior to the experiment and the salinities were checked and adjusted if necessary before the introduction of any juvenile prawns. During an experiment the salinities were checked daily and adjustments were usually not necessary.

The juvenile prawns were fed on the evening prior to their transfer to the experimental aquaria. Usually 20 prawns were placed in each experimental aquarium. On some occasions 25 prawns per aquarium were used. When fewer prawns were available only 10 per aquarium were used. There appeared to be no difference in the mortality of prawns held in the holding aquaria at those densities. The prawns were not fed during the first 48 hours of the experiments but were fed every second day thereafter.

The number of dead prawns was counted each morning for ten days, and the dead prawns were removed from each aquarium. Except at the low salinities mortalities usually occurred at night and the dead prawns would be lying on the substrate next morning. Lack of response when prodded with a glass rod was taken as the criterion for death. Distressed animals would often be found quiescent on the substrate but always responded by flexing the abdomen or rapid movement of the pleopods when touched with a glass rod.

Besides counting the numbers of dead prawns each morning, some notes were made on the behaviour of the juvenile prawns in the experimental aquaria. Venkataramiah Lakshmi and Gunter (1974) noted that changes in the activity of *P. aztecus* occurred when they were transferred abruptly from one salinity to another, and defined five states of activity - inactive, normal, hyperactive, restless, and depressed.. Inactive animals were quiescent on the substrate or remained burrowed. Hyperactivity denotes a faster swimming and burrowing rate than normal. Repeated collisions with the sides of the aquarium and substrate, and rapid swimming in ascending and descending spirals is defined as "restless activity". "Depression" usually followed restless activity and is characterized by muscular paralysis and convulsions which cause the prawn to lie on its side on the substrate instead of resting in the normal upright stance. (Definitions after Venkataramiah *et. al.*(*op. cit.*)).

6.3 RESULTS

6.3.1 Behaviour of prawns in experimental salinities

Abnormal behaviour was observed immediately after transfer of the juvenile prawns to the salinity extremes. Prawns acclimatized to 36‰ showed signs of immediate distress when transferred to salinities less than 18‰ (fig 27). At salinities between 14 and 18‰ those prawns were generally hyperactive for periods up to several hours until their activity either returned to normal levels or the prawns became restless. Continued rapid burrowing and re-emergence from the substrate was common, as well as rapid swimming around the aquarium. Below 14‰ immediate restlessness was common and the prawns usually died following the "depressed" stage which usually occurred several hours after transfer to the experimental aquarium. Many prawns however were hyperactive before assuming normal activity and depression would occur later, not necessarily preceeded by restlessness or further hyperactivity. The "normal" response usually occurred when prawns acclimatized to 36‰ were transferred to salinities of between 20 and 60‰. The prawns would immediately swim to the substrate and make exploratory movements for several minutes, then burrow into the sand. Commonly they would re-emerge and burrow two or three times. In the higher salinities some prawns became hyperactive and many prawns swam quietly around the surface of the water apprarently due to overbuoyancy until they adjusted to the higher water density and were able to settle to the bottom.

The responses of prawns acclimatized to 42.5‰ were similar (fig 28) however immediate restlessness often occurred at salinities of 18‰ and less. Hyperactivity followed by restlessness or more commonly

FIGURE 27

CHART OF THE BEHAVIOUR OF JUVENILE *P. LATISULCATUS* ACCLIMATIZED TO WINTER SALINITY, WHEN EXPOSED TO VARIOUS EXPERIMENTAL SALINITIES.

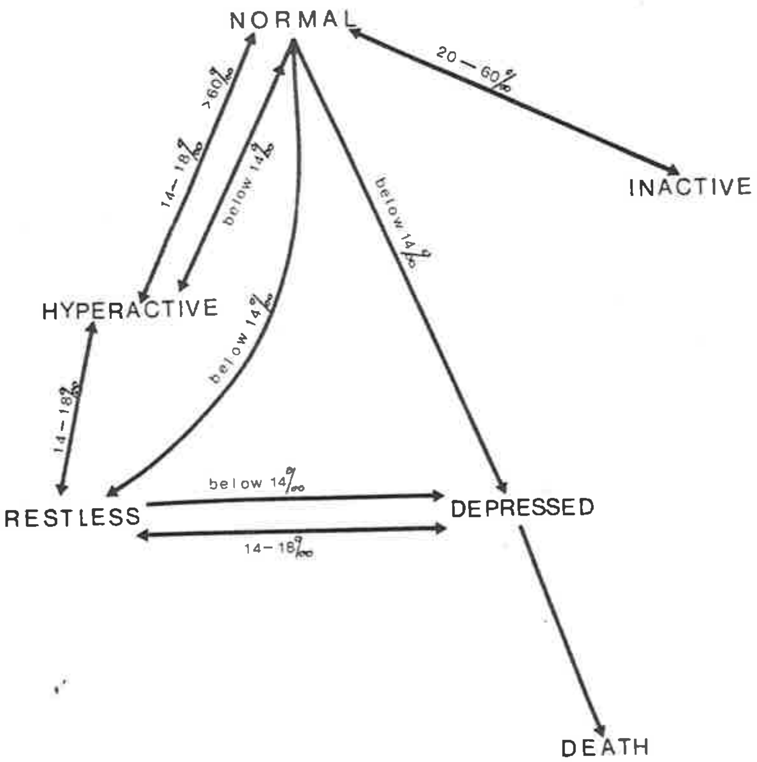
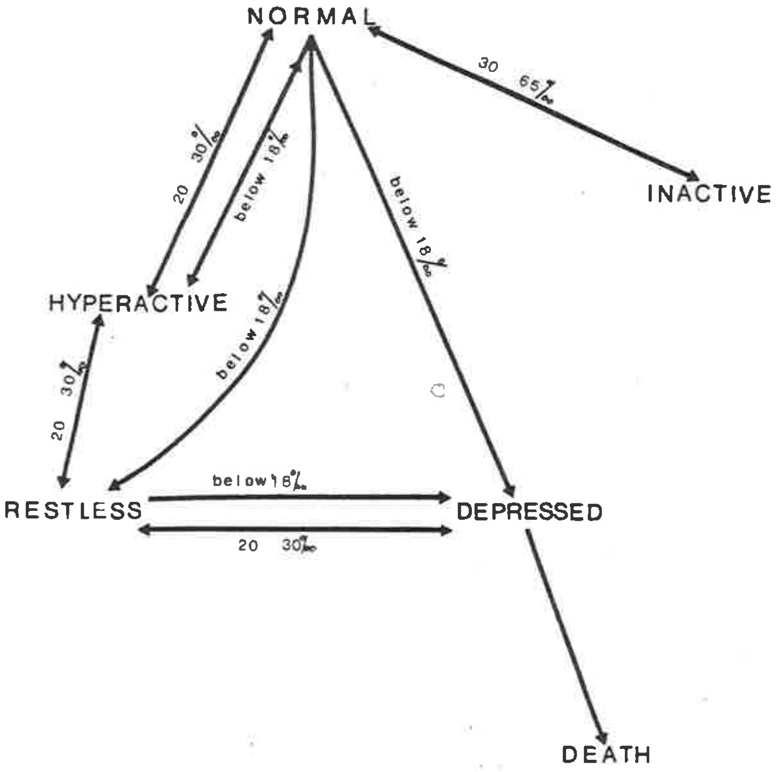


FIGURE 28

CHART OF THE BEHAVIOUR OF JUVENILE *P. LATISULCATUS* ACCLIMATIZED TO SUMMER SALINITY, WHEN EXPOSED TO VARIOUS EXPERIMENTAL SALINITIES.



return to normal behaviour occurred at salinities between 20 and 30‰. "Normal" behaviour occurred on transfer to salinities between 30 and 65‰ although at the higher salinities some prawns were overbuoyant.

In the case of both prawns acclimatized to 36‰ and those acclimatized to 42.5‰, transfer to the intermediate salinities resulted in the immediate "normal" response and the juvenile prawns usually became inactive several minutes after transfer.

Venkatamariah *et al.* (1974) noted that moulting frequently occurred following sudden transfer of juvenile *P. aztecus* from one salinity to another. Although moulting sometimes occurred following the transfer of juvenile *P. latisulcatus* to the experimental aquaria, this was not common. Moulting prawns never survived in salinities less than 25‰ when they had been acclimatized to 36‰ and did not survive salinities less than 30‰ when acclimatized to 42.5‰. When moulting occurred it was usually 2 or 3 days after the transfer and was more frequent after transfer to the lower salinities than to the higher salinities.

6.3.2 Salinity tolerance

Venkataramiah *et al.* (1974) considered that juvenile *P. aztecus* surviving in their test salinities for at least 96 hours were "indefinite" survivors. In those experiments it appears that mortality can be considered in two ways. Mortality of juvenile *P. latisulcatus* that occurred within the first 24 hours was probably due to the immediate osmotic shock when prawns were transferred from the acclimatization to the experimental salinities. The prawns which died within the first 24 hours were those that became immediately depressed on transfer to the experimental salinities or which became very restless and then depressed. It was further noted that those prawns found in a state of "depression" after the first day usually accounted for most of the deaths recorded the following day. Thus mortality within the first two days is referred to as immediate mortality. Further mortality continued after the second day until day nine after which mortality seldom occurred. Survival of juvenile *P. latisulcatus* after 10 days exposure to the experimental salinity will therefore be considered as indefinite.

Because of the difficulty in obtaining adequate numbers of wild prawns for experimentation, especially in the early stages of the project, and the limited aquarium facilities, experiments could sometimes only be conducted over part of the range of salinities being considered. Alternatively there were sometimes large differences between the salinities of the experimental aquaria and subsequent experiments were conducted at intermediate salinities. Thus in order to obtain adequate data for analysis it is desirable to pool the results of experiments conducted on juvenile prawns with similar acclimatization histories whenever possible. The results of the experiments conducted with the four different acclimatization groups will now be discussed. As well as following the usual convention of describing the tolerance in terms of the salinity required to kill 50% or more of the experimental prawns (LD_{50}), it will be advantageous to define a range of tolerance within which the mortality is less than 10%.

6.3.2.1 Prawns acclimatized to winter temperature and salinity

The first set of experiments was conducted during May and July 1973, using "wild" prawns caught near Torrens Island and acclimatized to winter temperatures and salinities. Since insufficient prawns were available to test survival in the entire range of salinities from

5‰ to 65‰, the first experiment concentrated on the range 5 to 40‰ using only 10 prawns per experimental aquarium. The second experiment covered the range 30 to 65‰ and the third 15 to 50‰. Twenty prawns per aquarium were used in the second and third experiments. The results, expressed in daily cumulative mortalities are shown in Table 18.

Since the temperature and salinity at which the prawns were captured was similar in all three groups (table 28), because there was no mortality in the control salinity (36‰) in each group and since there appeared to be no significant difference in the degree of mortality at salinities tested in all three experiments. (table 28), the results of the experiments were combined. The cumulative percentage mortality after two days and ten days exposure is shown in Table 19 and graphically in Figure 29. These results show that there was a fairly broad range from 22.5‰ to 55‰ in which the mortality is less than 10% after two days exposure to the experimental salinities, and that more than 50% of the prawns died in salinities less than about 15‰. After 10 days exposure mortalities less than 10% occurred in a very narrow range of salinities from about 32.5‰ to 40‰. At salinities less than 22.5‰ and greater than about 60‰ more than 50% of the prawns died. However, from the shape of the curve (fig 29) it appears that some factor other than salinity may be causing a a small number of the deaths especially in the higher salinities. No deaths occurred at the acclimatization salinity and in fact one of the acclimatization aquaria served as the "experimental" aquarium for this salinity. There appears to be a sudden increase in the mortality between 36 and 40‰, after which the mortality increases in the expected manner. This factor may be the shock of handling or of being briefly exposed to the air during transfer

TABLE 18

CUMULATIVE MORTALITY OF JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO WINTER TEMPERATURE AND SALINITY

Salinity ‰		5	10	15	20	25	30	35	40	45	50	55	60	65
15.5.73, day	1	10	10	3	1	1	1	0	0					
	2	10	10	4	2	1	1	0	0					
10 wild prawns acclimatized to 36.8‰ and 13.7°C	3	10	10	4	3	2	1	0	0					
	4	10	10	4	3	2	1	0	0					
	5	10	10	5	4	3	2	0	0					
	6	10	10	6	4	3	3	0	0					
	7	10	10	7	4	3	3	0	0					
	8	10	10	7	5	3	3	0	0					
	9	10	10	7	6	4	3	0	1					
	10	10	10	9	7	5	3	0	1					
29.5.73 day	1						1	0	0	0	1	1	3	5
	2						2	0	0	0	1	2	3	6
20 wild prawns acclimatized to 36.1‰ and 13.7°C	3						2	0	0	1	2	2	4	8
	4						3	0	0	1	3	3	5	10
	5						3	0	0	1	3	3	5	10
	6						3	0	0	2	3	4	6	11
	7						3	0	0	3	3	4	7	12
	8						4	0	1	3	4	4	8	13
	9						4	0	1	3	4	5	9	14
	10						4	0	2	3	4	5	9	14
4.7.73, day	1			5	3	1	1	0	0	0	1			
	2			7	4	2	1	0	0	0	2			
20 wild prawns acclimatized to 35.6‰ and 14.4°C	3			8	5	3	2	0	0	1	2			
	4			12	7	4	3	0	1	1	3			
	5			14	9	5	3	0	1	1	3			
	6			14	11	6	4	0	1	2	3			
	7			15	13	7	4	0	1	2	3			
	8			16	14	8	4	0	2	3	3			
	9			17	16	9	4	0	2	3	4			
	10			18	16	9	4	0	3	3	4			

TABLE 19

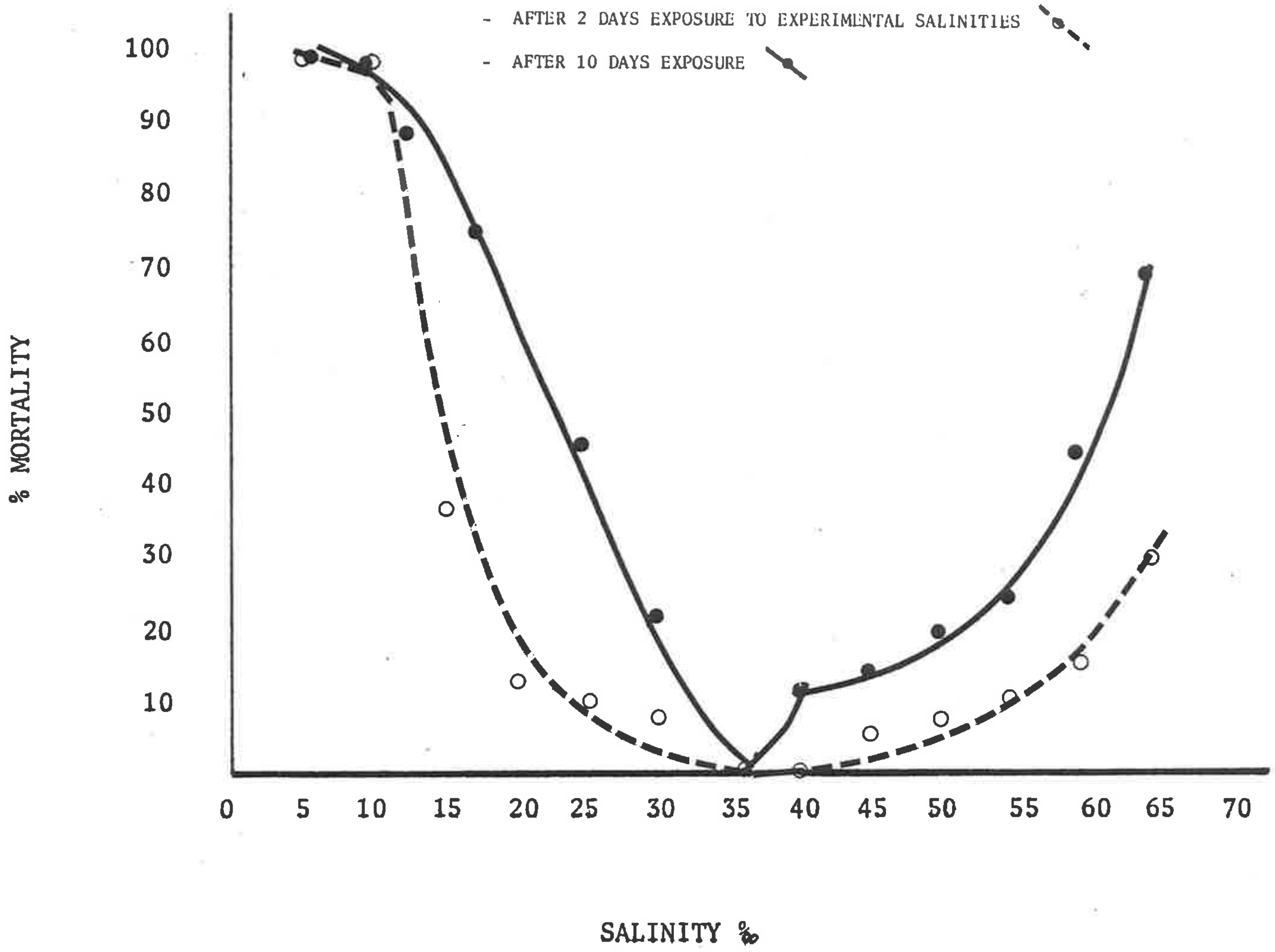
PERCENTAGE MORTALITY OF JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO WINTER TEMPERATURE AND SALINITY

Salinity ‰	5	10	15	20	25	30	35	40	45	50	55	60	65
initial number of prawns	10	10	30	30	30	50	50	50	40	40	20	20	20
% mortality													
day 2	100	100	36.7	13.3	10.0	8.0	0	0	5.0	7.5	10.0	15.0	30.0
day 10	100	100	90.0	76.7	46.7	22.0	0	12.0	15.0	20.0	25.0	45.0	70.0

FIGURE 29

% MORTALITY OF 'WILD' JUVENILE *P. LATISULCATUS*

ACCLIMATIZED TO WINTER TEMPERATURE AND SALINITY:



from one aquarium to the other, or the sudden encounter with higher salinity regardless of the salinity concentration or, more likely, a combination of both these factors. The effect is not manifest during the first few days of exposure. Transfer to the lower salinities does not appear to have the same effect since the mortalities increase with decreasing salinity in the expected manner after both two and ten days exposure.

6.3.2.2. Prawns acclimatized to summer temperature and winter salinity

During 1974 salinities appeared not to attain the high levels reached during the summers of other years (for example 1972 and 1975). This may be due to the very heavy rainfall throughout 1973 and 1974. Thus juvenile *P. latisulcatus* collected from the vicinity of Torrens Island in March and April 1974 were acclimatized to summer temperatures and "winter" salinities. Likewise prawns obtained from the Port Broughton Prawn Culture Centre during April and October 1974 were also acclimatized to summer temperatures and winter salinities. Six experiments using prawns acclimatized to these conditions were carried out, three using "wild" prawns and three using cultured prawns. The results are shown in Table 20. As before, the results of the experiments were pooled because of the similar acclimatization temperature and salinity and the apparent similarity of results. However the pooled results of the experiments using wild prawns were first compared with those of the experiments using cultured prawns. (Table 21). From Figure 30 it is obvious that there is no significant difference between the mortality of wild and cultured juvenile *P. latisulcatus* so the results were further pooled for later analyses (table 22).

TABLE 20

CUMULATIVE MORTALITY OF 'WILD' AND 'CULTURED' JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO SUMMER TEMPERATURE AND WINTER SALINITY

Salinity ‰		5	10	12	15	16.5	20	21.5	25	26	30	33.3	35	36	39	40	45	46	50	55	60	63	65	70
2.3.74 day	1				2		1		0		0		0	0		0	0		1	1				
	2				3		1		1		1		0	0		0	0		1	1				
10 wild prawns acclimatized to 36.6‰ and 18.5°C	3				4		2		1		1		0	0		0	0		1	1				
	4				4		3		2		1		0	0		0	0		1	1				
	5				5		3		2		1		0	0		0	0		1	1				
	6				6		3		3		2		0	0		0	0		1	1				
	7				6		3		3		2		0	0		0	0		1	1				
	8				7		4		3		3		0	0		1	0		1	1				
	9				7		5		4		3		0	0		1	0		2	1				
	10				9		6		4		3		1	0		1	0		2	2				
18.3.74 day	1												0	0		0	0		0	1	2		4	
	2												0	0		0	0		1	2	3		6	
20 wild prawns acclimatized to 36.9‰ and 18.9°C	3												0	0		0	1		1	2	5		7	
	4												0	0		1	1		2	2	4		8	
	5												0	0		1	1		2	2	4		10	
	6												0	0		1	2		2	3	5		11	
	7												0	0		1	2		3	3	6		11	
	8												0	0		1	2		3	4	7		12	
	9												0	0		2	2		3	5	8		13	
	10												1	0		2	3		3	5	8		14	

TABLE 20 CONTD.

Salinity ‰		5	10	12	15	16.5	20	21.5	25	26	30	33.3	35	36	39	40	45	46	50	55	60	63	65	70
25.4.74 day	1						1		0		1		0	0		0	1							
	2						2		1		1		0	0		0	1							
10 wild prawns acclimatized to 37.1‰ and 18.1°C	3						3		2		1		0	0		0	1							
	4						3		2		1		0	0		0	1							
	5						4		2		1		0	0		0	1							
	6						4		2		1		0	0		1	1							
	7						5		3		2		0	0		1	1							
	8						6		3		3		0	0		2	1							
	9						7		3		3		1	0		2	1							
	10						7		3		3		1	0		2	1							
5.4.74 day	1												0	0		0	0		0	1	1		3	
	2												0	0		0	0		0	1	3		5	
20 cultured prawns acclimatized to 36.8‰ and 18.8°C	3												0	0		0	1		1	2	3		6	
	4												0	0		0	1		2	2	3		7	
	5												0	0		1	2		2	3	4		9	
	6												0	0		1	2		3	3	5		10	
	7												0	0		1	2		3	4	6		11	
	8												0	0		1	2		3	4	7		11	
	9												0	0		2	3		4	5	7		13	
	10												0	0		2	3		4	6	7		13	

TABLE 20 CONTD.

Salinity ‰		5	10	12	15	16.5	20	21.5	25	26	30	33.3	35	36	39	40	45	46	50	55	60	63	65	70
1.10.74 day	1				3		2		1		0		0	0		0	0							
	2				5		3		2		1		0	0		0	0							
20 cultured prawns acclimatized to 37.3‰ and 19.1°C	3				8		4		2		2		0	0		0	0							
	4				9		6		4		2		0	0		0	1							
	5				11		7		4		2		0	0		1	1							
	6				13		8		5		2		0	0		1	1							
	7				14		8		5		3		0	0		1	1							
	8				16		11		7		3		0	0		2	1							
	9				16		12		7		3		0	0		2	1							
	10				17		14		7		4		1	0		2	2							
19.10.74 day	1	25	23	22	4	2		1		0	0	0		0	0	0		0	0			2		5
	2	25	25	23	6	4		4		0	0	0		0	1	0		0	1			4		6
25 cultured prawns acclimatized to 37.3‰ and 19.6°C	3	25	25	24	10	7		4		1	2	1		0	1	1		1	3			6		7
	4	25	25	25	12	9		5		2	2	1		0	1	1		1	3			6		8
	5	25	25	25	15	10		5		2	2	1		0	1	1		1	3			7		11
	6	25	25	25	17	11		6		3	2	2		0	1	1		2	3			9		14
	7	25	25	25	19	13		7		3	3	2		0	1	2		2	3			10		18
	8	25	25	25	20	14		8		4	3	2		0	1	2		2	3			11		21
	9	25	25	25	20	17		9		4	3	2		0	2	2		2	3			13		22
	10	25	25	25	20	18		10		5	3	2		0	2	2		2	3			15		22

TABLE 21

PERCENTAGE MORTALITY OF WILD AND CULTURED JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO SUMMER TEMPERATURE AND WINTER SALINITY

Salinity ‰	5	10	12	15	16.5	20	21.5	25	26	30	33.3	35	36	39	40	45	46	50	55	60	63	65	70
Initial number of prawns wild				10		20		20		20		40	40		40	40		30	30	30		20	
cultured	25	25	25	45	25	20	25	20	25	45	25	40	65	25	65	40	25	45	20	20	25	20	25
day 2 wild				30		30		10		10		0	0		0	2.5		6.7	10	13.3		30	
cultured	100	100	92	24.4	16	15	16	10	0	2.2	0	0	0	4	0	0	0	2.2	5	15	16	25	24
day 10 wild				90		65		35		30		7.5	0		12.5	10		16.7	23.3	40		70	
cultured	100	100	100	82.2	72	70	40	35	20	15.5	8	1.5	0	8	9.2	12.5	8	15.6	30	35	60	65	88

TABLE 22

COMBINED PERCENTAGE MORTALITY OF WILD AND CULTURED JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO SUMMER TEMPERATURE AND WINTER SALINITY

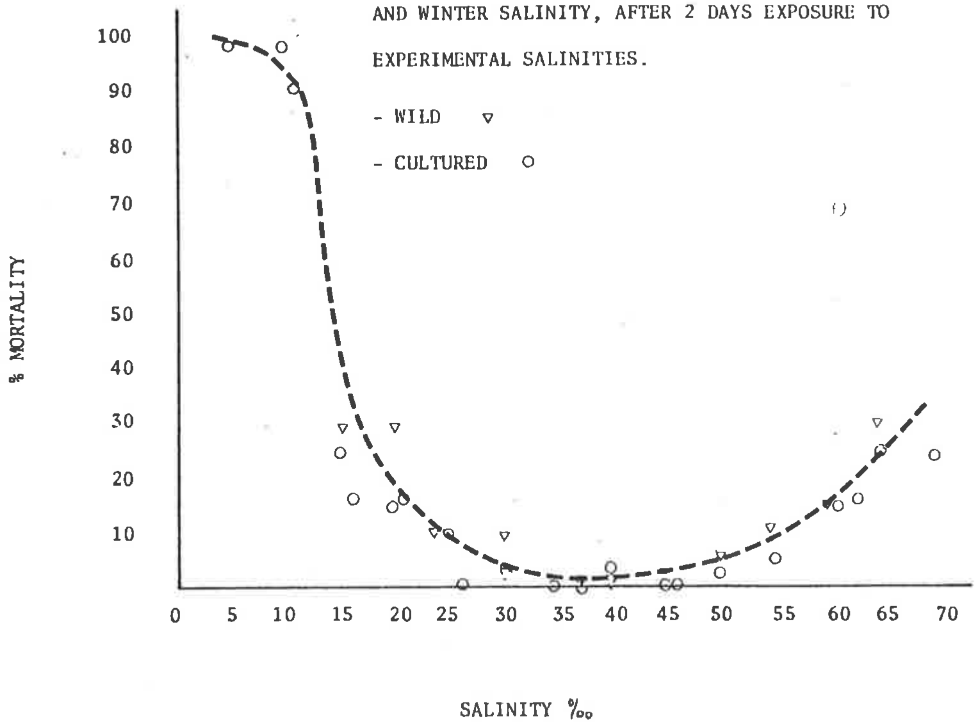
Salinity ‰	5	10	12	15	16.5	20	21.5	25	26	30	33.3	35	36	39	40	45	46	50	55	60	63	65	70
initial no. of prawns	25	25	25	55	25	40	25	40	25	65	25	80	105	25	105	80	25	75	50	50	25	40	25
day 2	100	100	92	25.5	16	15	16	10	0	4.6	0	0	0	4	0	1.2	0	4.0	8.0	14	16	27.5	24
day 10	100	100	100	83.6	72	67.5	40	35	20	20	8	5	0	8	10	11.2	8	16	26	38	60	67.5	88

Despite the different acclimatization temperature, the results of these experiments are very similar to those of the previous set of experiments. A fairly broad range of salinities from 25‰ to 55‰ where mortalities are less than 10‰ is tolerated for two days exposure. At salinities less than 15‰, 50% of the juvenile prawns died within two days. (fig 30). After ten days exposure to the experimental salinities 50% of the prawns had died in salinities less than 22.5‰ and greater than about 62.5‰ (fig 30). The range of salinities in which less than 10% mortalities occurred after 10 days exposure is extended a little, from 32.5‰ to 45‰ (fig 30) compared to the prawns acclimatized to winter temperatures where the range tolerated was only 32.5‰ to 40‰. Again there is a sudden increase in mortality between 36 and 40‰ which does not appear to be related to salinity.

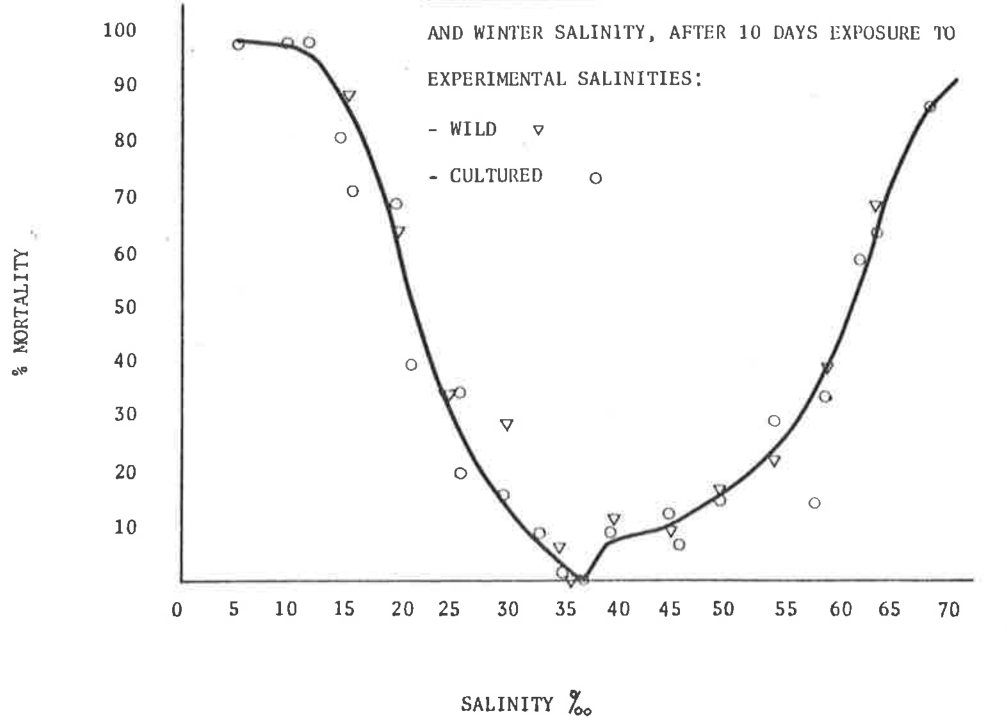
6.3.2.3 Prawns acclimatized to winter temperature and summer salinity

Juvenile *P. latisulcatus* acclimatized to winter temperatures but "summer" salinities were obtained during July and August 1975, and during August 1976. Four experiments, three with cultured prawns and one with wild prawns were carried out and the results are presented in Table 23. Because of the similarity of the results of all four experiments and the fact that there was no significant difference between the mortality of wild and cultured prawns in the second set of experiments, these results have been pooled and are shown in Table 24. The pooled results show that juvenile prawns acclimatized to summer salinity and winter temperature have greater mortality at the lower salinities than did the prawns acclimatized to winter salinity and summer or winter temperature. After two days exposure, over 50% of the prawns died in salinities less than 21‰ (fig 31) whereas 50% mortality did not occur until 15‰ with the

FIGURE 30


% MORTALITY OF 'WILD' AND 'CULTURED' JUVENILE *P. LATISULCATUS* ACCLIMATIZED TO SUMMER TEMPERATURE AND WINTER SALINITY, AFTER 2 DAYS EXPOSURE TO EXPERIMENTAL SALINITIES.

- WILD ▽
- CULTURED ○


% MORTALITY OF 'WILD' AND 'CULTURED' JUVENILE *P. LATISULCATUS* ACCLIMATIZED TO SUMMER TEMPERATURE AND WINTER SALINITY, AFTER 10 DAYS EXPOSURE TO EXPERIMENTAL SALINITIES:

- WILD ▽
- CULTURED ○

TABLE 23

CUMULATIVE MORTALITY OF 'WILD' AND 'CULTURED' JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO WINTER TEMPERATURE AND SUMMER SALINITY

Salinity ‰		5	10	12	14	15	16	18	20	22.5	25	28	29	30	32.5	33.3	35	36	40	42.5	45	50	55
14.8.75, day	1					18			8		3			0			0			0		0	0
	2					19			11		4			1			0			0		0	0
20 cultured prawns acclimatized to 43.7‰ and 12.9°C	3					19			14		6			1			1			0		0	1
	4					19			15		8			2			1			0		0	1
	5					20			16		10			3			1			0		0	1
	6					20			17		11			5			1			0		0	2
	7					20			17		12			6			2			0		0	2
	8					20			18		13			7			2			0		0	2
	9					20			19		15			9			3			0		1	2
	10					20			19		16			9			3			0		1	2
10.8.76, day	1	20	20	18	19	18	18	16	7	4	2	1	0		0	0	0	0	0	0	0	0	0
	2	20	20	19	19	18	19	17	12	7	5	2	2		1	1	0	0	0	0	0	0	0
20 cultured prawns acclimatized to 43.0‰ and 13.7°C	3	20	20	20	19	19	19	18	15	10	7	3	2		1	1	0	0	0	0	0	0	1
	4	20	20	20	20	20	19	18	16	12	9	5	3		1	1	0	0	0	0	0	0	1
	5	20	20	20	20	20	20	19	16	15	10	7	4		2	1	0	0	0	0	0	0	2
	6	20	20	20	20	20	20	19	17	15	11	9	5		2	1	0	0	0	0	0	1	2
	7	20	20	20	20	20	20	19	17	16	12	10	6		2	1	0	0	0	0	0	1	3
	8	20	20	20	20	20	20	20	17	17	13	11	7		2	1	1	0	0	0	0	1	3
	9	20	20	20	20	20	20	20	18	17	15	11	8		3	2	1	0	0	0	0	2	3
	10	20	20	20	20	20	20	20	18	18	15	12	9		3	2	2	1	0	0	1	3	4

TABLE 23 CONTD.

CUMULATIVE MORTALITY OF 'WILD' AND 'CULTURED' JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO WINTER TEMPERATURE AND SUMMER SALINITY

Salinity ‰		5	10	12	14	15	16	18	20	22.5	25	28	29	30	32.5	33.3	35	36	40	42.5	45	50	55
22.7.75, day	1		20			17			8		3			1			0		0	0	0	0	0
	2		20			18			11		4			2			0		0	0	0	0	1
20 wild prawns acclimatized to 40.6‰ and 13.6°C	3		20			19			15		7			2			0		0	0	0	0	1
	4		20			19			16		10			4			0		0	0	0	0	1
	5		20			20			16		11			4			0		0	0	0	0	2
	6		20			20			17		11			6			1		0	0	0	1	2
	7		20			20			17		12			8			1		0	0	0	1	2
	8		20			20			18		13			9			1		0	0	0	1	2
	9		20			20			19		14			10			2		0	0	0	1	3
	10		20			20			19		14			10			2		0	0	0	2	3
3.7.75, day	1					9			2		1			0			0		0	0	0	0	
	2					10			4		2			1			0		0	0	0	1	
10 cultured prawns acclimatized to 41.8‰ and 14.3°C	3					10			7		4			2			0		0	0	0	1	
	4					10			8		5			2			0		0	0	0	1	
	5					10			8		5			2			0		0	0	0	1	
	6					10			8		6			3			0		0	0	0	1	
	7					10			9		6			3			0		0	0	0	1	
	8					10			9		6			3			0		0	0	0	1	
	9					10			9		7			4			1		0	0	0	2	
	10					10			9		7			4			1		0	0	0	2	

prawns acclimatized to winter salinity. The situation for 10 day exposure was similar, with 50% mortalities at 30‰ and 22.5‰ for prawns acclimatized to summer salinity and winter salinity respectively.

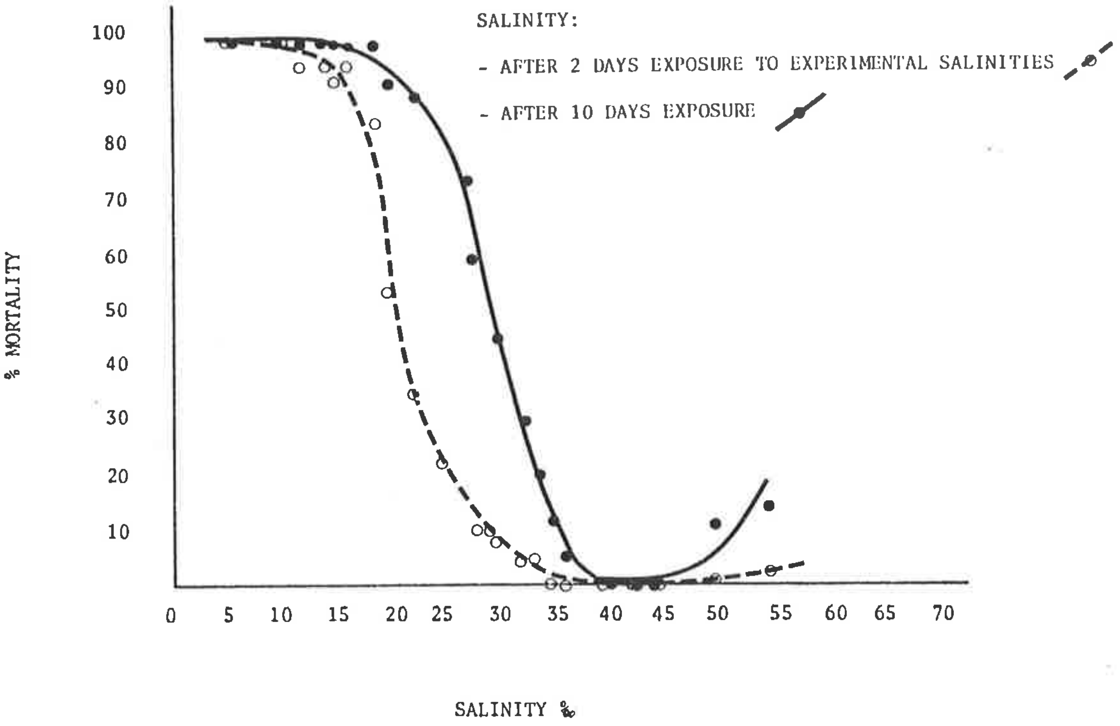
There is some indication of a sudden increase in mortality of prawns transferred to higher salinities after 10 days exposure. The mortality increased from zero at 45‰ to 11.4% at 50‰, but only from 11.4% to 15% over the 50‰ to 55‰ increment. However there are insufficient results to justify drawing anything but a smooth curve through these points (fig 31).

6.3.2.4 Prawns acclimatized to summer temperature and salinity

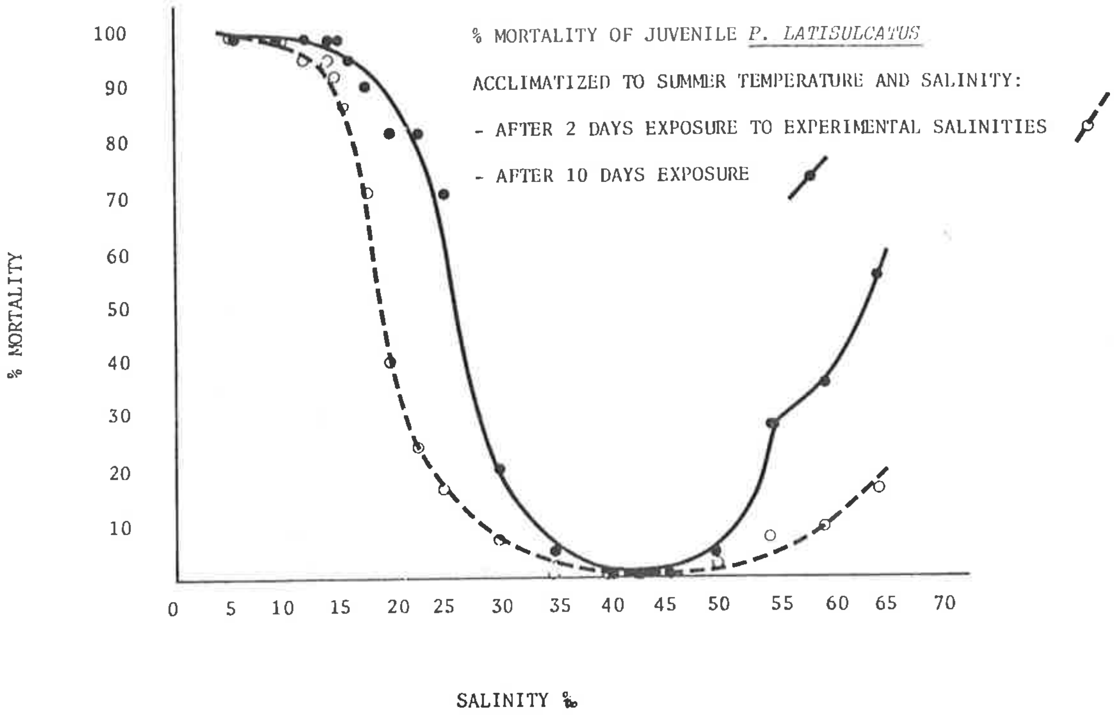
Two experiments with juvenile *P. latisulcatus* acclimatized to summer temperature and salinity were carried out in October and November 1976. The prawns were obtained from the Pt. Broughton Prawn Culture Centre, and the results of each experiment are shown in Table 25. Because these results appear to be similar and because of the similar acclimatization, they are pooled in Table 26. In comparison to the prawns acclimatized to winter temperature and summer salinity, those acclimatized to summer temperature and salinity appear to have slightly lower mortality in the lower salinity range. The salinity below which at least 50% mortality occurred after two days exposure is 19‰ in these experiments (fig 31) whereas mortality of 50% or more occurred in salinities below 21‰ in the previous experiments. After 10 days exposure the difference between the two acclimations is even more pronounced, the salinity at which mortalities greater than 50% occurred being 26‰ and 30‰ respectively.

The results again suggest a steeper than expected increase in mortality in the juvenile prawns exposed to the higher salinities for 10 days.

FIGURE 31



% MORTALITY OF JUVENILE *P. LATISULCATUS*
ACCLIMATIZED TO WINTER TEMPERATURE AND SUMMER
SALINITY:
- AFTER 2 DAYS EXPOSURE TO EXPERIMENTAL SALINITIES
- AFTER 10 DAYS EXPOSURE



% MORTALITY OF JUVENILE *P. LATISULCATUS*
ACCLIMATIZED TO SUMMER TEMPERATURE AND SALINITY:
- AFTER 2 DAYS EXPOSURE TO EXPERIMENTAL SALINITIES
- AFTER 10 DAYS EXPOSURE

TABLE 24

PERCENTAGE MORTALITY OF WILD AND CULTURED JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO WINTER TEMPERATURE AND SUMMER SALINITY

Salinity ‰	5	10	12	14	15	16	18	20	22.5	25	28	29	30	32.5	33.3	35	36	40	42.5	45	50	55
initial number of prawns	20	40	20	20	70	20	20	70	20	70	20	20	50	20	20	70	20	70	70	50	70	60
% mortality																						
day 2	100	100	95	95	92.8	95	85	54.3	35	21.4	10	10	8	5	5	0	0	0	0	0	1.4	1.
day 10	100	100	100	100	100	100	100	92.9	90	74.3	60	45	46	30	20	11.4	5	0	0	0	11.4	15

TABLE 25

CUMULATIVE MORTALITY OF JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO SUMMER TEMPERATURE AND SALINITY

Salinity ‰		5	10	12	14	15	16	18	20	22.5	2.5	30	35	40	42.5	45	50	55	60	65	70
10.10.76 day	1	25	24	23	23	22	21	18	9	5	4	1	0	0	0	0	0	1	2	3	
	2	25	25	24	24	23	22	18	10	6	4	2	0	0	0	0	1	2	2	4	
25 cultured prawns acclimatized to 43.1‰ and 17.8°C	3	25	25	25	24	23	23	19	12	10	6	2	0	0	0	0	1	2	3	6	
	4	25	25	25	25	24	23	20	13	12	9	3	0	0	0	0	1	3	4	7.	
	5	25	25	25	25	24	23	21	15	14	10	3	0	0	0	0	1	4	5	8	
	6	25	25	25	25	25	24	22	16	16	12	4	0	0	0	0	1	5	6	9	
	7	25	25	25	25	25	24	23	17	17	14	4	0	0	0	0	1	6	7	10	
	8	25	25	25	25	25	24	23	18	18	16	4	1	0	0	0	1	6	8	11	
	9	25	25	25	25	25	24	23	20	21	18	5	1	0	0	0	1	7	9	14	
	10	25	25	25	25	25	24	23	20	21	18	5	1	0	0	0	1	7	9	14	
3.11.76 day	1	20	20	19	19	18	17	14	7	3	1	1	0	0	0	0	0	1	2	3	
	2	20	20	19	19	19	18	14	8	5	3	1	0	0	0	0	0	1	2	3	
20 cultured prawns acclimatized to 43.6‰ and 18.9°C	3	20	20	20	19	19	18	14	10	7	4	2	0	0	0	0	0	2	2	4	
	4	20	20	20	20	19	18	15	11	8	7	2	0	0	0	0	0	2	2	5	
	5	20	20	20	20	20	18	16	13	9	9	3	0	0	0	0	1	3	3	7	
	6	20	20	20	20	20	19	16	14	11	10	3	0	0	0	0	1	4	4	7	
	7	20	20	20	20	20	19	17	15	12	11	4	0	0	0	0	1	5	5	9	
	8	20	20	20	20	20	19	18	16	13	12	4	0	0	0	0	1	6	6	10	
	9	20	20	20	20	20	19	18	16	14	13	4	0	0	0	0	1	6	7	10	
	10	20	20	20	20	20	19	18	17	16	14	4	1	0	0	0	1	6	7	11	

TABLE 26.

PERCENTAGE MORTALITY OF JUVENILE *PENAEUS LATISULCATUS* ACCLIMATIZED TO SUMMER TEMPERATURE AND SALINITY

Salinity ‰	5	10	12	14	15	16	18	20	22.5	25	30	35	40	42.5	45	50	55	60	65
Initial number of prawns	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
% mortality																			
day 2	100	100	95.6	95.6	93.3	88.9	71.1	40.0	24.4	15.6	6.7	0	0	0	0	2.2	6.7	8.9	15.6
day 10	100	100	100	100	100	95.6	91.1	82.2	82.2	71.1	20	4.4	0	0	0	4.4	28.9	35.6	55.6

6.3.2.5 Analysis

The results of mortality after two days exposure to the experimental salinities (fig 32) suggests that regardless of the acclimatization temperature, juvenile *P. latisulcatus* acclimatized to summer salinities are less susceptible to mortality in high salinities than are prawns acclimatized to winter salinities. Prawns acclimatized to winter salinity have fewer mortalities in low salinities than do prawns acclimatized to summer salinity.

Acclimatization temperature seems to have little effect on the salinity tolerance of prawns acclimatized to winter salinity (fig 32) but prawns acclimatized to summer salinity have different responses to transfer to low salinities when acclimatized to summer and winter temperatures.

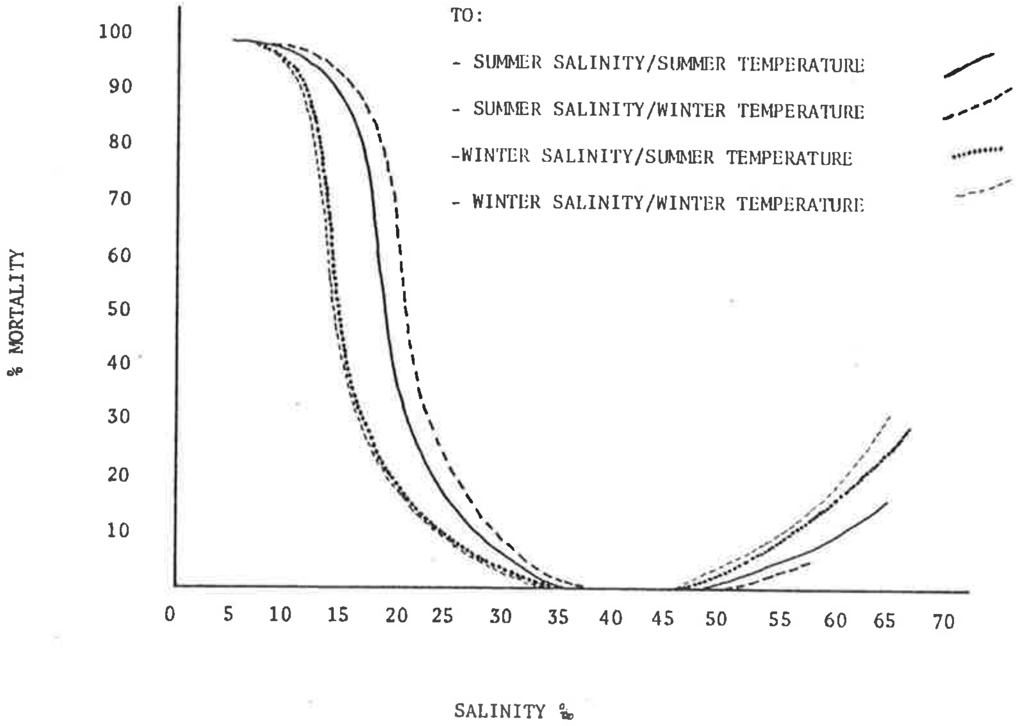
The results after 10 days exposure to the experimental salinities follow a similar pattern to those after two days exposure in the lower salinity range (fig 32). In the upper salinity range it appears that of the prawns acclimatized to winter salinity, those acclimatized to winter temperature have a slightly higher mortality than those acclimatized to summer temperature. Prawns acclimatized to summer salinity generally have lower mortality at higher salinities than do prawns acclimatized to winter salinity. There is, however, some confusion due to the unexpectedly high mortality of prawns acclimatized to summer salinity and temperature at 55‰ (fig 32).

A statistical analysis was undertaken to make more precise estimates of the salinity at which 50% of the prawns died (LD_{50}) than those in

FIGURE 32

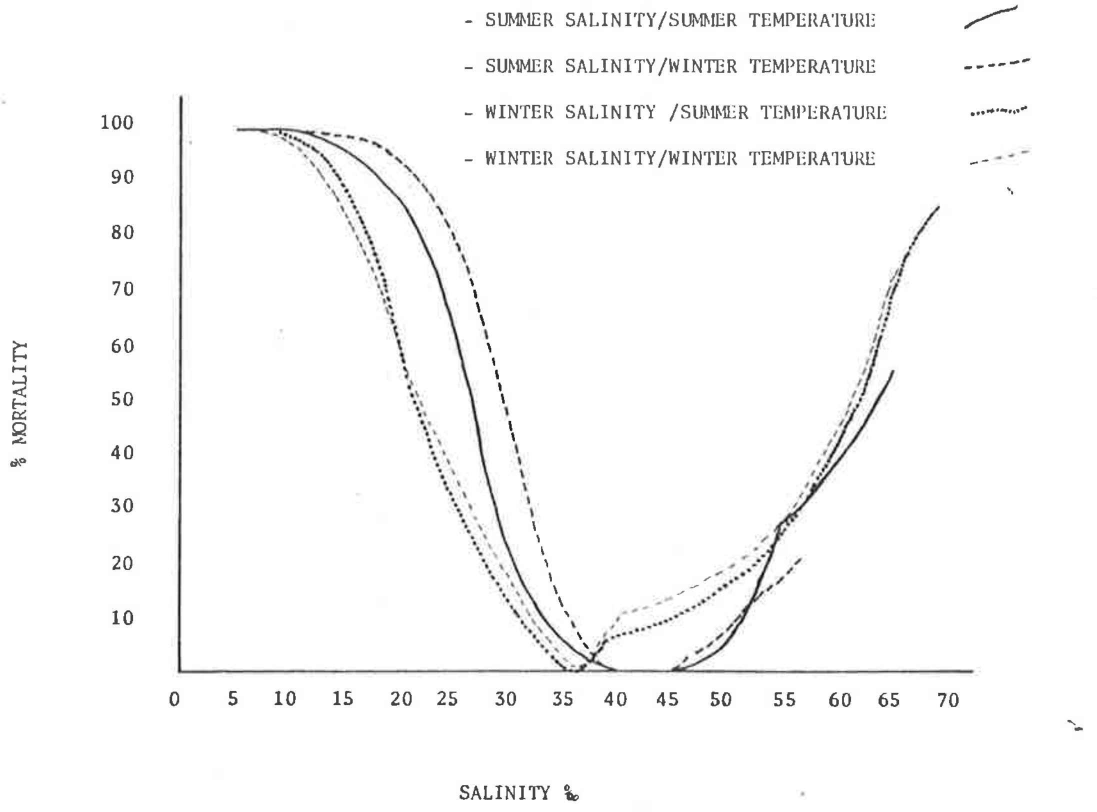
% MORTALITY AFTER 2 DAYS EXPOSURE TO EXPERIMENTAL SALINITIES OF JUVENILE *P. LATISULCATUS* ACCLIMATIZED TO:

- SUMMER SALINITY/SUMMER TEMPERATURE
- SUMMER SALINITY/WINTER TEMPERATURE
- WINTER SALINITY/SUMMER TEMPERATURE
- WINTER SALINITY/WINTER TEMPERATURE



% MORTALITY AFTER 10 DAYS EXPOSURE TO EXPERIMENTAL SALINITIES OF JUVENILE *P. LATISULCATUS* ACCLIMATIZED TO:

- SUMMER SALINITY/SUMMER TEMPERATURE
- SUMMER SALINITY/WINTER TEMPERATURE
- WINTER SALINITY /SUMMER TEMPERATURE
- WINTER SALINITY/WINTER TEMPERATURE



sections 6.3.2.1 to 6.3.2.4, to test the significance of the apparent differences in the LD_{50}s and to test for any interaction between temperature and salinity of acclimatization. The data were analysed by the method of logits (Cox, 1970) by P.I. Leppard, statistician, Department of Applied Mathematics, University of Adelaide.

The logit model $$p = \frac{e^{\alpha + \beta x}}{1 + e^{\alpha + \beta x}}$$

where - p is the probability of survival

- α and β are unknown parameters to be estimated

was found to satisfactorily fit the data on mortality at reduced salinities. There were insufficient mortalities in the upper salinity regime after two days exposure to calculate LD_{50}s. The model could not be fitted to the data for the upper salinity regime after 10 days exposure and it was inadvisable to fit a different model to this part of the data (P. Leppard, pers comm.) so precise LD_{50}s for 10 days exposure to the higher salinities were not calculated. The LD_{50}s and their associated 95% confidence limits, with respect to reductions in salinity are shown in Table 27. After both 2 and 10 days exposure to the experimental salinities there is no significant difference between the LD_{50}s of prawns acclimatized to winter salinity/summer temperature and winter salinity/winter temperature, so a common model was fitted to those sets of data (table 27). Of the prawns acclimatized to summer salinity, there was, however, a significant difference between those acclimatized to summer temperature and those acclimatized to winter temperature. The difference was significant after both two and ten days exposure. The salinity tolerance of juvenile *P. latisulcatus* to reductions in salinity was significantly greater in prawns acclimatized to winter salinity than in those acclimatized to summer salinity.

TABLE 27

LOGIT ANALYSIS OF THE SALINITY TOLERANCE TO REDUCED SALINITIES FOR a) 2 DAYS and b) 10 DAYS EXPOSURE

a) Salinity tolerance after 2 days:

Acclimatization Temperature	Acclimatization Salinity	
	Summer	Winter
Summer	$\alpha = -7.64$ $\beta = 0.36$ $LD_{50} = 21.49^{o}/oo$ 95% confidence limits $(20.43, 22.62)^{o}/oo$	* $\alpha = -4.16$ $\beta = 0.28$ $LD_{50} = 14.67^{o}/oo$ 95% confidence limits $(13.61, 15.65)^{o}/oo$
Winter	$\alpha = -8.39$ $\beta = 0.41$ $LD_{50} = 20.27^{o}/oo$ 95% confidence limits $(19.77, 20.81)^{o}/oo$	

b) Salinity tolerance after 10 days:

Acclimatization Temperature	Acclimatization Salinity	
	Summer	Winter
Summer	$\alpha = -9.21$ $\beta = 0.35$ $LD_{50} = 26.35^{o}/oo$ 95% confidence limits $(25.36, 27.39)^{o}/oo$	* $\alpha = -5.89$ $\beta = 0.26$ $LD_{50} = 22.86^{o}/oo$ 95% confidence limits $(21.81, 23.91)^{o}/oo$
Winter	$\alpha = 10.07$ $\beta = 0.35$ $LD_{50} = 28.80^{o}/oo$ 95% confidence limits $(27.89, 29.63)^{o}/oo$	

*Prawns acclimatized to winter salinities showed no significant difference in salinity tolerance between those acclimatized to summer or winter temperatures.

From these results and the graphical analysis it can be concluded that juvenile *P. latisulcatus* acclimatized to summer salinity suffer greater mortality than do those acclimatized to winter salinity, when exposed to low salinities. When exposed to higher salinity they generally have fewer mortalities. Acclimatization temperature appears to have no practical effect on the mortality of prawns acclimatized to winter salinity, in the lower salinity range, but to have an effect on the mortality of prawns acclimatized to summer salinity in this range. In the upper salinity range acclimatization temperature may have a slight effect on the mortality of prawns acclimatized to winter salinity.

6.4 DISCUSSION

6.4.1 The effects of acclimatization on salinity tolerance

The results show that the salinity tolerance of juvenile *P. latisulcatus* increases slightly when the acclimatization temperature is increased from 14°C to 18.5°C, especially in prawns acclimatized to summer salinities. This is in agreement with Zein-Eldin and Aldrich (1965) who found that the salinity tolerance range of postlarval and juvenile *P. aztecus* generally increases with temperature. Venkataramiah *et al* (1974) however, found that in direct transfer experiments the salinity tolerance range of juvenile *P. aztecus* was wider in prawns acclimatized to 21°C and 26°C than in prawns acclimatized to 31°C. These temperatures are in the upper range of temperatures investigated by Zein-Eldin and Aldrich *op cit* and it was found that the survival of *P. aztecus* was reduced at temperatures approaching 35°C regardless of the salinity. This may explain the apparent conflict between their general conclusions and the findings of Venkatamariah *et al* (1974).

It is not known why the range of salinity tolerance of juvenile *P. latisulcatus* tolerance appears to be extended more by increased temperature when the prawns are acclimatized to summer salinity than when they are acclimatized to winter salinity. A possible explanation might be that the offshore migration of subadults occurs in the warmer months and is towards waters of lower salinity than in the nursery areas. The extension of the range of salinities tolerated, especially in favour of the lower salinities would therefore be advantageous. Prawns acclimatized to winter salinity would experience very little salinity change if they were to migrate offshore and therefore an extension of the tolerance range would be of little advantage. Increasing water temperatures are generally associated with increasing salinity as the summer approaches and it may even be an advantage for juvenile prawns acclimatized to winters to have an increased tolerance to high salinities at higher temperatures, but there is no evidence from the results of such a shift in the salinity tolerance.

The experimental results clearly show that regardless of the acclimatization temperature the salinity tolerance of juvenile *P. latisulcatus* is dependent on the acclimatization salinity. Less than 10% of the prawns acclimatized to 36‰ died in the salinity range 24‰ to 56‰ When exposed to experimental salinities for two days. In the case of prawns acclimatized to summer salinity (42.5‰ the range of salinity in which less than 10% died within two days was 27.5‰ to approximately 61‰ This shift in the range of tolerance is in agreement with the findings of Venkataramiah *et al* (1974) that depending on the acclimatization salinity the range of tolerance of juvenile *P. azetcus* could be extended from the normal 8.5 to 34‰ either towards the lower or higher salinities. Bursey and Lane (1971a) found that acclimatization to low salinities reduced the mortality of juvenile *P. duorarum* exposed to low salinities. Their data however, do not show any extension in the range of tolerance of this species.

The ability of juvenile *P. latisulcatus* to shift the range of their salinity tolerance depending on the acclimatization salinity is of importance in the ecology of this species. In South Australian waters and in Shark Bay, the usual physico-chemical environment of juvenile *P. latisulcatus* is hypersaline. The hypersalinity is due to low effective rainfall and freshwater run off, combined with high rates of evaporation (Thomas and Edmonds, 1956). The salinity thus increases gradually, during which time juvenile *P. latisulcatus* become acclimatized to increasingly higher salinities. This extends the tolerance range towards the higher salinities and thus represents an adaptation to the hypersaline environment.

The fact that acclimatization to low salinity leads to a reduced tolerance to high salinity is not a disadvantage to juvenile *P. latisulcatus* living in a generally hypersaline environment because sudden increases in salinity are not likely to occur. Increases in salinity occur gradually due to evaporation thus allowing prawns to acclimatize to increasingly higher salinities. In any case salinities higher than 55‰ have not been measured in Spencer or St. Vincent Gulf waters and this salinity is within the range tolerated to juvenile *P. latisulcatus* acclimatized to winter salinity. Higher salinities, up to 70‰ occur in Shark Bay, but juvenile *P. latisulcatus* are generally not found in waters where the salinity exceeds 60‰. The ability to shift the range of salinity tolerance depending on the acclimatization salinity therefore appears to be more advantageous to a species such as *P. latisulcatus* which inhabits a hypersaline habitat in imparting increased tolerance to high salinities than in extending the range of tolerance to low salinities.

6.4.2 Salinity tolerance of juvenile *P. latisulcatus* compared to that of other penaeid prawns

Despite the economic importance of the penaeid Crustacea in both fisheries and aquaculture there have been few studies of the salinity tolerance of these species, especially of the juvenile stages. Williams (1960) found that the survival of juvenile *Penaeus aztecus* was not as good as that of *P. duorarum* over the range of 10 to 30‰. Zein-Eldin and Aldrich (1965) found that postlarval *P. aztecus* had a tolerance range from 10 to 39‰ at 25°C, and this is in agreement with the findings of Venkataramiah *et al* (1974) that postlarval *P. aztecus* tolerate higher salinities than do the juveniles. Juvenile *P. aztecus* could survive direct transfer in the normal tolerance range of 8.5 to 34‰. This range could be extended to 3.4‰ to 47.6‰ with acclimatization Vankatamariah (*et al*) Less than 10% of juvenile *P. duorarum* acclimatized to salinities between 33 and 36‰ and temperatures of 22 to 24°C died when transferred directly to salinities ranging between 20.4 and 47.6‰ and most of the mortalities occurred during the first 24 hours (Bursey and Lane 1971a) Besides these studies, circumstantial evidence derived from the distribution of juvenile penaeid prawns in relation to salinity suggests that many species are tolerant of low salinities.

The range of salinities over which mortalities of juvenile *Penaeus latisulcatus* are less than 10% after two days exposure is from approximately 25 to 30‰ up to 55 to 60‰ depending on the salinity and to a lesser extent the temperature acclimatization. In comparison to *P. aztecus* and *P. duorarum*, juvenile *P. latisulcatus* appear to be less tolerant of low salinities but more tolerant of higher salinities.

It is advantageous to discuss the salinity tolerance of juvenile *P. latisulcatus* in terms of the survival curve as defined by Dorgelo (1976). The maximum of the survival curve may be extended to a plateau, meaning that a range of salinities instead of one value has the same survival value. Using this concept Dorgelo (1976) has classified the salinity tolerance of Crustacea into five main categories (fig 33). The survival curves of *P. aztecus*, *P. duorarum* and *P. latisulcatus* are shown in Figure 34. These curves appear to be intermediate between types II and III of Dorgelo (1976). *P. aztecus* is an example of an extremely euryhaline species, tolerating the entire range of salinities from marine to almost limnetic conditions equally well. The tolerance to hypersaline conditions drops steeply between 47.5 and 55‰. *P. duorarum* is much less tolerant of low salinity than *P. aztecus* but is more tolerant of high salinities and this may reflect an adaptation to the drier coastline along which this species is found (Gunter and Edwards 1969). The tolerance of *P. latisulcatus* to low salinity is slightly less than that of *P. duorarum*, and this is in keeping with the hypersaline conditions in which juvenile *P. latisulcatus* are generally found. The tolerance of *P. latisulcatus* to high salinities is markedly greater than that of both *P. aztecus* and *P. duorarum*.

The increased survival of *P. latisulcatus* at high salinity compared to that of the other penaeid species for which data are available indicates an adaptation to the hypersaline habitat.

In South Australian waters and in Shark Bay, juvenile *P. latisulcatus* are usually acclimatized to salinities greater than 40‰ and under

FIGURE 33

FROM DORGELO (1976)

CLASSIFICATION OF SALT TOLERANCE AS MODELLED BY MEANS OF SURVIVAL CURVES. TYPE I: POLYSTENOHALINE, TRUE OCEANIC SPECIES. TYPE II: MORE OR LESS EURYHALINE SPECIES FROM HYPERSALINE, MARINE, INTERTIDAL OR ESTUARINE ENVIRONMENTS. TYPE III: EXTREMELY EURYHALINE SPECIES THAT TOLERATE MARINE AS WELL AS LIMNETIC CONDITIONS EQUALLY WELL. TYPE IV: MORE OR LESS EURYHALINE, GENUINE BRACKISH-WATER SPECIES. TYPE V: OLIGOSTENOHALINE, TRUE FRESH-WATER SPECIES. ARROWS INDICATE VARIATION IN THE LENGTH OF THE PLATEAU OR IN STEEPNESS OF THE SLOPES. IN TYPES I AND V THE ARROWS ARE ASYMMETRICAL TOWARDS MARINE AND LIMNETIC CONDITIONS, RESPECTIVELY. MAXIMAL SURVIVAL IS INDICATED BY A ZONE TO CLARIFY THE DIAGRAM.

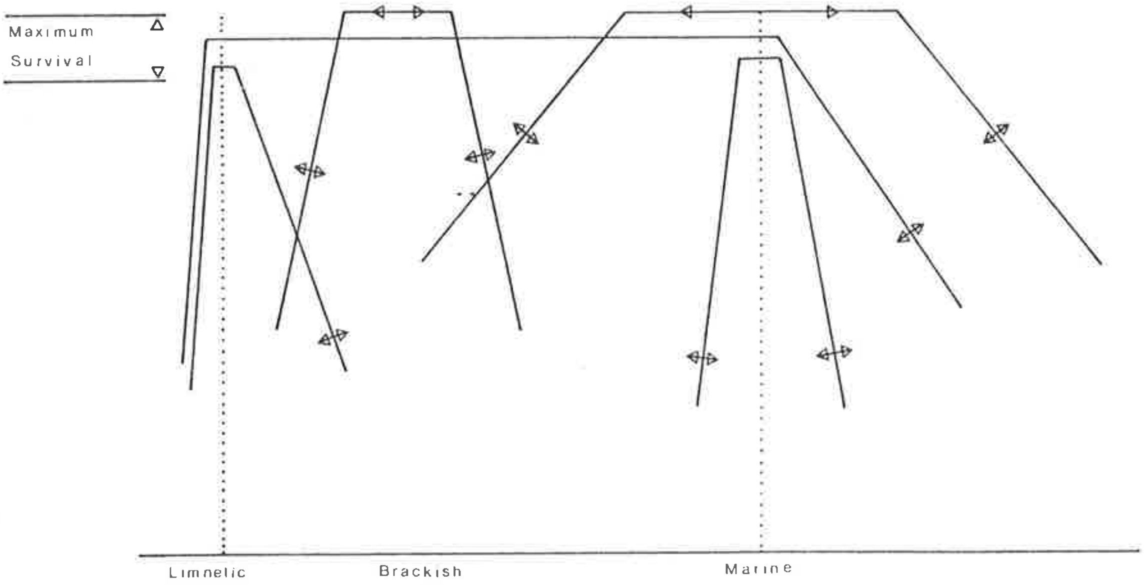
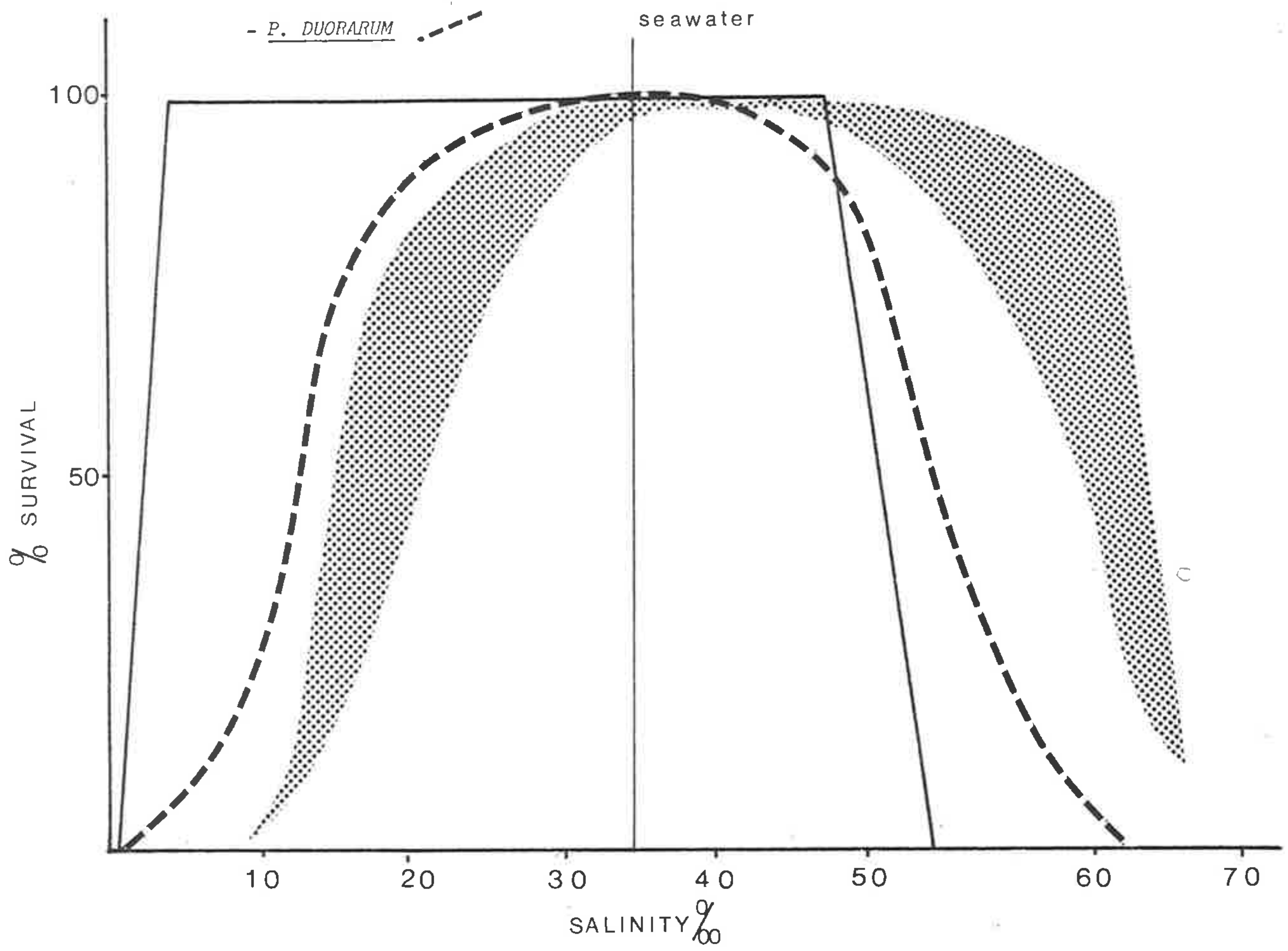


FIGURE 34

SURVIVAL CURVES OF:

- *P. LATISULCATUS* (RANGE OF SURVIVAL DEPENDING ON ACCLIMATIZATION) ▨
- *P. AZTECUS* ─
- *P. DUORARUM* - - -



these conditions survival is reduced in salinities less than 30‰. Since salinity in the nursery areas can be reduced from values as high as 50‰ to less than 10‰ following heavy rainfall and local flooding, such events are of great importance to the survival of juvenile *P. latisulcatus* in the nursery areas.

CHAPTER SEVEN

OSMOTIC AND IONIC REGULATION OF JUVENILE *P. latisulcatus*

7.1 INTRODUCTION

Juvenile *Penaeus latisulcatus* occur naturally in salinities up to 50‰ in Spencer Gulf and 60‰ in Shark Bay. The tolerance of prawns from these localities to high salinity is probably greater than that observed in the laboratory experiments since it has been shown that the salinity tolerance is influenced by the field acclimatization, and in the laboratory experiments prawns were acclimatized to 42.5‰. It is therefore of interest to examine the osmotic regulation of juvenile *P. latisulcatus* to determine the physiological basis for this wide salinity tolerance.

Species in which the haemolymph is isosmotic with the external medium over the range of salinities tolerated (osmoconformers) are generally of marine origin and have a limited salinity tolerance. Species that maintain the haemolymph hyperosmotic to the medium in diluted seawater but are isosmotic in high salinities (hyperosmotic regulators) are usually estuarine inhabitants which are usually exposed to dilutions of seawater. Those species which maintain the haemolymph hyperosmotic to dilute media and hypo-osmotic to concentrated media (hyper/hypo-osmotic regulators) come from a variety of habitats that are likely to be associated with fluctuating salinities. These species generally have a wide range of salinity tolerance (Lockwood, 1962).

The pattern of osmoregulation has been studied in a number of penaeid prawns. *Metapenaeus monoceros* (Panikkar and Viswanathan, 1948), *M. dobsoni*, *Penaeus indicus* and *P. carinatus* (Panikkar, 1951), *P. aztecus* (Williams, 1960; MacFarland and Lee, 1963), *P. duorarum*

(Williams, 1960; Bursey and Lane, 1971a,b), *P. setiferus* (MacFarland and Lee, 1963) and *Metapenaeus bennettae* (Dall, 1964) have been found to be hyper/hypo-osmotic regulators. Of these species *M. bennettae* is unusual in that it still has the ability to regulate the haemolymph hypo-osmotic to the medium in salinities above 20‰ yet it does not migrate out of the estuarine environment (Dall, 1964). Osmoregulation has been studied in two stenohaline penaeid prawns, *Trachypenaeus similis* and *Sicyonia dorsalis*, and these species are capable of hyperosmotic regulation but do not show the marked hypo-osmotic regulation characteristic of *Penaeus setiferus* and *P. aztecus* when exposed to high salinities (MacFarland and Lee, 1963).

Because of the occurrence of juvenile *P. latisulcatus* in hypersaline waters and the results of the salinity tolerance experiments, *P. latisulcatus* should be capable of hypo-osmotic regulation in high salinities and that their powers of hyperosmoregulation might be reduced compared to that of the other euryhaline penaeids so far examined, all of which inhabit estuarine waters while juveniles. Bayly (1972) also holds the opinion that *P. latisulcatus* should be capable of hypo-osmotic regulation in high salinities, based on the distribution of the species in Australian waters. In addition the isosmotic point of juvenile *P. latisulcatus* might be expected to be greater than that observed in juveniles of other penaeid prawns which live in salinities less than normal seawater. This would be in agreement with the findings of Brand and Bayly (1971) that the isosmotic points of four species of calanoid copepods were correlated to their natural distributions in relation to salinity.

The ability of an animal to maintain the osmotic concentration of the blood at a different level to that of the external medium is a function of its ability to regulate the concentration of the various ionic constituents of the blood. Ionic regulation has been studied in *Penaeus setiferus* (MacFarland and Lee, 1963), *P. duorarum* (MacFarland and Lee, 1963; Venkataramiah, Lakshmi and Gunter, 1974) and in *Metapenaeus bennettae* (Dall 1964, 1967b). It is of interest to investigate the regulation of haemolymph ions in *P. latisulcatus* in order to determine whether any marked difference exists between the ionic regulation of this species and that of the other penaeids.

During the course of these osmotic and ionic determinations it became apparent that for prawns at high salinities the osmotic concentration of the haemolymph could not be completely accounted for by the ionic concentrations. Free amino acids have been found to be important in the osmoregulation of some Crustacea (Dall, 1975). Although they have generally been considered to be associated with osmoregulation at the cellular level (Kasschau, 1975; Tucker and Costlow, 1975) Gilles (1977) has recently shown that the concentration of free amino acids in the haemolymph of *Eriocheir sinensis* varies according to the salinity of the medium. Therefore the level of amino acids in the haemolymph of juvenile *P. latisulcatus* exposed to high and low salinities was investigated.

7.2 METHODS

7.2.1 General Methods

The general methods of collection of juvenile *P. latisulcatus* and their maintenance in aquaria have been discussed in section 6.2.1 Haemolymph samples were taken from both wild and cultured juvenile prawns but most were taken from cultured prawns because of the ease of collecting large numbers. The juvenile prawns were returned to the laboratory in 50 L plastic bins and were left to equilibrate to the laboratory temperature (18.5°C) overnight. Except for the prawns maintained at 10‰ to 12.5‰, which were gradually acclimated to these salinities by dilution of the medium by daily increments of 2‰, prawns were transferred directly from the water in which they were obtained to the experimental salinities which ranged up to 70‰. Some osmotic and ionic measurements were made on the survivors of the salinity tolerance experiments described in Chapter 6. In this case the prawns had been exposed to the experimental salinities for at least 10 days and were considered to be acclimated to those salinities. Bursey and Lane (1971a) found that juvenile *Penaeus duorarum* reached osmotic and ionic equilibrium with experimental media within 48 hours, but in the present study haemolymph was only taken from juvenile *P. latisulcatus* which had been exposed to experimental salinities for at least one week. The prawns were fed until 48 hours prior to sampling. Since the osmotic and ionic concentrations in the haemolymph of *P. duorarum* vary during the moult cycle (Bursey and Lane, 1971b) only intermoult juvenile *P. latisulcatus* were sampled. Intermoult prawns were identified after the method of Bursey and Lane (1971b).

Haemolymph was first withdrawn from each juvenile prawn by inserting a previously unused 20μl glass "Microcap" capillary tube through the intersegmental membrane between the cephalothorax and the first abdominal segment, and into the pericardial cavity, after the method of Bursey and Lane (1971a). However, the haemolymph either coagulated almost immediately on puncture of the intersegmental membrane, or else spurted out to form a thin film on the exoskeleton and in either case was difficult to recover. It was later found that the microcapillary tube could be inserted through the base of the 5th walking leg and the haemolymph then flowed easily into the tube or could be drawn out by suction applied through a length of vinyl tube (Medical Grade single lumen clear vinyl tube, catalogue number SV55, Dural Plastics, Dural N.S.W.) attached to the distal end of the glass capillary tube. Most of the haemolymph samples were taken in this way.

7.2.2 Osmotic determinations

Measurements of the osmotic concentration of the haemolymph were made with a Kalber Biological Cryoscope (Serial number 007, Clifton Technical Physics, Wanamassa N.J., U.S.A.) calibrated to read directly off a digital scale in freezing point depression "Δ" units.

The cryoscope was calibrated to read zero with double distilled water and Δ2°C with a standard solution of 0.585 M NaCl. A series of standard solutions of Δ0.5, 1.0, and 3.5°C were made up, having concentrations of 0.145, 0.545 and 1.010 molar NaCl. These standards were used to check the linearity of the calibration and to make adjustments to account for slight shifts in the calibration between measurements.

After extraction, the haemolymph was drawn up into the length of vinyl tubing. The glass capillary tube used for extraction of the haemolymph was removed from the end of the vinyl tube and replaced by a previously unused micropipette through which small drops of haemolymph could be forced out onto the freezing stage of the cryoscope. Six small holes in the freezing stage were first filled with microscope immersion oil then replicate samples of the haemolymph were placed into the holes, forming droplets in the immersion oil.

The haemolymph was quick-frozen then gradually warmed up and the temperature at which each droplet melted was recorded.

7.3.2 Ionic Determinations

Measurements of the ionic concentrations in the haemolymph of juvenile *Penaeus latisulcatus* were made on samples taken from prawns exposed to salinities over the range 10‰ to 70‰ at 18.5^{0}C for at least two days. Measurements of ionic concentrations were sometimes made in association with the osmotic determinations described in section 7.2.2.

Haemolymph samples were taken with a 20μl "Microcap" glass capillary tube attached to a length of vinyl tube through which suction could be applied by mouth. Each 20 μl sample was immediately blown into a plastic sample tube containing 5 ml of double distilled water, giving an effective dilution of 1:251, and frozen until analysis.

The concentrations of sodium, potassium, calcium and magnesium ions were measured by atomic absorbtion spectrophotometry (Geddes 1975) with a "Varian Techtron" model 1200 atomic absorbtion spectrophotometer.

An air-acetylene flame was used for atomization of the sample. The spectrophotometer was calibrated against standard solutions of known ionic concentrations to read directly in parts per million (μg/ml). The standard solutions were prepared according to the recommendations contained in the comprehensive manual provided with the spectrophotometer (Varian Techtron, 1972). Likewise the instrument was set to the recommended values of lamp current, spectral band width and wavelength to obtain the optimum sensitivity. One (1) ml of the diluted sample was sufficient for the determination of Na^+, K^+ and Mg^{++}. For the measurement of Ca^{++}, 35µl of a 200,000 ppm strontium solution was added to 1.5 ml of the diluted sample to prevent interference in the ionization of the calcium giving a final dilution of 1:257.

7.2.4 Amino acid determinations - methods

The concentration of free amino acids in the haemolymph of juvenile *P. latisulcatus* was determined for two groups of prawns acclimatized to 30‰ and 55‰ salinity. Juvenile prawns from the Pt. Broughton Prawn Culture Centre were held in the laboratory in these salinities for at least one week before sampling.

Haemolymph samples (20µl) were withdrawn from each prawn and the protein was precipitated by the addition of 2 mls of 10% trichloracetic acid (TCA). The precipitated protein was centrifuged out of suspension at 3000 rpm for 5 minutes in a desk centrifuge. The supernatant was drawn off and retained. The precipitant was resuspended in a further 2 mls of 10% TCA and again centrifuged out of suspension. The supernatant was drawn off and added to that obtained previously. The plasma solution was therefore diluted by 1:200 in 10% TCA. A 20µl sample of seawater of each salinity was treated in the same manner as the haemolymph samples.

The modified ninhydrin colorimetric analysis of Rosen (1957) was used to determine the concentration of free amino acids in the samples. The optical densities were measured with a Perkin-Elmer model 124 double beam spectrophotometer at a wavelength of 570mµ. Since Dall (1975) found that glutamic acid is one of the important amino acids associated with the osmoregulation of *Panulirus longipes*, a triplicate series of standards were made up from a stock solution of 0.01M glutamic acid by adding 5, 10, 15, 20, 30, 40, 50 and 70 µl aliquots to 1 ml of 10% TCA. The optical densities of the ninhydrin compound produced by treating the standards in the same was as the haemolymph samples were measured. A calibration curve of the molar concentration of glutamic acid against the optical density could then be drawn. Since each amino acid reacts with the ninhydrin reagent in the same way, (Rosen, 1957) the combined molar concentration of amino acids producing a given optical density will be the same as the molar concentration of glutamic acid (or any other particular amino acid) producing the same optical density.

7.3 RESULTS

7.3.1 Osmotic regulation

There was very little variation in the freezing point depressions of the six replicate samples of haemolymph from each individual prawn, except for the consistently higher value of the first sample loaded. It was thought that evaporation of the sample from the tip of the micropipette could lead to this difference. Since this experimental error could not be adequately accounted for, the Δs from replicate 1 are not included in the results (Appendix H). After eliminating this first replicate the greatest variation between the remaining five replicate samples from an individual prawn is from $\Delta 2.365^0$C to $\Delta 2.330^0$C in one prawn exposed to a salinity of 54‰. In many cases there is no variation at all between replicate samples and in most cases the variation is not greater than $\pm 0.005^0$C. The mean of the five replicates recorded in Appendix H is thus used as an estimate of the freezing point depression of the haemolymph of each prawn.

There were very few determinations made on the haemolymph of wild prawns. A wild prawn exposed to 15‰ had a haemolymph freezing point depression of $\Delta 1.329^{0}$C compared to $\Delta 1.323^{0}$C and $\Delta 1.257^{0}$C for cultured prawns. The mean freezing point depression of 5 wild prawns exposed to 36‰ was found to be $\Delta 1.751^{0}$C while the mean freezing point depression of 4 cultured prawns exposed to the same salinity was $\Delta 1.752^{0}$C. At 40‰ 2 wild prawns had haemolymph Δs of 1.974 and 1.931 compared to 1880, 1.904, 1.994, 2.208 and 2.034 for the 5 cultured prawns. Wild prawns exposed to salinities of 42.5, 47.5, 54, 63 and 70‰ had haemolymph freezing point depressions correspondingly similar to those of cultured prawns exposed to the same salinities (Table 28).

These results suggest that there is no significant difference between the haemolymph freezing point depressions of wild and cultured prawns exposed to the same salinities.

The mean freezing point depression of the haemolymph from each group of prawns exposed to the same salinity and the freezing point depression of the medium are presented in Table 39. The mean freezing point depression of each group of prawns is obtained from Appendix H, and includes the data from both wild and cultured prawns. The freezing point depression of the medium is the mean of 5 replicate determinations. Figure 35 relates the freezing point depression of the medium to the salinity. The values are very similar to those drawn from standard tables relating freezing point depression to salinity (Chemical Rubber Company, 1972-73), and this serves as an additional check on the accuracy of the procedure.

From these results it can be seen that juvenile *P. latisulcatus* maintain the haemolymph at higher osmotic concentration than the

TABLE 28

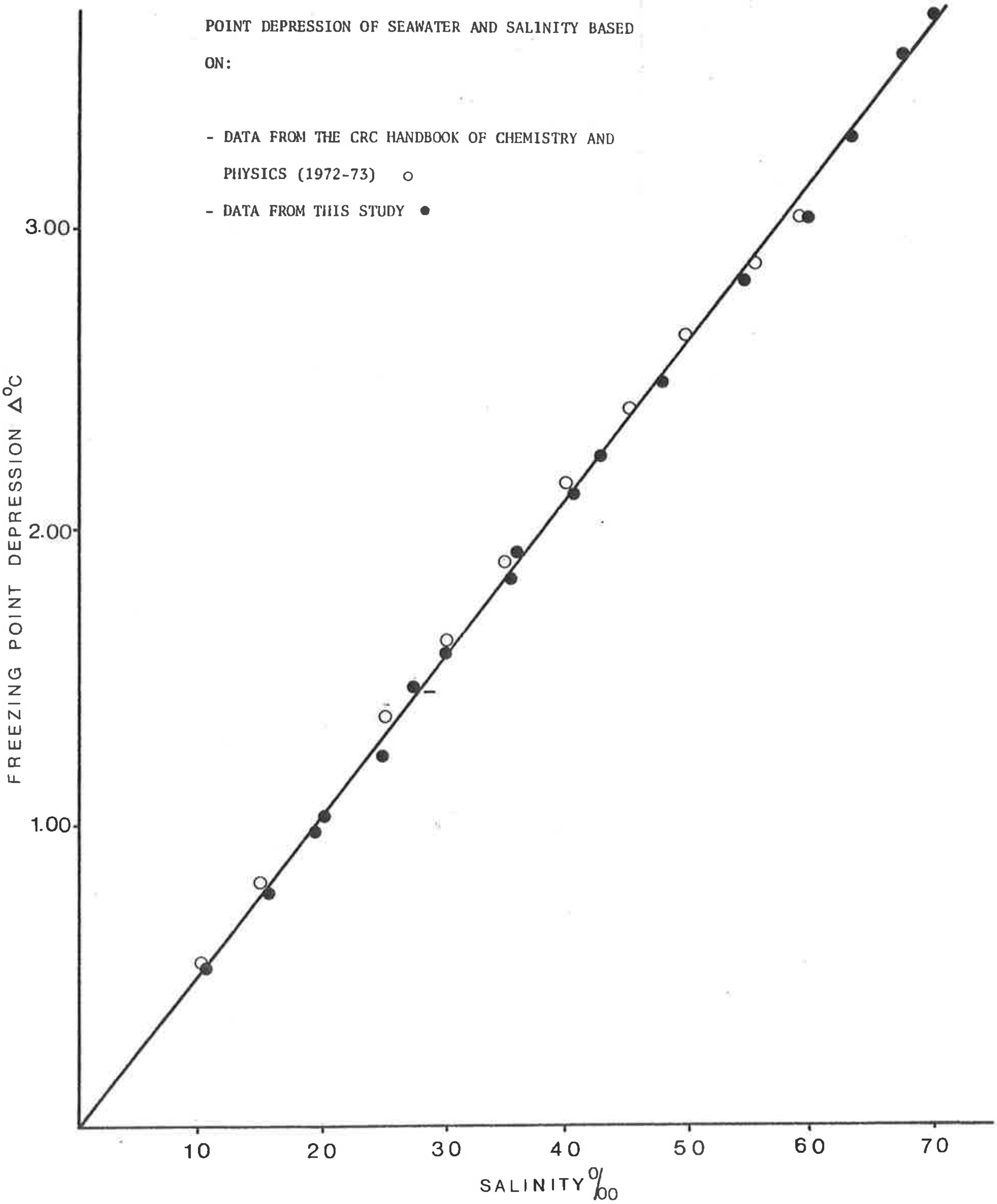
MEAN FREEZING POINT DEPRESSION OF THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* Δ °C

Salinity of medium ‰	Δ of medium °C	number of prawns	Mean Δ of haemolymph °C	S.D.
10.0	0.535	3	1.269	0.029
15.0	0.786	3	1.303	0.039
19.6	0.990	8	1.314	0.080
20.0	1.010	3	1.417	0.024
24.5	1.230	4	1.483	0.101
27.5	1.450	6	1.548	0.104
30.0	1.580	2	1.616	0.108
35.0	1.820	2	1.658	0.022
36.0	1.900	8	1.764	0.074
40.0	2.105	7	1.964	0.060
42.5	2.230	5	1.971	0.063
47.5	2.475	5	2.127	0.048
54.0	2.795	3	2.388	0.054
59.0	3.125	3	2.558	0.059
63.0	3.280	4	2.797	0.093
67.5	3.540	3	3.035	0.098
70.0	3.700	3	3.307	0.036

FIGURE 35

GRAPH OF THE RELATIONSHIP BETWEEN FREEZING POINT DEPRESSION OF SEAWATER AND SALINITY BASED ON:

- DATA FROM THE CRC HANDBOOK OF CHEMISTRY AND PHYSICS (1972-73) ○
- DATA FROM THIS STUDY ●



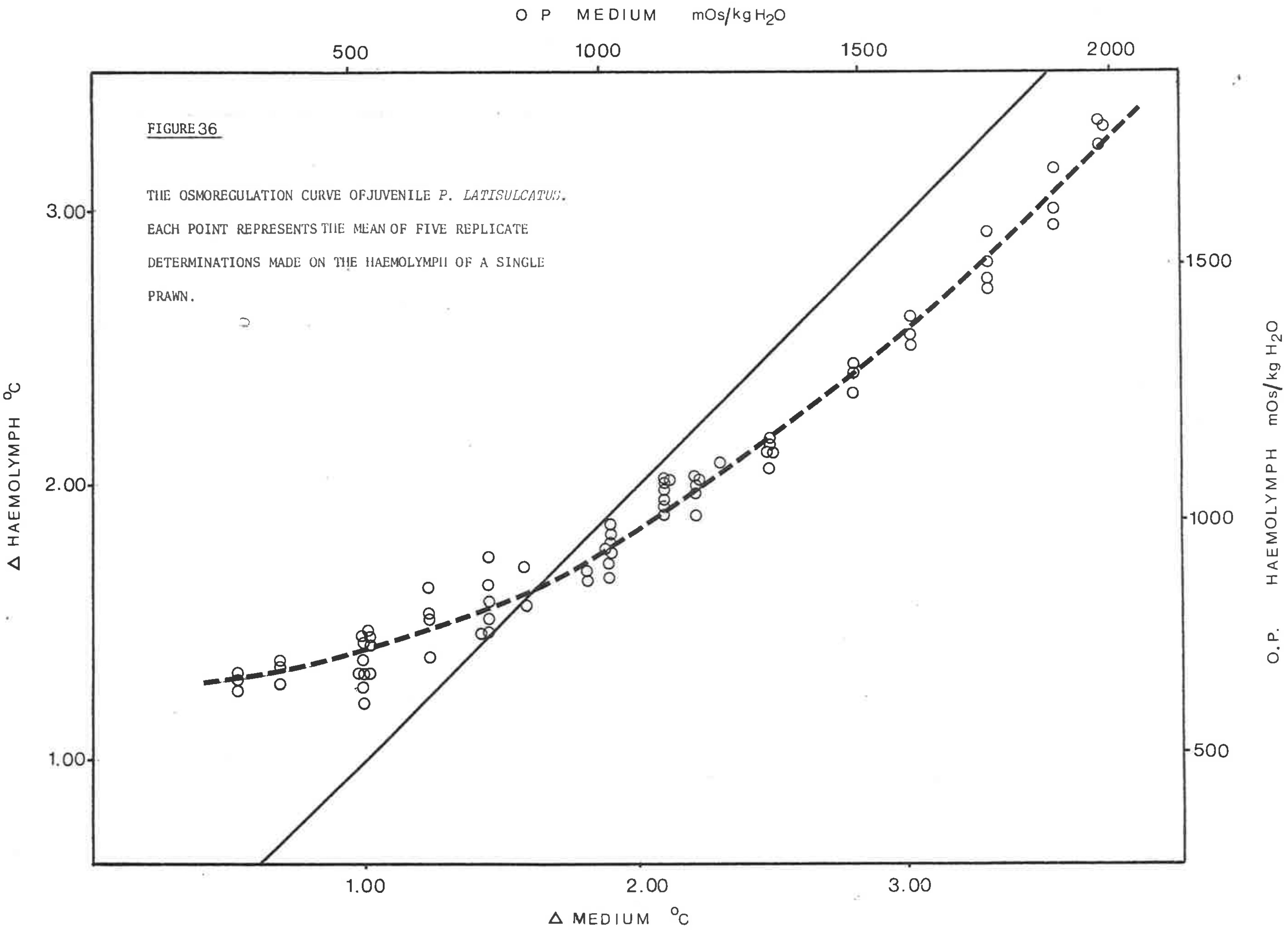


FIGURE 36

THE OSMOREGULATION CURVE OF JUVENILE *P. LATISULCATUS*. EACH POINT REPRESENTS THE MEAN OF FIVE REPLICATE DETERMINATIONS MADE ON THE HAEMOLYMPH OF A SINGLE PRAWN.

external medium in salinities less than 30‰ the haemolymph is maintained at lower osmotic concentrations than that of the medium. The relationship between freezing point depression and osmotic pressures of the medium and of the haemolymph is shown in Figure 36. The O.P. of the haemolymph increases gradually from 690 mOs/kg H_2O to 1030 mOs/kgH_2O as the salinity rises from 10‰ to 37‰, after which it approximately parallels the increase in O.P. of the medium, but remains below the isosmotic line. The isosmotic point is at 860mOsm/KgH_2O

7.3.2 Ionic Regulation

The concentrations of sodium, potassium, calcium and magnesium in the haemolymph of each juvenile *P. latisulcatus* sampled are set out in Appendix I. Tables 29 to 32 show the ionic concentrations in the haemolymph of juvenile prawns exposed to the various experimental salinities for at least one week at 18.5°C. Each value represents the mean of between 5 and 21 samples each from a different prawn, except for those at 66‰ where only one prawn was sampled. The high values of the standard deviation of each mean indicate a large degree of variation in the levels of the four cations between samples taken from prawns exposed to the same salinity. This may indicate that there is some individual variation in the ability to regulate the four cations. However, the variation may be due to the involved analytical procedure and in particular to inaccuracy in dilution of the samples.

P. latisulcatus haemolymph coagulates very quickly and may adhere to the capillary tube so although the haemolymph was discharged into the diluent as quickly as possible after extraction, and the solution drawn up and down the capillary tube several times to wash it out,

TABLE 29

CONCENTRATIONS OF SODIUM IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS*

Salinity of medium (‰)	Na^+ in medium (ppm)	No of haemolymph samples	Mean Na^+(ppm) in haemolymph	S.D.	S.D. as % of the mean
11.5	2698.5	10	6408.0	1253.2	19.5
12.5	3328.5	6	6793.3	96.6	1.4
16.0	4588.5	8	7021.7	1131.6	16.1
28.5	8137.5	20	8768.7	1436.4	16.4
31.5	8946.0	10	9676.1	544.3	5.6
34.5	10227.0	8	9688.1	1430.0	14.8
39.0	11550.0	5	10288.1	1941.5	18.8
39.5	11655.0	8	10987.5	1654.9	15.0
41.5	12117.0	11	11114.7	1274.3	11.5
44.0	12715.5	13	11679.2	1327.5	11.4
50.5	15162.0	10	11837.2	839	7.1
65.5	19540.5	10	13172.5	1359.5	10.3
66.0	21409.5	1	20180.4	-	-

concentrations in ppm. (µg/ml)

TABLE 30

CONCENTRATION OF POTASSIUM IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS*

Salinity of medium ‰	K^+ in medium	No of haemolymph samples	Mean K^+ in haemolymph	S.D.	S.D. as a % of the mean
11.5	214.2	10	372.2	144.5	38.6
12.5	275.3	6	378.1	96.2	25.4
16.0	297.3	9	385.0	74.2	19.2
28.5	416.4	21	400.5	120.7	30.0
31.5	473.5	10	431.3	78.5	18.1
34.5	513.5	8	425.8	97.7	22.7
39.0	539.5	5	486.8	42.1	8.6
39.5	549.5	8	449.4	87.0	19.4
41.5	559.6	12	526.4	112.9	21.5
44.0	570.6	13	548.4	97.5	17.8
50.5	807.8	10	601.1	57.4	9.5
65.5	831.8	10	678.8	157.0	23.1
66.0	620.6	1	988.9	-	-

concentration in ppm (µg/ml)

TABLE 31

CONCENTRATION OF CALCIUM IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS*

Salinity of medium ‰	Ca^{++} in medium	No of haemolymph samples	Mean Ca^{++} in haemolymph	S.D.	S.D. as a % of the mean
11.5	195.6	10	627.0	106.6	16.9
12.5	218.5	6	658.3	115.2	17.5
16.0	282.7	9	686.4	256.9	37.5
28.5	393.2	21	895.9	213.9	23.7
31.5	420.7	10	910.4	141.5	15.5
34.5	434.6	8	947.5	329.9	34.7
39.0	449.8	5	937.1	231.7	24.6
39.5	460.0	8	945.3	143.8	15.1
41.5	470.3	12	973.3	123.3	12.6
44.0	498.6	13	1042.5	131.6	12.6
50.5	506.3	10	1069.7	133.6	12.4
65.5	534.6	10	1112.0	162.1	14.6
66.0	478.0	1	1211.7	-	-

concentrations in ppm (μg/ml)

TABLE 32

CONCENTRATION OF MAGNESIUM IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS*

Salinity of medium	Mg^{++} in medium	No of haemolymph samples	Mean Mg^{++} in haemolymph	S.D.	SD as a % of the mean
11.5	706.7	10	170.0	34.9	20.5
12.5	541.5	6	105.0	14.0	13.3
16.0	609.6	9	127.3	49.7	39.1
28.5	1098.1	21	205.8	80.6	39.3
31.5	1142.1	10	158.6	47.8	30.1
34.5	1252.3	8	171.6	73.3	42.7
39.0	1459.5	5	396.0	100.7	25.4
39.5	1335.3	9	434.6	278.7	63.9
41.5	1496.5	10	237.2	88.8	37.4
44.0	1620.6	14	306.1	146.9	48.0
50.5	1732.7	10	288.6	234.6	81.3
65.5	2454.5	10	509.2	297.5	50.5
66.9	1575.6	1	790.1	-	-

concentrations in ppm (μg/ml.)

some coagulated haemolymph may still have adhered to the capillary tube. It was not possible to distinguish between these two possible sources of variation since only very small volumes of haemolymph could be extracted from each prawn and therefore replicate determinations could not be made. In the case of Na^+, K^+ and Ca^{++} there is no apparent pattern in the variation, but the ability to regulate Mg^{++} appears to become more variable as the magnesium concentration in the external medium increases (table 32).

The pattern of sodium regulation is shown in Figure 37. It can be seen that the haemolymph of juvenile *P. latisulcatus* is isionic with the external medium at 9500 µg/ml. Below this level sodium is regulated hyperionic to the medium, and above it is hypoionic. The degree of hypoionic regulation appears to increase somewhat in the higher salinity media.

Potassium is also regulated hyperionic to the medium in low salinities and hypoionic to the medium in high salinities (fig 37). The isionic point is at 400 µg/ml of potassium and this concentration occurs in seawater of about 28‰ salinity. Unlike the sodium regulation, potassium is maintained at about the same level throughout the range of hypoionic regulation.

The concentration of calcium in the haemolymph is always greater than that in the medium (Table 31) but increases as the concentration in the medium increases. There is some tendency for the calcium concentration in the haemolymph to level off at the higher concentrations in the medium (figure 37). and to a lesser extent to maintain similar levels in the very low salinities. The concentration of magnesium in the haemolymph remains lower than that in the medium throughout the range of salinities tested (Table 32). There is

FIGURE 37

THE REGULATION OF CATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS*. EACH POINT REPRESENTS THE MEAN OF DETERMINATIONS MADE ON THE HAEMOLYMPH OF A NUMBER OF PRAWNS EXPOSED TO THE SAME SALINITY.

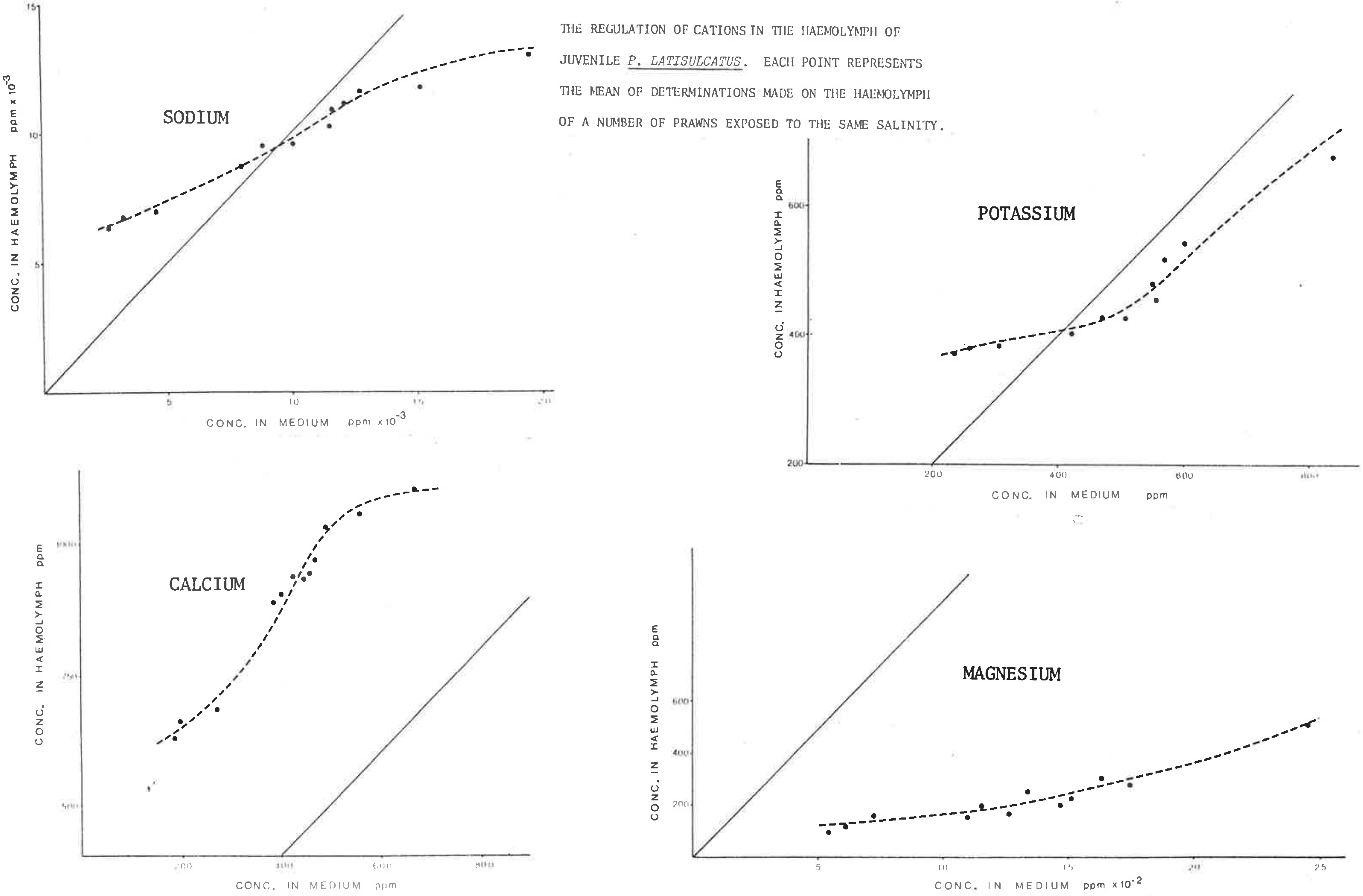
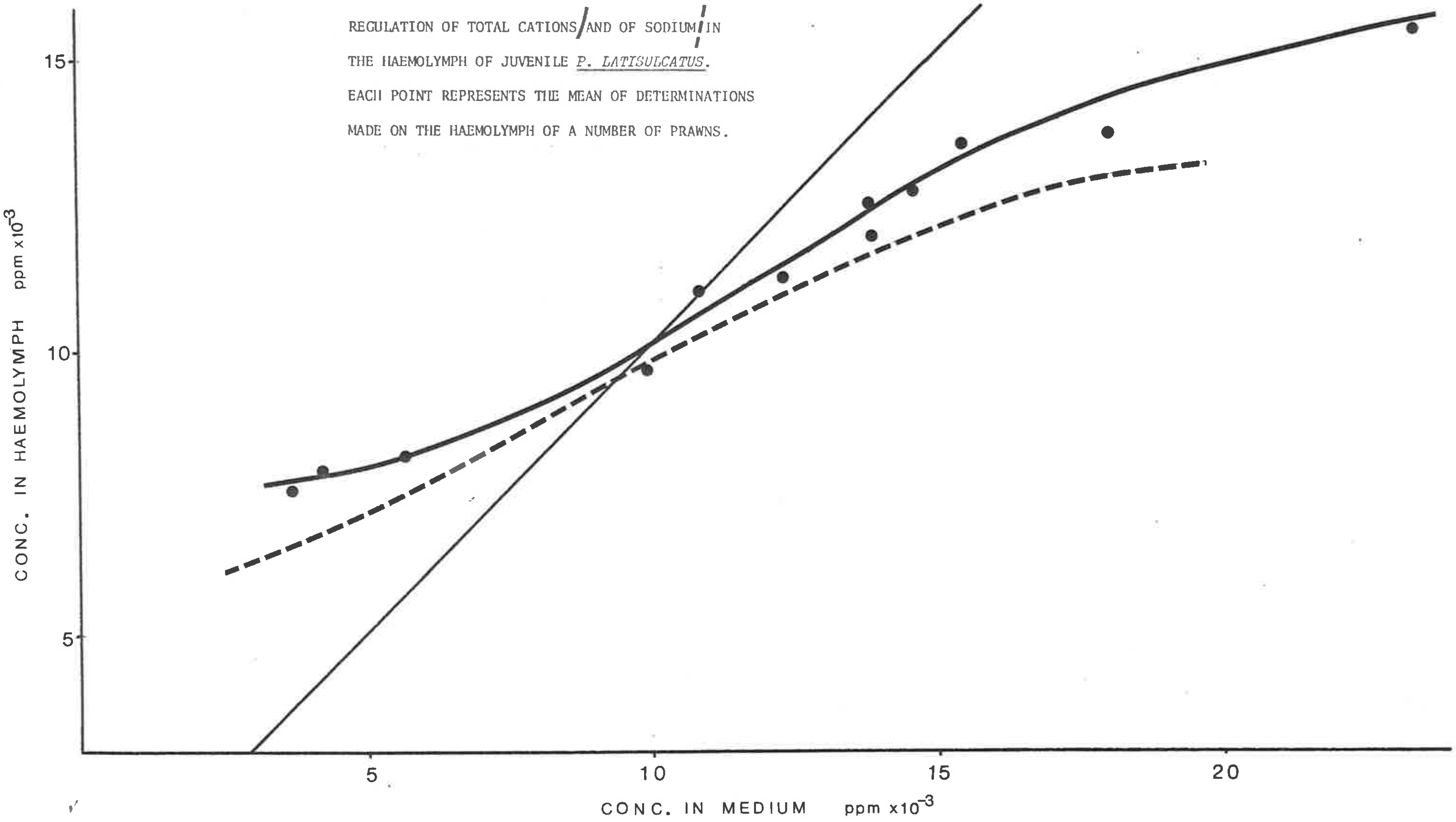


FIGURE 38

REGULATION OF TOTAL CATIONS / AND OF SODIUM / IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS*. EACH POINT REPRESENTS THE MEAN OF DETERMINATIONS MADE ON THE HAEMOLYMPH OF A NUMBER OF PRAWNS.



some tendency for the magnesium concentration in the haemolymph to increase as the concentration in the medium increases (fig 37) but the magnitude of increase is small.

From tables 29 to 32 it can be seen that the relative proportions of the cations remain similar regardless of the salinity except in the case of the prawn held at 66‰. This medium was prepared by dissolving unrefined salt in seawater, and thus contained a disproportionate amount of sodium. Figure 37 shows that if the haemolymph concentrations at 66‰ are plotted with the concentrations from the remaining salinities, the values are well above those that would be expected.

That sodium is the dominant cation can be seen from Figure 38 which represents the combined concentrations of cations in the haemolymph plotted against that in the medium. The concentration of sodium only is also shown and it can be seen that the pattern of cation regulation is similar to that of the sodium regulation.

7.3.3 Amino acid concentrations

The molar concentration of glutamic acid in the standard solutions and the optical densities of the product of the ninhydrion reaction are shown in Table 33. It can be seen from Figure 39 that Beer's Law, that the optical density (O.D.) is directly proportional to concentration (Rosen, 1957), holds over this range of concentrations and therefore a linear regression of the form concentration

$$(C) = a + b \times O.D.$$

can be calculated. The relationship was found to be:

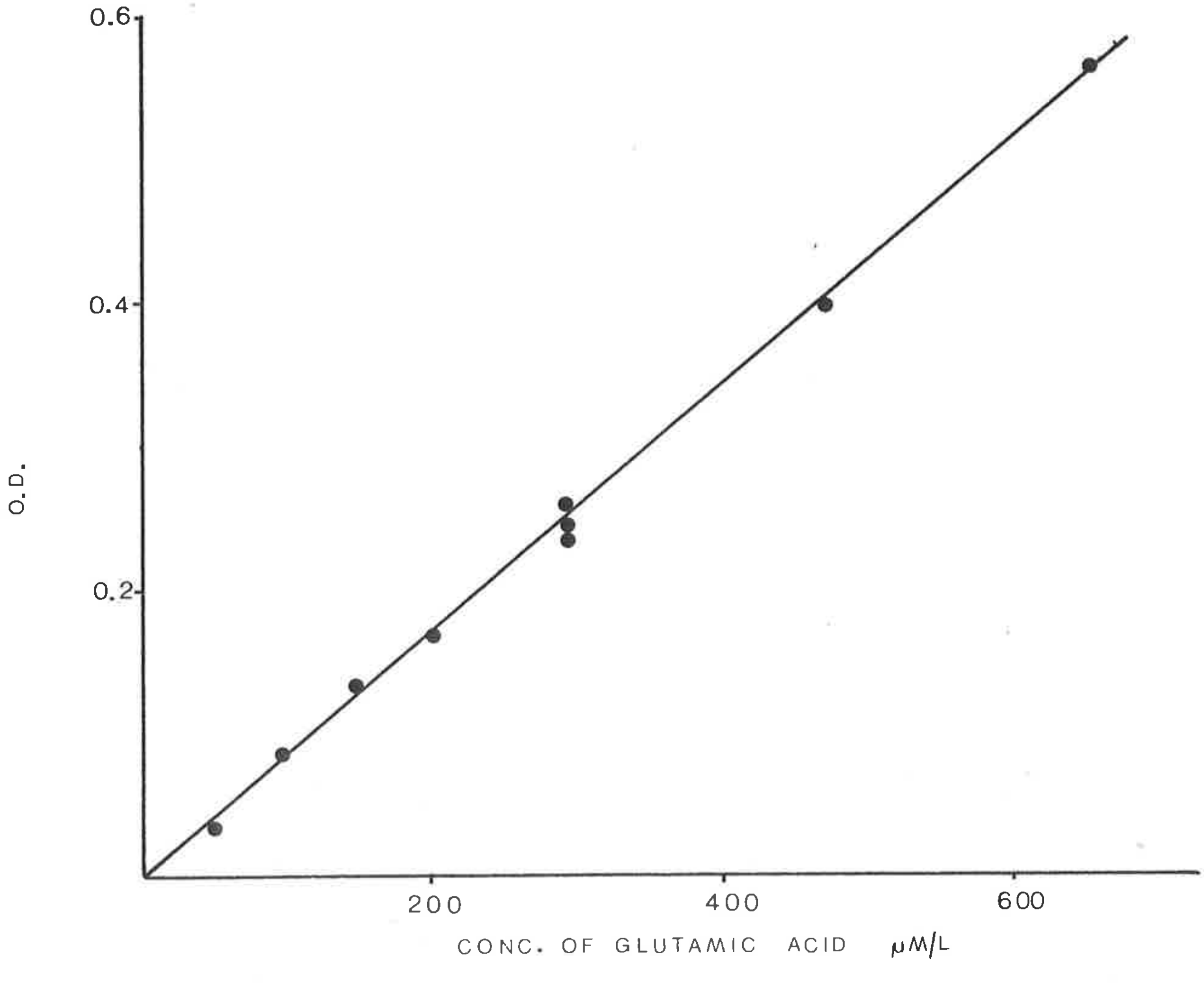
TABLE 33

	Y	X		
µl of Glutamic acid stock solution (0.01m)	molar concentration ($\times 10^6$) in standard *	O.D. (triplicate determinations)		
0	0	0	0	0
5	49.75	0.030	0.029	0.035
10	99.013	0.070	0.075	0.080
15	147.84	0.125	0.126	0.125
20	196.12	0.155	0.164	0.175
30	291.24	0.245	0.235	0.328
40	384.61	0.325	0.325	0.328
50	471.93	0.404	0.410	0.410
70	654.54	0.570	0.573	0.575

*This is the concentration in the 1ml aliquot before treatment with the ninhydrin reagents. A further 1:6 dilution occurs during treatment.

FIGURE 39

CALIBRATION OF O.D. AGAINST MOLAR CONCENTRATION OF GLUTAMIC ACID.



$$C = 6.87 + 1141.71 \text{ O.D.}$$

(Coefficient of determination, $r^2 = 99.998$).

where (C) is the concentration of glutamic acid in M/L

This expression can be used to evaluate the molar concentration of free amino acids in the haemolymph samples. Tables 34 and 35 show the optical densities of the ninhydrin treated haemolymph samples, and the concentration of amino acids in the diluted sample and in the haemolymph of prawns exposed to 30‰ and 55‰ salinity for at least one week.

The results show that there is a large amount of variation in the free amino acid concentrations in the haemolymph of juvenile *P. latisulcatus*, the standard deviation (S.D.) being 33% and 26% of the mean concentration for each group of prawns respectively. Gilles (1977) also found that there was a large variation in the concentration of free amino acids in the haemolymph of *Eriocheir sinensis*, the standard deviation being about 30% of the mean concentration. Despite the large variation observed in *P. latisulcatus* haemolymph the difference between the mean values of each group of prawns is statistically significant. Prawns exposed to 30‰ salinity had a mean free amino acid concentration of 0.0241 M (table 35) A Students 't' test was carried out, yielding a 't_{44}' value of 5.667, which is significant at the 1% level.

7,4 DISCUSSION

7.4.1 The relationship between osmotic and ionic regulation

It might be expected that the osmotic concentration of the haemolymph

TABLE 34

CONCENTRATION OF FREE AMINO ACIDS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 30‰ SALINITY

Prawn number	O.D.	Concentration in sample (M/L)	Concentration in haemolymph (M/L)
1	0.040	52.54	0.0105
2	0.040	52.54	0.0105
3	0.072	89.08	0.0178
4	0.047	60.54	0.0121
5	0.105	126.75	0.0254
6	0.162	191.83	0.0384
7	0.135	161.01	0.0322
8	0.090	109.63	0.0219
9	0.098	118.76	0.0238
10	0.108	130.18	0.0260
11	0.097	117.62	0.0235
12	0.088	107.35	0.0215
13	0.142	169.00	0.0338
14	0.122	146.16	0.0292
15	0.140	166.71	0.0333
16	0.158	187.26	0.0375
17	0.110	132.46	0.0265
18	0.060	75.38	0.0151
19	0.107	129.04	0.0258
20	0.100	121.05	0.0242
21	0.080	98.21	0.0196
22	0.090	109.63	0.0219
Mean			0.0241
S.D.			0.0080
Sea water sample	0.005	12.58	0.0025

TABLE 35

CONCENTRATION OF FREE AMINO ACIDS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 55‰ SALINITY

Prawn number	O.D.	Concentration in sample (M/L)	Concentration in haemolymph (M/L)
1	0.120	143.88	0.0288
2	0.170	200.97	0.0402
3	0.163	196.80	0.0394
4	0.170	200.97	0.0402
5	0.100	121.05	0.0242
6	0.133	158.72	0.0317
7	0.240	280.88	0.0562
8	0.153	181.56	0.0363
9	0.156	184.98	0.0370
10	0.192	226.08	0.0452
11	0.149	176.99	0.0354
12	0.158	187.26	0.0375
13	0.269	313.99	0.0628
14	0.170	200.97	0.0402
15	0.160	189.55	0.0379
16	0.120	143.88	0.0288
17	0.110	132.46	0.0265
18	0.142	169.00	0.0338
19	0.122	146.16	0.0292
20	0.140	166.71	0.0333
21	0.195	235.34	0.0471
22	0.240	280.88	0.0562
23	0.245	286.59	0.0573
24	0.168	198.68	0.0397
Mean			0.0394
S.D.			0.0103
Sea water sample	0.004	11.44	0.0023

of juvenile *P. latisulcatus* is largely determined by the concentration of inorganic ions and that the ionic concentrations measured in section 7.3.2 should therefore account for the freezing point depressions measured in section 7.3.1 In order to compare the two sets of results they must be expressed in similar units. It is possible to express the ionic concentrations in terms of freezing point depression (Δ). The molar concentration of each cation in the haemolymph of each prawn at each salinity can be calculated by dividing the cation concentration in gm/L (equivalent to μg/ml x 10^{-3}) by the atomic weight of the element. The sum of the molar concentrations of the four major cations in the haemolymph can then be obtained. Since each mole of cations is complemented by about one mole of anions it is assumed that the osmotic effect of the ions is equivalent to that of a solution of NaCl having the same molar concentration as the combined molar concentration of the cations. This assumption is further justified by the fact that over 85% of the haemolymph cation concentration is due to the presence of sodium ions which are known to be associated in other Crustacea, with chloride ions (Florkin 1960). Using this approximation the cation concentrations can be converted to freezing point depressions using a conversion table of Concentrative Properties of Aqueous Solutions (C.R.C. Handbook of Chemistry and Physics, 1972-73, P. D181). The freezing point depressions of the experimental media can be obtained from Figure 35. The results obtained from these calculations are shown in Table 36. Comparison of Figures 36 and 40 shows that these results are more variable than the freezing point depressions determined directly by cryoscopy in section 7.3.2. The most probable reason for this is that the cryoscopic method is more accurate since the samples need not be diluted. For the ionic determinations the samples were diluted and some error may have

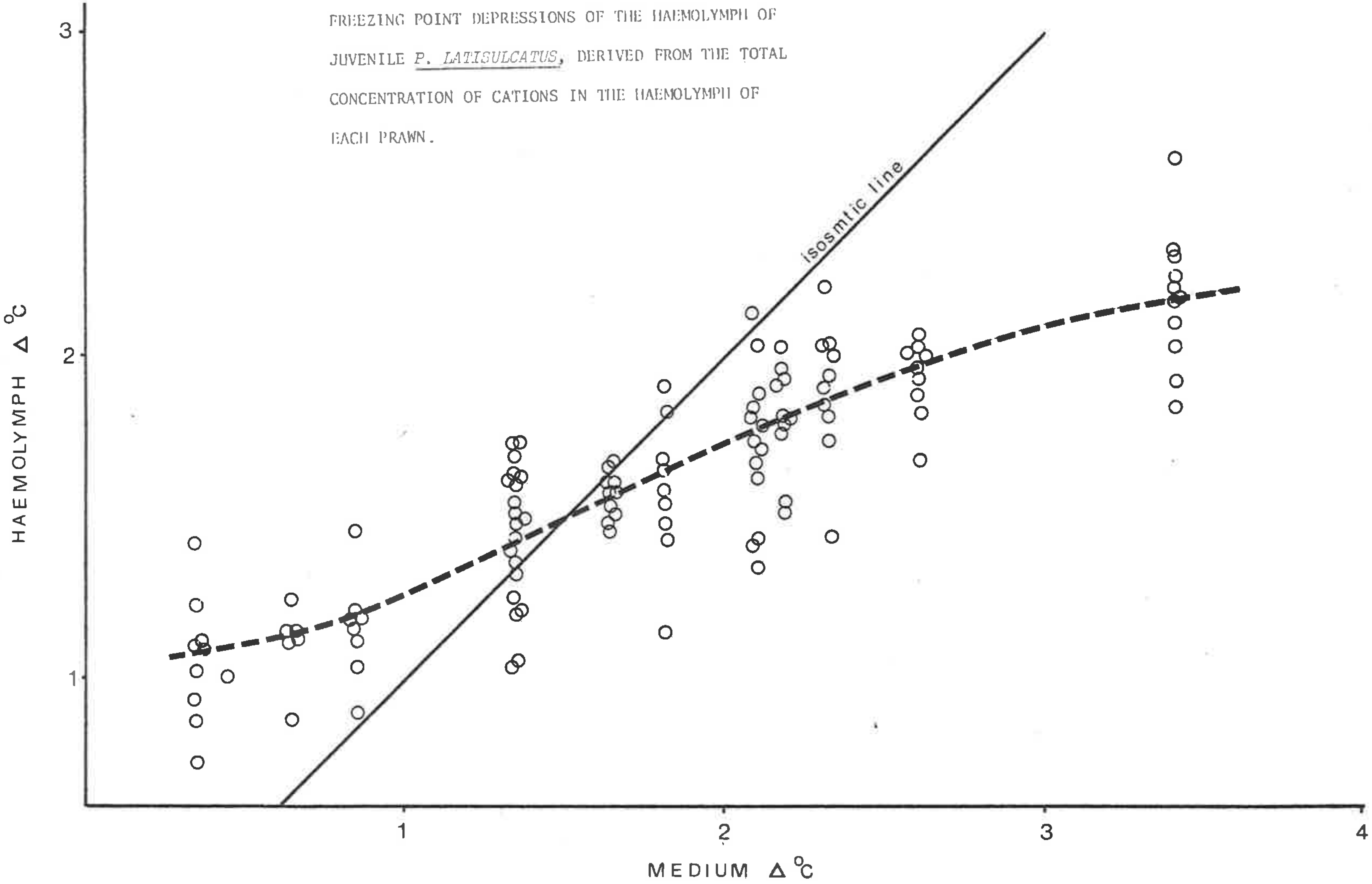
TABLE 36

FREEZING POINT DEPRESSIONS OF THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS*, DERIVED FROM THE IONIC CONCENTRATIONS

Salinity of medium ‰	11.5	12.5	16.0	28.5	31.5	34.5	39.0	39.5	41.5	44.0	50.5	65.5
Δ of medium °C	0.450	0.658	0.850	1.350	1.630	1.305	2.070	2.090	2.165	2.320	2.605	3.400
Δ of haemolymph °C	0.9391	1.1319	1.1822	1.4840	1.6121	1.8160	2.1491	1.8423	1.9340	1.8443	2.0210	2.2673
	1.0826	1.2545	1.1928	1.0654	1.6676	1.4249	1.8362	1.8960	1.9684	1.8330	2.0163	2.6163
	1.1137	0.8742	1.4731	1.6354	1.6580	1.4840	1.4077	2.0550	2.0303	2.0419	1.9111	2.3218
	0.7524	1.1517	1.0332	1.3254	1.4502	1.5636	1.4117	1.6066	1.5176	1.8255	2.0036	2.1783
	0.8726	1.1148	1.2024	1.2004	1.6210	1.6390	1.7525	1.6580	1.5241	1.4333	1.9899	2.2176
	1.1199	1.1761	1.1812	1.5573	1.6778	1.1552		1.3463	1.7974	2.0104	2.0354	2.3464
	1.0884		0.8757	1.5197	1.5899	1.6850		2.1344	1.9101	1.9501	1.8905	2.1060
	1.0493		1.1363	1.0411	1.5395	1.9090		1.8289	1.8238	2.0389	1.6926	1.8614
	1.4364			1.6926	1.4878				1.7883	2.0347	2.0731	1.9378
	1.2497			1.5056	1.5029					2.2149	1.8560	2.0508
				1.2086						1.7580		
				1.2538						2.0800		
				1.3114								
				1.3699								
				1.7354								
				1.6111								
				1.4069								
				1.7581								
				1.6292								
Mean derived Δ of haemolymph °C	1.0724	1.1172	1.1596	1.4474	1.5806	1.5871	1.7114	1.7959	1.8099	1.8539	1.9489	2.1904
SD	0.1911	0.1287	0.1687	0.2175	0.0810	0.2375	0.3126	0.2541	0.1827	0.2021	0.1137	0.2182

FIGURE 40

FREEZING POINT DEPRESSIONS OF THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS*, DERIVED FROM THE TOTAL CONCENTRATION OF CATIONS IN THE HAEMOLYMPH OF EACH PRAWN.



occurred. Further variation in the operation of the atomic absorption spectrophotometer will be compounded since each of the "derived" freezing point depressions is calculated from the sum of four ionic determinations. The greater variability of the derived Δs cannot however, account for the difference in the shape of the regulation curves. From figure 41, it can be seen that in the region from Δ1.3 to 2.3 in the external medium (i.e. in salinities from 25 to 45‰) there is little difference between the osmoregulation curves obtained by direct measurement of the freezing point depression and derived from the ionic concentrations. Below salinities of 25‰ it appears that the Δ derived from the ionic concentrations is less than that determined directly but the values obtained by direct determination still lie within the range of values obtained from the ionic concentrations. In salinities above 45‰ there appears to be a marked difference between the two sets of results. Values obtained from the ionic determinations are lower than those obtained by cryoscopy and there is no overlap in the values obtained in salinities greater than 50‰. Since the curves are of different shapes and the variances of each set of results markedly different no statistical analysis of the results can be made. Even so, the values obtained from the ionic determinations seem significantly lower than those obtained by cryoscopy in salinities greater than 50‰. In salinities between 25 and 45‰ there appears to be no practical difference between the results, while below 25‰ the data are inconclusive. These results are in agreement with those of MacFarland and Lee (1963) who found that the major ions Na^+, Cl^-, K^+, Mg^{++} and Ca^{++} contribute approximately 92 to 96% of the osmotically active substance of the serum of *P. setiferus* and *P. aztecus* "except in hypersalinities where ions are slightly less important."

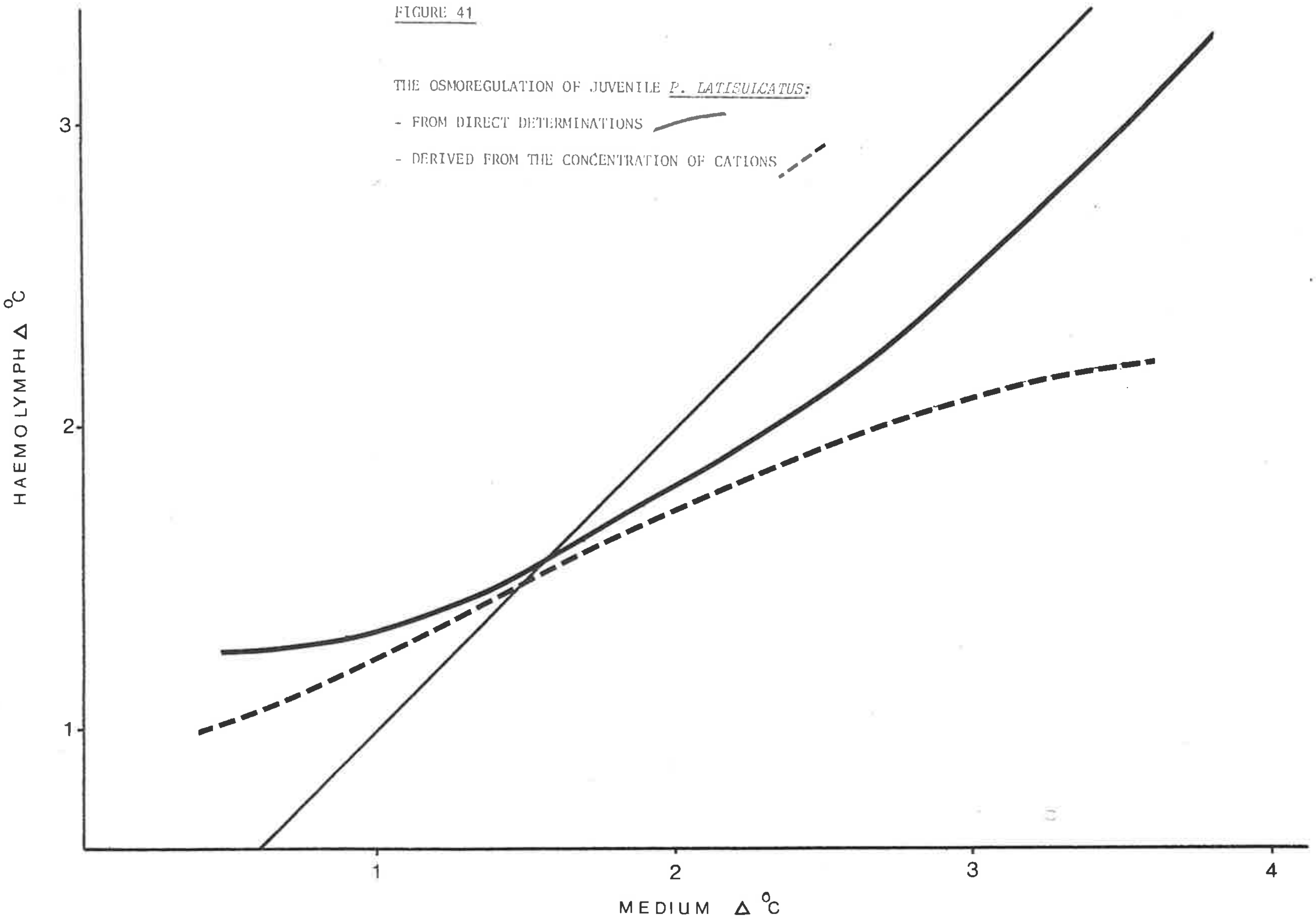


FIGURE 41

THE OSMOREGULATION OF JUVENILE *P. LATISULCATUS*:

- FROM DIRECT DETERMINATIONS
- DERIVED FROM THE CONCENTRATION OF CATIONS

It therefore appears that in salinities greater than 50‰ some factor other than the concentration of the major ions is contributing to the osmotic concentration of the haemolymph. Since free amino acids in the intracellular fluid of crustaceans are known to play a part in osmoregulation (Gilles 1975) it was thought that these compounds may account for the apparent difference between osmotic and ionic regulation results. The concentrations of amino acids in the haemolymph of prawns acclimatized to 30‰ and to 55‰ were therefore determined. These salinities were selected since at 30‰ there appears to be no practical difference between the osmotic pressure measured by freezing point depression and that calculated from the ionic determinations. In addition 30‰ is close to both the isosmotic and isionic point for juvenile *P. latisulcatus* and the level of amino acids in the haemolymph of prawns exposed to this salinity should therefore be independent of any osmoregulatory requirements. At 55‰ there is a clear difference between the osmotic pressure measured by freezing point depression and that calculated from the ionic determinations and so amino acids may have some osmoregulatory significance.

The results presented in section 7.3.3 show that there is a significantly greater concentration of free amino acids in the haemolymph of prawns acclimatized to 55‰ than in prawns acclimatized to 30‰. Prawns acclimatized to 30‰ had a haemolymph free amino acid concentration of 0.0241M. Those acclimatized to 55‰ had a haemolymph free amino acid concentration of 0.0394M. Since each mole of amino acids will have about the same osmotic activity as 0.5 moles of NaCl, the additional amount of freezing point depression due to the presence of the amino acids can be obtained from the conversion table of "Concentrative Properties of Aqueous Solutions" (op. cit.).

Thus the 0.0394M amino acids present in the haemolymph at 55‰ increases the derived freezing point depression by 0.07°C, while that of 0.0241M at 30‰ increases the freezing point depression by 0.04°C. This latter increase does not significantly affect the results and the freezing point depression at 30‰ derived from the ionic and amino acid determinations would be almost identical to that obtained by direct measurement. At 55‰ the increase in freezing point depression due to the presence of amino acids is greater but this still does not account for the difference between the freezing point depression determinations and freezing points estimated from the ionic concentrations at this salinity. The observed difference in freezing point depression at 55‰ is 0.35°C and so the amino acids account for only about 20% of this difference. Furthermore, at both 30 and 55‰ the proportion of amino acids to the molar concentration of ions plus amino acids is similar at about 5%. This suggests that the difference between the actual concentrations of amino acids at these two salinities may be due to the maintenance of a constant proportion of amino acids in the haemolymph, so the function of the free amino acids may not be one of osmoregulation. Further determinations over a range of salinities are needed to substantiate this proposition. However, Dall (1975) found that free amino acids were stable components of the haemolymph of *Panulirus longipes* but that since they occur in such low concentrations any variation in response to changing salinities would have little adaptive value. It appears that this is also the case with *Penaeus latisulcatus* and that some other osmotically active substances account for the apparent difference between the patterns of osmotic and ionic regulation.

7.4.2 Osmotic and ionic regulation in relation to salinity tolerance

Since the osmotic and ionic determinations were made on prawns exposed to the experimental salinities for at least one week, and in some cases on those prawns which survived the salinity tolerance experiments after 10 days of exposure, these results can be related to those of the previous chapter.

7.4.2.1. Osmotic regulation

Figure 42 shows the freezing point depression (Δ) of the haemolymph plotted against the salinity of the external medium, and the generalized survival curve for juvenile *P. latisulcatus* exposed to the experimental salinities for 10 days. In the lower salinity range the survival of juvenile *P. latisulcatus* previously acclimatized to winter salinity has been used to draw this curve. In the upper salinity range the survival of prawns acclimatized to summer salinity has been used. It can be seen that although juvenile *P. latisulcatus* that survive salinities below the isosmotic point (30‰) are able to regulate the osmotic concentration of the haemolymph, the survival rate is reduced. The zone of maximum survival lies above the isosmotic point, from 30‰ to 52.5‰. Within this range the haemolymph osmotic concentration remains lower than the external medium, but as the salinity of the medium increases, so too does the osmotic concentration of the haemolymph. Within the range of maximum survival the freezing point depression of the haemolymph of juvenile *P. latisulcatus* increases from Δ1.6^{0}C (860 mOs/kgH$_2$0) to Δ2.1^{0}C (1130mOs/kgH$_2$0) while the salinity of the medium varies from 30‰ (870 mOs/kgH$_2$0) to 52.5‰ (1,466 mOs/kgH$_2$0). The capacity of juvenile *P. latisulcatus* to regulate the osmotic concentration of the haemolymph means that the rise in osmotic pressure experienced by the cells is less than half the rise in osmotic pressure of the external medium.

FIGURE 42

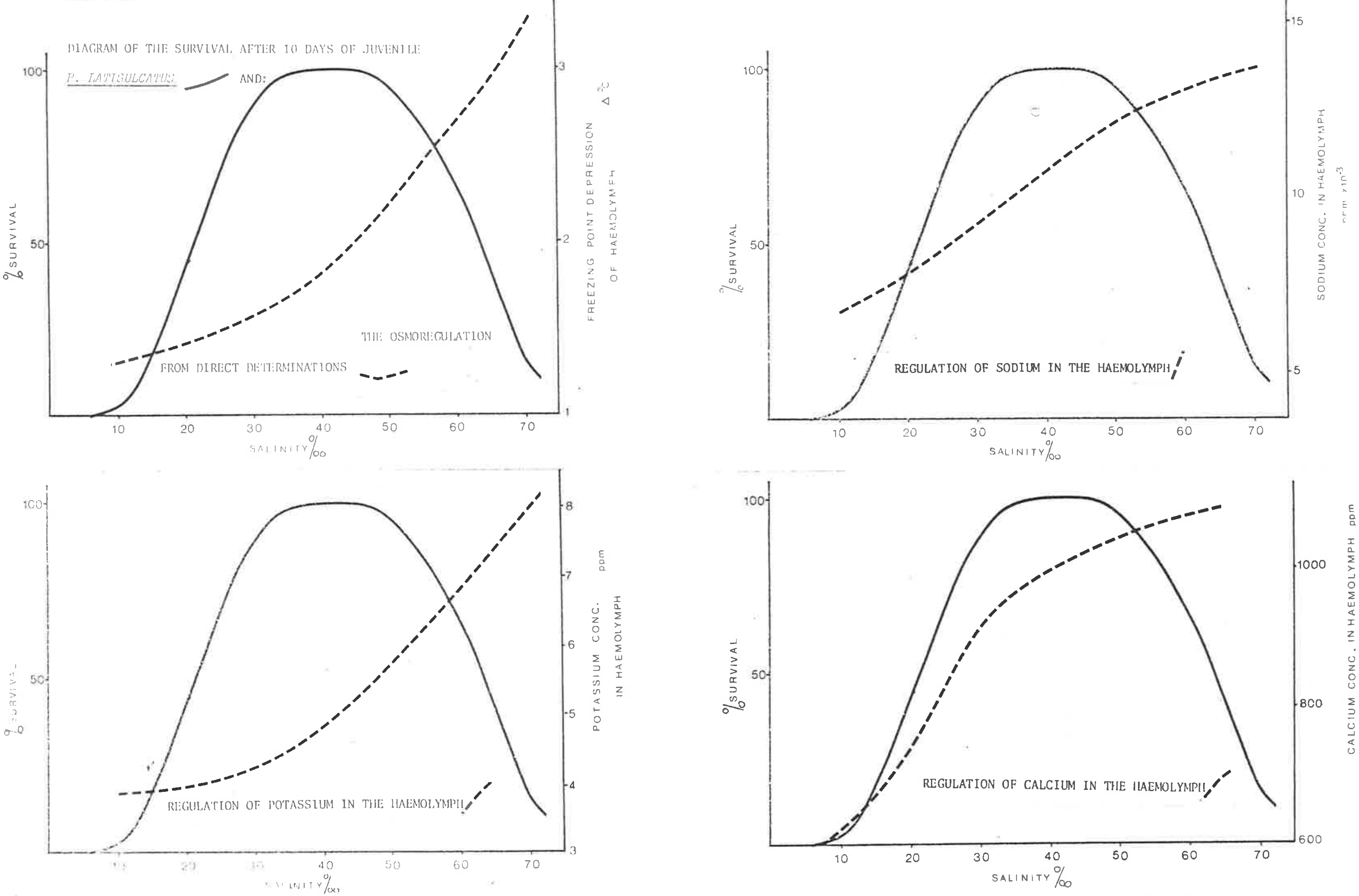


DIAGRAM OF THE SURVIVAL AFTER 10 DAYS OF JUVENILE
P. LATISULCATUS AND:
THE OSMOREGULATION
FROM DIRECT DETERMINATIONS
% SURVIVAL
FREEZING POINT DEPRESSION OF HAEMOLYMPH Δ°C
SALINITY ‰
100
50
10
20
30
40
50
60
70
1
2
3
REGULATION OF SODIUM IN THE HAEMOLYMPH
SODIUM CONC. IN HAEMOLYMPH ppm x10³
5
10
15
REGULATION OF POTASSIUM IN THE HAEMOLYMPH
POTASSIUM CONC. IN HAEMOLYMPH ppm
3
4
5
6
7
8
REGULATION OF CALCIUM IN THE HAEMOLYMPH
CALCIUM CONC. IN HAEMOLYMPH ppm
600
800
1000

7.4.2.2 Ionic regulation

With respect to the ionic regulation, magnesium was always maintained at much lower levels in the haemolymph than in the medium and only showed a very slight tendency to increase with increasing medium concentrations at the lower salinities, while increasing to a greater extent in the upper salinity range (fig 37). High levels of magnesium are generally considered toxic to Crustacea (Florkin, 1960), but in juvenile *P. latisulcatus* the levels are generally low. The concentration of magnesium is regulated so that the haemolymph to medium magnesium ratio is 0.2 over the entire range of salinities investigated.

Haemolymph to medium magnesium ratios in *P. setiferus* and *P. aztecus* were found to be 0.43 and 0.49 (MacFarland and Lee, 1963) so there is no reason to suspect that magnesium toxicity is the cause of mortality in the present study.

From figure 42 it can be seen that in the zone of maximum survival sodium and potassium are regulated below the concentrations of these ions in the medium. The sodium concentration is isionic at a salinity of 31‰, while potassium is isionic at 27.5‰. Below these salinities these ions are regulated at levels above the concentrations in the medium, and in the case of potassium the level is relatively constant (fig 42). The survival rate, however, falls sharply in salinities less than 30‰. Hedgpeth (1957) and Carpelan (1967) have proposed that eryhalinity and the ability to regulate the haemolymph concentration once evolved, are characteristics not easily lost. Thus the ability to regulate the haemolymph concentration is a property not of individuals, species or even genera but of a phyletic stock (Hedgpeth, 1957).

if this is so the high mortalities of *P. latisulcatus* in salinities less than 30‰ cannot be explained by genetic inability to regulate the concentrations of sodium and potassium, since those prawns which survived the low salinities have been shown to be capable of ionic regulation. The stress imposed by such regulation however, may be intolerable to some of the prawns.

The haemolymph calcium concentration is regulated at levels greater than that in the medium over the entire range of salinities investigated. This may serve to offset the ion 'debt' due to the constant low levels of magnesium in the haemolymph, and bearing in mind the importance of calcium in cuticle formation in crustaceans it is likely that there is a critical haemolymph calcium concentration below which survival will be jeopardized. The ability to regulate haemolymph calcium at levels above this critical level is therefore of great importance to crustaceans. Figure 42 shows that within the range of maximum survival the calcium concentration is maintained at a high level and appears to be approaching a constant level as the salinity increases. This is more apparent from Figure 37. At salinities below 30‰ the calcium level falls sharply as the salinity decreases. The inability to regulate calcium at higher levels in salinities less than 30‰ may explain why the survival of juvenile *P. latisulcatus* is greatly reduced in these salinities despite the general ability to osmoregulate down to salinities of 10 to 15‰. An experiment to determine the survival of juvenile *P. latisulcatus* in calcium depleted seawater was carried out. A calcium-depleted medium was made up by precipitating $CaCO_3$ from seawater (38‰, pH 8.31) with the addition of 1 gm of anhydrous Na_2CO_3 per litre of seawater. Since this has the effect of adding Na^+ to the medium and increasing the pH, HCl was added to the medium until the pH returned to its previous level. The pH was monitored *in situ* with a Metrohm Herisau model E488 pH meter.

There was no measurable difference in salinity between the untreated and treated seawater. The calcium concentration in the untreated seawater was 460 ppm, and after decalcification was found to be 97.4 ppm (equivalent to the calcium concentration in water of about 5‰ salinity). 25 prawns were placed in the calcium-depleted medium and prawns remaining in the holding tank from which the experimental prawns were taken served as a control. All the prawns exposed to the calcium-depleted seawater died within 24 hours. There were no deaths in the holding aquarium. It would be desirable to carry out further experiments to test the survival of juvenile *P. latisulcatus* in various concentrations of calcium at constant salinity. One difficulty to be overcome in setting up such experiments is that of providing a calcium-free substrate as provision of a suitable substrate in which the prawns can burrow is essential for the maintenance of juvenile *P. latisulcatus* in aquaria. Dall (1965d) found that *Metapenaeus bennettae* showed a marked lack of co-ordination after three hours, followed by death at six hours when exposed to artificial seawater made up with the omission of calcium. Greenaway (1976) also found that *Carcinus maenas* could not survive in calcium-depleted seawater. Although the results are not complete it appears that reduced levels of calcium in the haemolymph when juvenile *P. latisulcatus* are exposed to salinities less than 30‰ may explain the high mortality in these low salinities.

7.4.3 Osmotic and ionic regulation in comparison to other penaeid prawns.

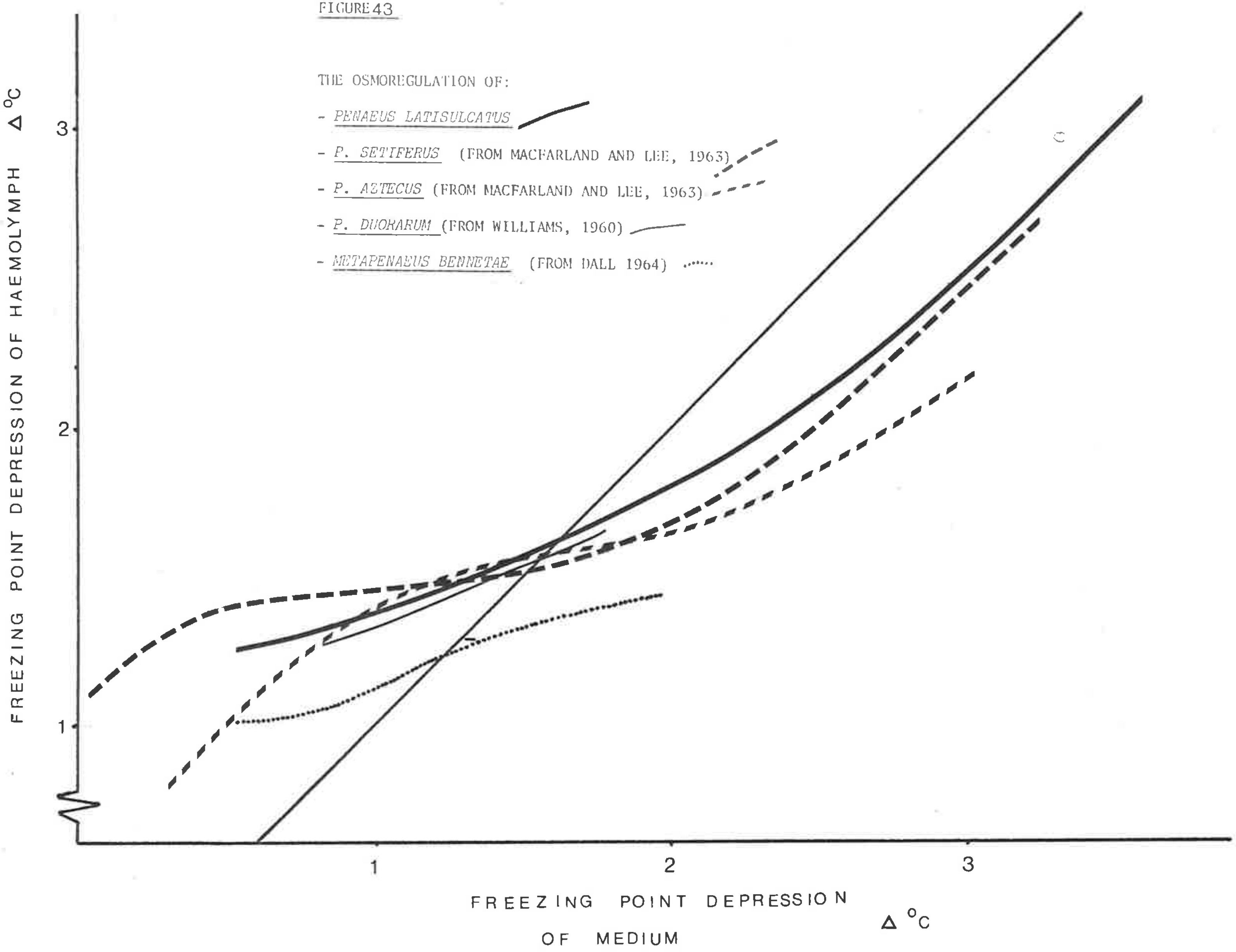
Figure 54 shows the osmoregulation curves of *Penaeus latisulcatus*, *P. duorarum*, Williams (1960) *P. aztecus* and *P. setiferus*, MacFarland and Lee, 1963) and *Metapenaeus bennettae* (Dall 1964). It can be seen that within the narrow range over which determinations were made on

P. duorarum (Williams, 1960), these results are very similar to those for *P. latisulcatus*. The isosmotic points are similar for *P. latisulcatus*, *P. duorarum*, *P. aztecus* and *P. setiferus*, the values being between Δ1.6 (860 mOs/kgH_2O) and Δ1.5°C (800 mOs/kgH_2O) *Metapenaeus bennettae*, however, has a much lower isosmotic point (Δ1.25°C (610mOs/kgH_2O)) and this is correlated with the ability of this species to complete its life cycle within low salinity estuarine waters (Dall 1964).. Although *P. latisulcatus* has the highest isosmotic point (fig 43), the difference between that and the other species (except for *M. bennettae* is not great and it would appear that *P. latisulcatus* is no better adapted to hypersaline water in this respect.

Of the species with similar isosmotic points, *P. setiferus* is better able to regulate the haemolymph osmotic concentration in low salinities than the remaining three species. This is in keeping with the apparent preference of this species for low salinity waters (Gunter, Christmas and Killibrew, 1964). In salinities lower than the isosmotic concentration, the osmoregulation of *P. aztecus*, *P. duorarum* and *P. latisulcatus* is similar down to medium freezing point depressions of Δ0.8 (fig 43) which corresponds to a salinity of 15‰. Below this salinity the regulatory ability of *P. latisulcatus* appears to be better than that of *P. aztecus* but *P. aztecus* were able to survive in lower salinities than *P. latisulcatus*.

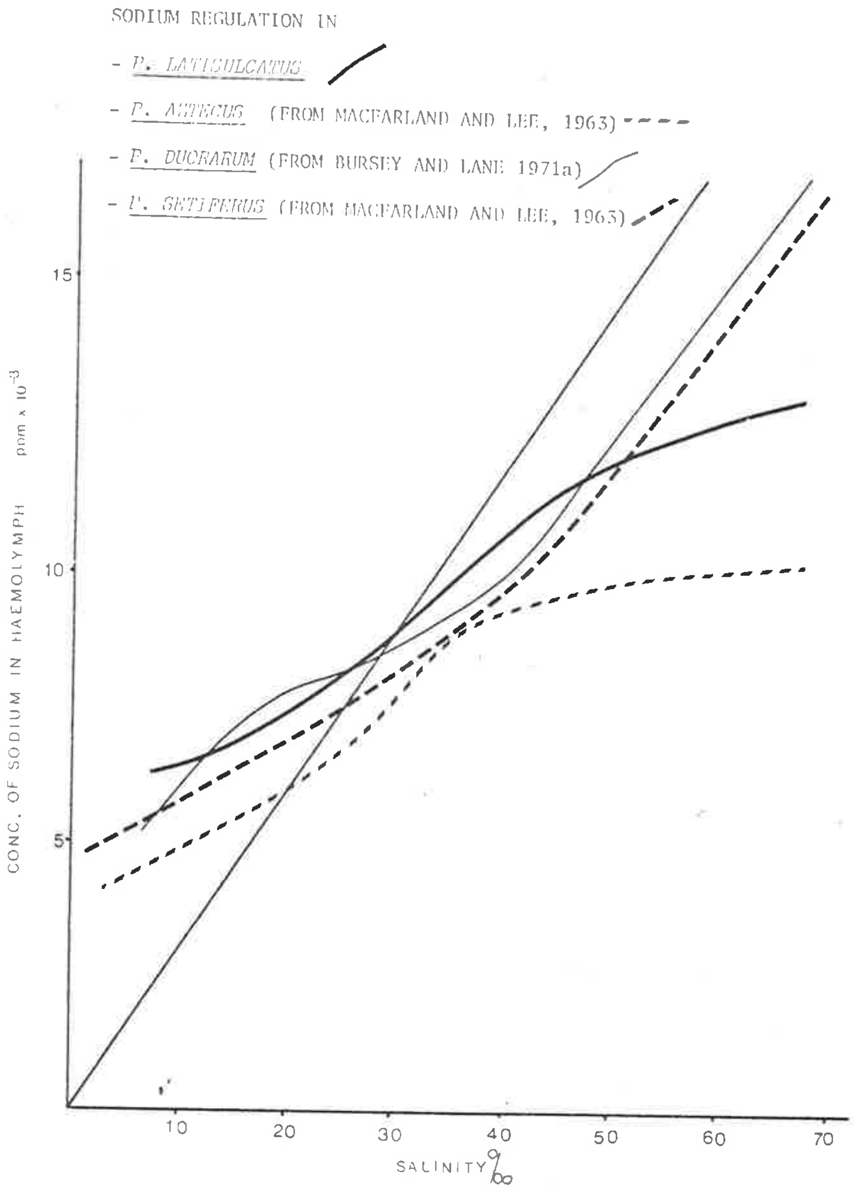
In view of the distribution of juvenile *P. latisulcatus* in relation to salinity, and the greater survival of this species in high salinities compared to other penaeids so far studied, it is surprising that the other species appear to be stronger hypo-osmotic regulators.

FIGURE 43


THE OSMOREGULATION OF:
- PENAEUS LATISULCATUS
- P. SETIFERUS (FROM MACFARLAND AND LEE, 1963)
- P. AZTECUS (FROM MACFARLAND AND LEE, 1963)
- P. DUORARUM (FROM WILLIAMS, 1960)
- METAPENAEUS BENNETAE (FROM DALL 1964)
FREEZING POINT DEPRESSION OF HAEMOLYMPH Δ °C
3
2
1
1
2
3
FREEZING POINT DEPRESSION OF MEDIUM Δ °C

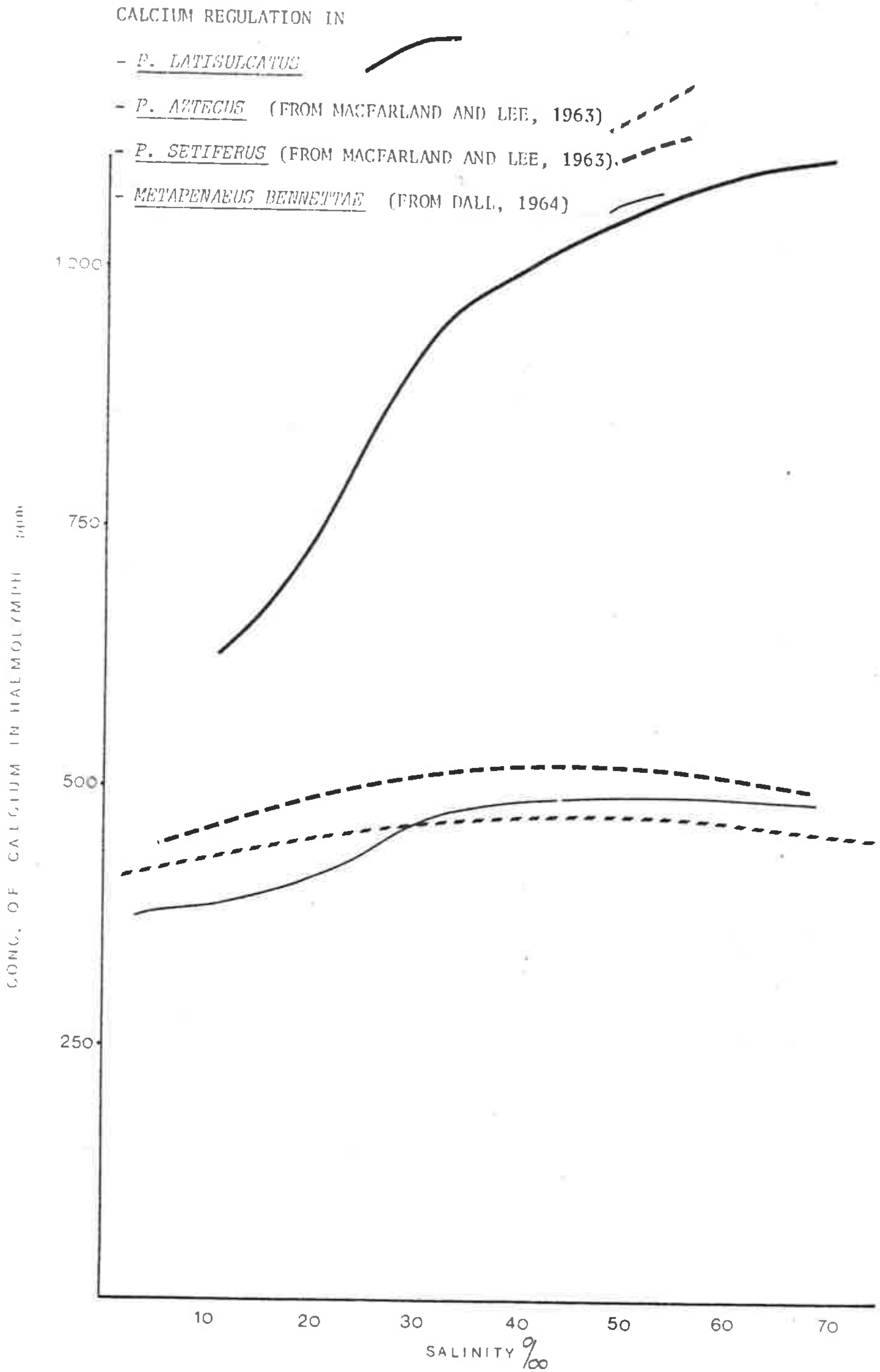
P. latisulcatus appears to be the least effective hypo-osmotic regulator (fig 43). From Figure 38, however, it can be seen that the regulation of the major cations and in particular sodium, is quite marked in the upper salinity regime. From Figure 44 it can be seen that sodium is regulated least in *P. duorarum* and *P. setiferus*. The pattern of sodium regulation in *P. latisulcatus* is similar to that in *P. aztecus* but in *P. aztecus* sodium is maintained at lower levels, especially in the upper salinities range. The relationships between the osmoregulation and sodium regulation of these species are not correlated with their observed distributions in respect to salinity, nor to their salinity tolerances. This is in contrast to the findings of Brand and Bayly (1971) that four species of calanoid copepod had degrees of osmotic regulation consistent with their distributions in relation to salinity. The survival of these prawns in high salinities does not therefore appear to depend on the degree of osmotic and ionic homeostasis maintained in the haemolymph. Survival at high salinities may be dependent on the degree of cellular and tissue regulation and tolerance evolved by the different species. The pattern of regulation of calcium may explain the decreased tolerance of *P. latisulcatus* to low salinities. From figure 44 it can be seen that calcium levels in *P. latisulcatus* are higher than in *P. aztecus*, *P. setiferus* and *Metapenaeus bennettae*. The haemolymph calcium concentration in these latter three species is relatively constant at 400 µg/ml over the entire salinity range, indicating a high degree of calcium regulation. In *P. latisulcatus*, the calcium concentration is 1100 µg/ml at 60‰, falling to about 975 µg/ml at 35‰, and from 30‰ to 12‰ the haemolymph calcium drops sharply to a minimum of 600 µg/ml. Although the absolute level of calcium in the haemolymph of *P. latisulcatus* at low salinities is high, the marked drop in haemolymph calcium levels in salinities below 30‰ may contribute to mortalities at these salinities.

FIGURE 44



SODIUM REGULATION IN

- *P. LATISULCATUS*
- *P. AZTECUS* (FROM MACFARLAND AND LEE, 1963)
- *P. DUORARUM* (FROM BURSEY AND LANE 1971a)
- *P. SETIFERUS* (FROM MACFARLAND AND LEE, 1963)



CALCIUM REGULATION IN

- *P. LATISULCATUS*
- *P. AZTECUS* (FROM MACFARLAND AND LEE, 1963)
- *P. SETIFERUS* (FROM MACFARLAND AND LEE, 1963).
- *METAPENAEUS BENNETTAE* (FROM DALL, 1964)

In conclusion it appears that with respect to the position of the isosmotic point and to the degree of hypo-osmotic regulation *P. latisulcatus* is not especially adapted to hypersaline waters compared with the other penaeid prawns. However, the regulation of sodium, the major cation, is much more marked in *P. latisulcatus* than in *P. setiferus* and *P. duorarum*, especially in salinities greater than 45‰ (fig 44). The sodium regulation of *P. aztecus* is of a similar pattern to that of *P. latisulcatus* but haemolymph concentrations are maintained much higher in the latter species. From figures 43 and 44 it can be seen that *P. latisulcatus* appears to be capable of strong hyperosmotic regulation although the species is unable to survive in low salinities. This may be related to the fact that juvenile *P. latisulcatus* do not maintain calcium at constant levels in lowered salinities as do the other penaeids.

CONCLUSIONS

The migratory penaeid prawn *Penaeus latisulcatus* Kishinouye 1900, has a life cycle typical of other migratory penaeid prawns. Maturation of the adults, mating and spawning occur in offshore waters. The larval stages move inshore and the postlarvae settle in nursery areas. The juvenile prawns live in these sheltered nursery areas for some time before the sub-adults emigrate to the offshore waters.

In Australian waters large populations of *P. latisulcatus* occur in Shark Bay, Western Australia and in Spencer and St. Vincent Gulfs in South Australia. Smaller populations occur on the west coast of South Australia. In these regions the nursery areas for juvenile *P. latisulcatus* are similar in many respects to those occupied by other penaeid prawns. The nursery areas are often associated with mangrove swamps and are always associated with seagrass beds. Penaeid prawns are opportunistic detritivores and it is likely that the seagrasses and mangroves constitute an important primary food resource for juvenile *P. latisulcatus*.

Unlike the nursery areas occupied by other penaeid species, which are usually low salinity estuaries, the shallow inshore waters of Shark Bay and the South Australian Gulfs are hypersaline and a "negative estuary" situation exists in the nursery areas for *P. latisulcatus*. *P. latisulcatus* is quite unusual amongst the penaeid prawns in respect to the salinity of the nursery areas occupied by the juvenile prawns.

The recruitment of prawns to the fishery in Spencer Gulf can be used as an estimate of the abundance of juvenile *P. latisulcatus* in the nursery areas. The annual recruitment can be estimated from the available fishery statistics which record the weight of catch per unit of fishing effort. These statistics show considerable variation throughout each year and from year to year. Changes in catch per unit effort are not due to changes in the fishing intensity nor to the effects of growth of prawns throughout the season. Estimates of mortality rates in the Spencer Gulf prawn fishery have been made but mortality alone does not account for the observed variation in the catch per unit effort throughout any year. It has been shown that temperature affects the activity of *P. latisulcatus* and that this may be related to the catchability of the prawns. A model of the fishery, based on mortality rates estimated from the catch per unit effort and on a relationship between temperature and catchability of prawns, can adequately describe the variation in catch per unit effort within each year. This model has been used to estimate the recruitment of prawns each year, and variations in catch per unit effort from year to year are due to differences in recruitment and mortality rates from year to year. There is no apparent relationship between the size of the adult stock and the subsequent recruitment nor does water temperature significantly affect the size of the recruitment.

A negative correlation exists between effective rainfall over the northern Spencer Gulf area and recruitment of *P. latisulcatus* to the fishery. This is in contrast to the positive correlations observed between rainfall and catches of other penaeid prawns. These other species inhabit true estuaries and it is likely that reduced salinity after heavy rainfall might benefit these species either directly or through the indirect consequences of reduced salinity such as the influx of nutrients into the estuary. The negative correlation between recruitment and effective rainfall found in this study supports the hypotheses that *P. latisulcatus* is adapted to the hypersaline conditions occurring in its nursery areas and that reduced salinities are detrimental to the survival of this species.

Laboratory studies have shown that the survival of juvenile *P. latisulcatus* in high salinities is better than that of other penaeid species, but that in low salinities the survival of *P. latisulcatus* is not as good as that of other species. These results are in keeping with the hypersaline nature of the habitat of juvenile *P. latisulcatus* and the negative correlation between recruitment and effective rainfall. They indicate that *P. latisulcatus* may be physiologically adapted to hypersaline conditions but that this adaptation is associated with lack of tolerance to low salinities.

The physiological basis for the survival of juvenile *P. latisulcatus* at high salinities was found to be the strong regulation of sodium in the haemolymph of the prawns. The total osmoregulation was,however, not as strongly marked as the ionic regulation in high salinities. This difference does not appear to be due to the presence of higher levels of osmotically active amino acids in the haemolymph of prawns exposed to high salinities.

Hyperosmotic regulation was quite marked in those prawns which survived the low salinities, but the stress imposed by this regulation may be high, accounting for the high mortality of prawns in the low salinities. Further work on the energetics of osmoregulation in *P. latisulcatus* is required to support this hypothesis. Another factor which may cause high mortality at low salinities is the inability of *P. latisulcatus* to maintain high levels of calcium where exposed to low salinities. Other penaeid prawns appear to maintain a relatively constant level of calcium in the haemolymph over the entire range of salinities tolerated. The calcium levels in the haemolymph of *P. latisulcatus* are always higher than those observed in other penaeid prawns but in salinities below 30‰ the calcium level in *P. latisulcatus* haemolymph drops sharply. *P. latisulcatus* did not survive in calcium-depleted seawater, however it is necessary to determine the survival of *P. latisulcatus* in various concentrations of calcium, at constant salinity in order to substantiate the hypothesis that calcium regulation is the critical factor in the survival of juvenile *P. latisulcatus* at low salinities.

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APPENDIX A

Salinities in *Penaeus latisulcatus* nursery areas in South Australia

Tables A1 and A2 list in chronological order, surface and bottom water salinities respectively, at nine stations near Torrens Island in St. Vincent Gulf. Data designated *1 were obtained from Zed (1972) that designated *2 from Engineering and Water Supply Department (1975) and that designated *3 were obtained from Nevarauskus (1977) and Leonaviscius (unpublished).

Salinity data from several locations in Spencer Gulf is presented in Table A3. Salinities at Eastern Shoal and Douglas Bank were measured by M.G. King (pers. comm.).

SALINITY ‰

LOCATION	1	2	3	MID	4	5	6	7	S.A.
DATE									
*3 6.12.74	37.7	37.8	37.8	38.4	38.8	37.7			39.9
*3 13.12.74	38.2	38.4	38.6		39.6	39.4	38.7		
*3 23.12.74	38.8	38.5	39.2		40.0	39.0			
*3 9.1.75	38.9	39.0	38.9	39.4	39.8	38.8			
*3 15.1.75	39.5	39.2	39.3	40.6	40.3	39.6	39.5		41.9
*3 21.1.75	39.1	39.0	39.2	40.7	40.4	39.3			
29.1.75	39.2						39.8		
30.1.75						39.6			
31.1.75								40.1	
3.2.75	38.9	39.2	39.1	39.8	40.5	39.1			
4.2.75			39.9						
11.2.75	39.0	39.2	39.8	40.4	40.7	39.5	39.4		41.9
*3 19.2.75	39.2	39.5	39.7	40.3	40.4	39.3			
*2 6.3.75	39.1	39.3	39.5	40.2	40.5	39.5			
*3 28.4.75			38.9						
*3 29.4.75	38.1								
*3 30.4.75						38.6			
1.5.75					39.3				
2.5.75		38.4	38.6		39.5	38.5	38.2	39.5	
12.5.75		37.6							
13.5.75								37.7	
14.5.75		37.4					36.7		
*3 20.5.75	36.8	37.2	36.5	36.2	36.5	37.1			
*3 22.5.75	37.0	37.2	37.0	36.3	36.4	37.1	37.1		33.4
2.6.75	36.9	37.1	37.0	36.4	36.4	37.4			
*3 20.6.75	37.1	37.4	37.5	37.6	37.6	37.5	37.5		37.0
11.7.75	37.1	37.2	37.3		37.4	37.3		37.6	
*3 22.7.75	36.1	36.0	35.2	33.4	34.5	34.6	36.1		
1.8.75	35.3	35.2	31.1	32.3	33.6	35.6			
*3 13.8.75	35.6	35.9	35.9	34.7	36.1	35.9	36.1		32.9
*3 21.8.75						36.4			
*3 22.8.75							36.5		
26.8.75		36.6			36.3				
27.8.75	36.7		36.6				36.3		
28.8.75	36.6	36.3	36.6		36.2	36.7	36.7	36.5	
*3 29.8.75								36.8	
2.9.75	36.6	36.9	37.0			37.2			
1.10.75	36.7		35.6		36.6	36.6			
*3 10.10.75	36.5								
20.10.75			36.6						
21.10.75		36.8							
22.10.75						37.1			
24.10.75								36.1	

TABLE A1

SURFACE SALINITIES (‰) IN WATERS OFF TORRENS ISLAND

					SALINITY ‰				
LOCATION	1	2	3	MID	4	5	6	7	S.A.
DATE									
*1 19.3.72	39.1								
*1 29.3.72	38.9	39.1	39.3						
*1 1.4.72	38.9	39.0	39.1	40.2					
*1 15.8.72	37.2	37.2	37.2						
*1 8.9.72	36.5	36.8	36.8	35.8					
*1 15.9.72		37.1							
*2 19.1.73								37.8	
*2 8.3.73								38.5	
*2 10.4.73								38.3	
8.8.73	35.6	35.2	35.15						
18.8.73	365.9	35.7	35.8						
19.8.73	35.8	35.9	35.9						
8.9.73	36.4	36.3	31.9	31.5		33.7			10.3
2.10.73		38.7							
3.10.73	36.1	36.2	36.3			36.5			
26.10.73		36.8							
17.4.74									37.3
5.8.74	34.1		34.4						
6.8.74					32.4				
7.8.74					32.6		34.8	33.2	
8.8.74		35.1				34.5			
12.8.74	35.4	35.4	35.0		34.2	35.2			
13.8.74	35.7	35.6	35.0		35.3	35.5			
*3 14.8.74	34.8	35.1	35.1	34.3	34.3	34.4			31.2
16.8.74	35.1	34.9					19.5		9.5
*3 26.8.74	35.4	35.5	35.5	35.2	35.9	35.5			16.0
*3 3.9.74	35.9	36.1	35.8	34.2	34.8	36.1	36.0		
4.9.74			35.9	32.5	35.2				23.5
16.9.74							36.1	35.7	
17.9.74						36.3			
18.9.74					36.0				
19.9.74		36.4							
*3 8.10.74	34.6	34.9	32.6	31.5	33.4	34.8			
*3 16.10.74	33.7	34.4	32.4	26.6	26.8	27.7	29.5		0.2
17.10.74	34.0								
18.10.74					32.4				
21.10.74							34.8		
23.10.74		35.0							
*3 30.10.74	35.4	35.1	34.7	33.4	32.6	34.8	34.8		18.2
5.11.74	35.6	35.4	35.5	35.3	36.2	35.6			
*3 13.11.74	36.3	36.0	36.3	36.1	36.3	36.1	36.2		33.1
21.11.74	36.8	36.9	36.8	37.4	37.5	36.8			
*3 27.11.74	37.3	36.8	37.3	37.7	37.9	37.4	37.4		36.9
28.11.74							37.0		
29.11.74					38.4				
2.12.74			37.9						
3.12.74						37.9			
4.12.74		37.5							

TABLE A2

BOTTOM SALINITIES (‰) IN WATERS OFF TORRENS ISLAND

SALINITY ‰

	LOCATION	1	2	3	MID	4	5	6	7	S.A.
	DATE									
*1	19.3.72	39.2								
*1	29.3.72	38.9	39.1	39.5						
*1	1.4.72	39.1	39.6	39.3	40.2					
*1	15.8.72	37.2	37.3	37.2						
*1	8.9.72	36.6	37.0	36.9	35.8					
*1	15.9.72		37.4							
*2	19.1.73								38.0	
*2	8.3.73								38.7	
*2	10.4.73								38.6	
	8.8.73	35.6	35.6	35.3						
	18.8.73	35.9	36.2	36.0						
	19.8.73	36.0	36.2	36.2						
	8.9.73	36.4	36.5	36.2	35.6		33.7			12.3
	2.10.73		39.9							
	3.10.73	36.7	37.2	36.3			36.5			
	26.10.73		37.7							
	17.4.74								37.9	
	5.8.74	34.1		34.2						
	6.8.74									
	7.8.74					32.8		35.1	33.2	
	8.8.74		35.1				34.4			
	12.8.74	35.5	35.5	35.7		34.2	35.2			
*3	13.8.74	35.7	35.6	35.1			35.3	35.5		
	14.8.74	35.2	35.1	34.4	34.3	34.7	35.0			31.4
*3	16.8.74	35.2	34.8					30.6		30.6
*3	26.8.74	35.6	35.6	35.7	35.2	35.1	35.6			29.2
	3.9.74	36.1	36.1	35.7	34.4	34.8	36.1	36.0		
	4.9.74			36.3	35.3	35.3				31.9
	16.9.74							36.1	35.7	
	17.9.74						36.3			
	18.9.74					35.8				
	19.9.74		36.4							
*3	8.10.74	35.0	35.0	34.5	33.4	34.1	34.9			
*3	16.10.74	35.0	35.0	33.8	27.4	30.1	32.0	33.9		6.1
	17.10.74	34.6								
	18.10.74					30.9				
	21.10.74							35.0		
	23.10.74		35.1							
*3	30.10.74	35.0	35.2	34.7	33.0	32.8	34.8	34.5		28.6
	5.11.74	35.9	35.8	35.7	35.3	36.2	35.6			
*3	13.11.74	36.8	36.9	36.4	36.3	36.3	36.1	36.4		33.4
	21.11.74	37.1	36.8	37.4	37.5	37.6	36.7			
*3	27.11.74	37.3	37.5	37.5	37.7	37.9	37.4	37.5		37.3
	28.11.74							37.0		
	29.11.74					38.4				
	2.12.74			38.0						
	3.12.74						37.9			
	4.12.74		38.1							

SALINITY ‰

LOCATION		1	2	3	MID	4	5	6	7	S.A.
DATE										
*3	6.12.74	38.0	37.9	37.9	38.9	37.6				40.2
*3	13.12.74	38.5	39.3	39.9		39.9	39.4	39.2		
*3	23.12.74	39.3	39.0	39.0		40.0	38.8			
*3	9.1.75	40.2	40.5	40.0	39.6	39.9	38.8			
*3	15.1.75	39.5	39.8	39.6	40.6	40.3	39.6	39.7		42.4
*3	21.1.75	39.6	39.9	40.7	40.7	40.5	39.3			
	29.1.75	39.4						39.3		
	30.1.75								40.4	
	3.2.75	39.3	39.5	40.5	40.7	40.4	39.2			
	4.2.75			40.1						
	11.2.75	39.4	39.9	40.0	41.3	40.7	39.5	39.4		42.1
*3	19.2.75	39.6	39.7	40.7	40.8	40.4	39.3			
*3	6.3.75	39.3	39.7	40.7	40.4	40.5	39.5			
*3	28.4.75			39.0						
*3	29.4.75	38.3								
*3	30.4.75						38.6			
	1.5.75					39.3				
	2.5.75		38.9	38.4		39.4	38.6	38.5	39.4	
	12.5.75		37.8							
	13.5.75								37.7	
	14.5.75		37.6					37.3		
*3	20.5.75	37.4	37.0	36.8	36.2	36.5	37.1			
*3	22.5.75	37.5	37.1	36.9	36.4	36.5	37.1	37.2		35.5
	2.6.75	37.1	37.1	37.0	36.3	36.3	37.1			
*3	20.6.75	37.6	37.8	37.6	37.6	37.6	37.5	37.4		37.5
	11.7.75	37.2	37.5	37.4		37.4	37.3		37.6	
*3	22.7.75	36.2	35.8	35.1	35.0	36.0	35.5	35.8		
	1.8.75	36.1	35.8	35.6	35.2	35.5	36.0			
*3	13.8.75	36.4	36.1	36.1	35.2	36.1	35.9	36.0		33.1
*3	21.8.75						36.4			
*3	22.8.75							36.6		
	26.8.75		36.9			36.6				
	27.8.75	36.9		36.6				36.1		
	28.8.75	36.9	36.9	36.6		36.2	36.7	36.8	36.6	
*3	29.8.75								36.8	
	2.9.75	36.9	37.1	37.1			36.9			
	1.10.75	37.1		36.7		36.6	36.8			
*3	5.10.75	37.1								
*3	10.10.75	36.9								
	20.10.75			36.9						
	21.10.75		37.2							
	22.10.75						37.1			
	24.10.75								36.1	

TABLE A3

SALINITIES IN NORTHERN SPENCER GULF

SALINITY (‰)

	Chinaman's Creek		Eastern Shoal		Douglas Bank		Port Davis		Port	Port	Port
DATE	Offshore	Inshore	Surface	Bottom	Surface	Bottom	Offshore	Inshore	Germein	Pirie	Broughton
14.3.73			41.4	41.5	42.5	42.6					
10.5.73			41.5	41.5	42.3	42.4					
10.7.73					41.7	42.1					
13.7.73							42.2	42.5	41.8	41.9	42.7
10.8.73			40.6		41.1						
20.9.73			41.0		41.5						
6.10.73	42.1	42.2									
7.10.73	41.9	42.1									
8.10.73	42.2	42.3									
9.10.73	41.7	42.3									
17.10.73			30.5		27.5						
27.10.73	39.0	41.2									
14.11.73			39.1		39.7						
17.12.73			40.2								
15.1.74					40.7						
18.3.74			39.8		40.9						
9.4.74					41.0						
15.5.74			41.1		41.8						
20.5.74	32.5	16.9					30.5	6.0			
11.6.74			41.5		41.7						
17.8.74					42.2						
9.9.74			40.7		41.1						
7.8.75	43.0	51.5									
8.8.75	44.2	52.0									
11.6.76											43.1
19.7.76											42.9
2.8.76											43.3
2.9.76									43.1	42.8	43.0
14.10.76									27.0	38.0	40.5

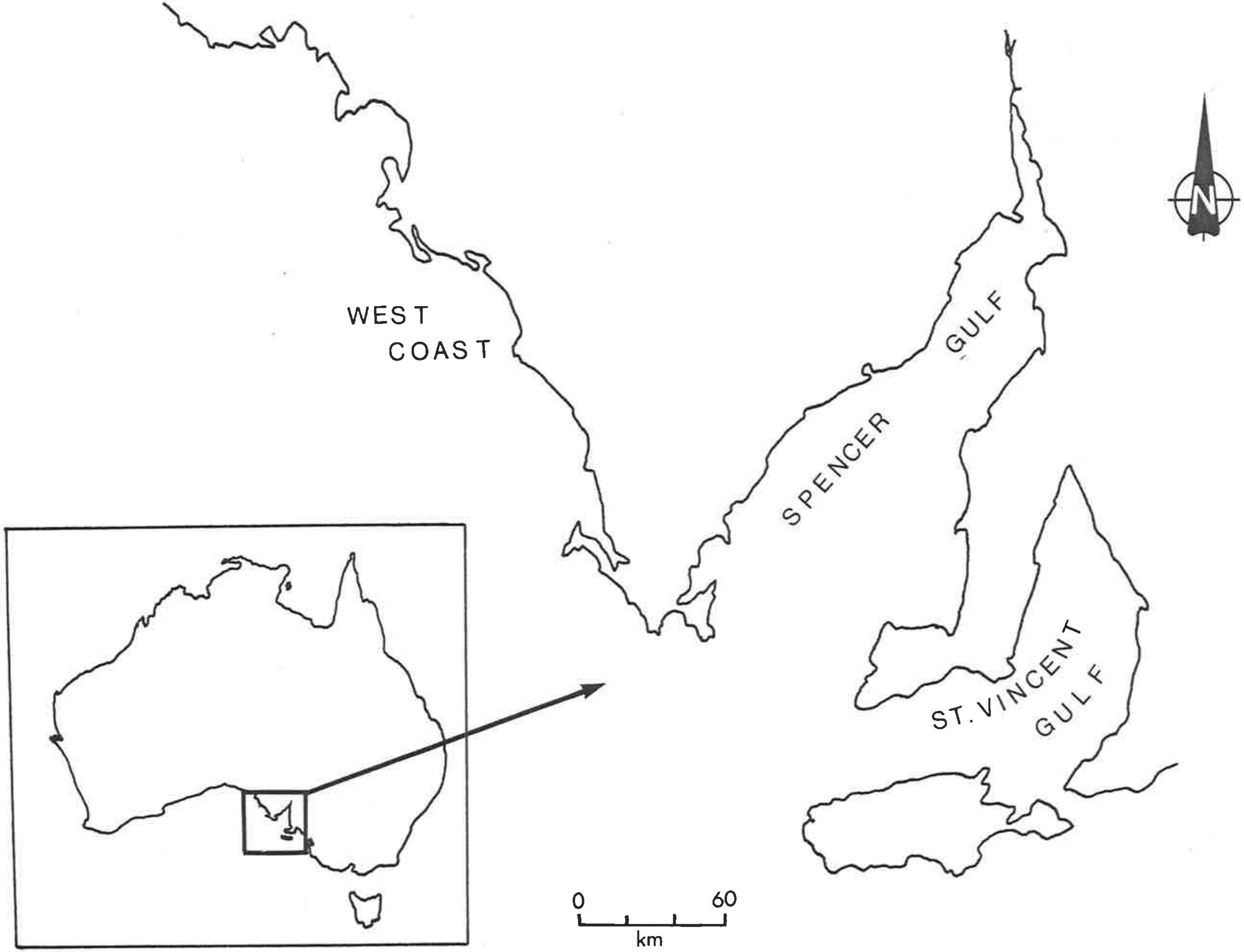
APPENDIX B

Catch, Effort and Catch per unit effort in the South Australian prawn fisheries

Western king prawns *Penaeus latisulcatus* are caught in three major zones in South Australia (fig B1). The data in the following tables have been obtained from the records of the South Australian Department of Agriculture and Fisheries and shows catch (c) in kilograms, Effort (E) in boat hours trawled and catch per unit effort (C/UE) in each of the three zones.

FIGURE B1

MAP OF SOUTH AUSTRALIA SHOWING THE MAIN PRAWN TRAWLING ZONES.


WEST COAST
SPENCER GULF
ST. VINCENT GULF
N
0
60
km

APPENDIX B

Catch, Effort and Catch per unit effort in the South Australian Prawn Fisheries

MONTH	WEST COAST			SPENCER GULF			ST. VINCENT GULF		
	CATCH (kg)	EFFORT (hr)	C/UE (kg/hr)	CATCH (kg)	EFFORT (hr)	C/UE (kg/hr)	CATCH (kg)	EFFORT (hr)	C/UE (kg/hr)
1968									
January	0	0	-	5151	126	40.9	0	0	-
February	0	0	-	7087	189	37.5	0	0	-
March	0	0	-	20365	256	79.6	0	0	-
April	0	0	-	9725	89	109.3	0	0	-
May	1034	30	34.5	38814	368	105.5	58	7	8.3
June	445	55	8.1	51955	883	58.8	980	46	21.3
July	181	5	36.2	31347	703	44.6	957	60	16.0
August	61	4	15.3	24190	536	45.1	483	23	21.0
September	670	39	17.2	47671	786	60.7	628	56	11.2
October	721	18	40.1	42910	1017	42.2	1459	98	14.9
November	424	20	21.2	67165	1011	66.4	1015	81	12.5
December	4110	86	47.8	37298	831	44.9			
TOTAL	7646	257	29.8	383678	6795	56.5	5580	371	15.0
1969									
January	2414	58	41.6	32135	753	42.7	2280	49	46.5
February	452	32	14.1	19818	522	38.0	1915	49	39.1
March	0	0	-	20623	511	40.4	1800	51	35.3
April	0	0	-	72200	1199	60.2	1301	36	36.1
May	0	0	-	65380	1142	57.3	1401	35	40.0
June	0	0	-	46712	1302	35.9	3127	73	42.8
July	672	41	16.4	82096	1458	56.3	3521	126	27.9
August	17140	408	42.0	31890	859	37.1	3530	151	23.4
September	18511	455	40.7	37147	810	45.9	7773	206	37.7
October	14665	468	31.3	52154	1377	37.9	7563	185	40.9
November	27300	752	36.6	60866	1479	41.2	1817	72	25.2
December	18060	586	30.8	36299	997	36.4	5456	182	30.0
TOTAL	99214	2800	35.0	557320	12409	44.9	41484	1215	34.1

APPENDIX B (Contd)

MONTH	WEST COAST			SPENCER GULF			ST. VINCENT GULF		
	CATCH (kg)	EFFORT (hr)	C/UE (kg/hr)	CATCH (kg)	EFFORT (hr)	C/UE (kg/hr)	CATCH (kg)	EFFORT (hr)	C/UE (kg/hr)
1970									
January	25823	799	32.3	50101	1107	45.3	8195	222	36.9
February	12005	605	19.8	65894	1546	42.6	8977	282	31.8
March	14801	634	23.4	133270	1808	73.7	10084	271	37.2
April	22849	766	29.8	161158	1901	84.6	12540	293	42.8
May	34276	1263	27.1	109664	1848	59.3	22501	405	55.6
June	20367	760	27.2	81159	1363	59.5	9217	160	57.6
July	28762	999	28.9	44637	1552	28.8	1038	61	17.0
August	14574	611	23.9	14260	577	24.7	764	46	16.6
September	17630	878	20.1	17750	669	26.5	2113	135	15.7
October	16575	990	16.7	34269	1104	31.0	8406	271	31.0
November	15994	860	18.6	50703	1404	36.1	12835	362	35.5
December	13716	827	16.6	22641	563	40.2	9273	305	30.4
TOTAL	237372	9987	23.8	785506	15442	50.9	105943	2813	37.7
1971									
January	6971	374	18.6	35060	907	27.6	12755	400	31.9
February	12526	653	19.2	69147	984	70.3	14351	499	28.8
March	2136	131	16.3	137188	1580	86.8	16227	585	27.7
April	723	27	26.8	190851	3087	61.8	20128	676	29.8
May	0	0	-	198077	3745	52.9	20153	709	28.4
June	21734	523	41.6	93930	2282	41.2	9070	324	28.0
July	67346	1776	37.9	24089	870	27.7	9342	388	24.1
August	29815	1067	27.9	17816	581	30.7	5482	243	22.6
September	19690	797	24.7	23537	730	32.2	9407	418	22.5
October	18194	753	24.2	28293	730	38.8	16941	521	32.5
November	42431	1682	27.0	58085	1020	57.0	12154	443	27.4
December	12936	562	23.0	60418	1165	51.9	16457	544	30.3
TOTAL	237502	8345	28.5	936491	17681	53.0	162467	5750	28.3

MONTH	WEST COAST			SPENCER GULF			ST. VINCENT GULF		
	CATCH (kg)	EFFORT (hr)	C/UE (kg/hr)	CATCH (kg)	EFFORT (hr)	C/UE (kg/hr)	CATCH (kg)	EFFORT (hr)	C/UE (kg/hr)
1972									
January	22935	1131	20.3	92895	1953	47.6	20760	598	34.7
February	6261	342	18.3	153362	2300	66.7	24370	862	28.3
March	0	0	-	134646	1943	69.3	17207	713	24.1
April	518	22	23.6	197671	3062	64.6	18850	688	27.4
May	22357	817	27.4	133355	3027	44.1	30408	1017	29.9
June	30161	1091	27.7	76900	1973	39.0	29379	945	31.1
July	23452	789	29.7	25403	605	42.0	2676	111	24.1
August	34596	1490	23.2	20780	569	36.5	5950	301	19.8
September	27836	1418	19.6	14585	559	26.1	14511	689	21.1
October	18657	845	22.1	39622	1172	33.8	20827	655	31.8
November	6586	215	30.6	138308	3131	44.2	41663	947	44.0
December	20790	747	27.8	48752	1513	32.2	17544	653	26.9
TOTAL	214148	8907	24.0	1076279	21807	49.4	244145	8179	29.9
1973									
January	0	0	-	93393	1920	48.6	13261	540	24.6
February	3323	154	21.6	229277	2659	86.2	22237	858	25.9
March	5957	205	29.1	222547	2766	80.5	19285	708	27.2
April	1425	92	15.5	180366	2566	70.3	22194	607	36.6
May	51876	1338	38.8	167072	2910	57.4	24823	806	30.8
June	48365	1262	38.3	63362	1494	42.4	24418	704	34.7
July	44132	1703	25.9	37607	1034	36.4	12721	499	25.5
August	26909	1054	25.5	66658	1616	41.2	15254	606	25.2
September	16536	639	25.9	72372	1454	49.2	12270	396	31.0
October	29977	929	32.3	146094	2589	56.4	37533	798	47.0
November	29649	843	35.2	149368	2758	54.2	44754	799	56.0
December	31738	1057	30.0	57230	1379	41.5	27354	716	38.2
TOTAL	289887	9276	31.3	1485346	25145	59.1	276104	8037	34.4

MONTH	WEST COAST			SPENCER GULF			ST. VINCENT GULF		
	CATCH	EFFORT	C/ UE	CATCH	EFFORT	C/ UE	CATCH	EFFORT	C/ UE
1974									
January	20415	483	42.3	101893	3101	32.9	14773	707	21.1
February	15206	280	54.3	306350	4326	70.8	19033	848	22.4
March	2725	284	9.6	419286	4627	90.6	39606	1512	26.2
April	21443	258	83.1	410601	4496	91.3	43957	1512	29.1
May	9245	192	48.1	323862	6004	53.9	51228	1765	29.0
June	13582	411	33.1	135686	4264	31.8	35706	1238	28.8
July	20632	652	31.6	43807	1459	30.0	16785	510	32.9
August	21805	963	22.6	75042	1816	41.3	13360	544	24.6
September	19151	577	33.2	100828	2352	42.9	15350	648	23.7
October	6106	302	20.2	156801	4270	36.8	29738	1227	24.2
November	11296	352	32.1	272782	5778	47.2	47715	1288	37.1
December	18952	438	43.3	114180	3304	34.6	42288	978	43.3
TOTAL	180558	5192	34.8	2521118	45797	55.1	369539	12771	28.9
1975									
January	19151	577	33.2	158096	4766	33.0	16123	981	16.4
February	2701	110	24.5	257771	7582	34.0	24516	1242	19.8
March	2579	153	16.9	298630	6634	45.0	20740	1089	19.0
April	4596	191	24.1	314236	8274	38.0	50480	2014	25.1
May	19537	570	34.3	173899	6358	27.4	23600	1043	22.6
June	38505	1256	30.7	79538	3821	20.8	41376	1784	23.2
July	23635	958	24.7	45792	2709	16.9	8686	798	10.9
August	16053	790	20.3	45770	2973	15.4	14189	1093	13.0
September	5834	329	17.7	62531	3813	16.4	20824	1661	12.5
October	6766	354	19.1	69357	4381	15.8	25731	1824	14.1
November	11009	474	23.2	164668	7090	23.2	75485	2800	27.0
December	6169	319	19.3	59753	3238	18.4	35283	1232	28.6
TOTAL	156535	6081	25.7	1730041	61639	28.1	357039	17561	20.3
1976									
January				164928	3812	43.3			
February				288539	5087	56.7			
March				455739	6276	72.6			
April				272674	4659	58.5			

APPENDIX C

Test for normality of catch per unit effort and fishing effort data

To test whether the data on catch per unit effort and fishing effort in the Spencer Gulf fishery are normally distributed, the data are first classified into approximately 20 class intervals and the frequency of the data in these intervals counted. Percentage cumulative frequencies are calculated. (See tables C_1 and C_2). The percentage cumulative frequencies are then plotted on probability graph paper (fig C_1). If the data are normally distributed the percentage cumulative frequencies should fall along straight lines (Sokal and Rohlf 1975). From the figure it can be seen that straight line plots could not be satisfactorily fitted to either sets of data. The distribution of the percent cumulative frequency data for catch per unit effort is typical of a skewed normal distribution (Sokal and Rohlf, 1975) and that of the effort data is irregular.

TABLE C1, TABLE C2. FREQUENCY DISTRIBUTION OF C/UE AND EFFORT DATA

(MONTHLY DATA OVER A PERIOD OF 8 COMPLETE YEARS)

1)C/UE (kg/hr)

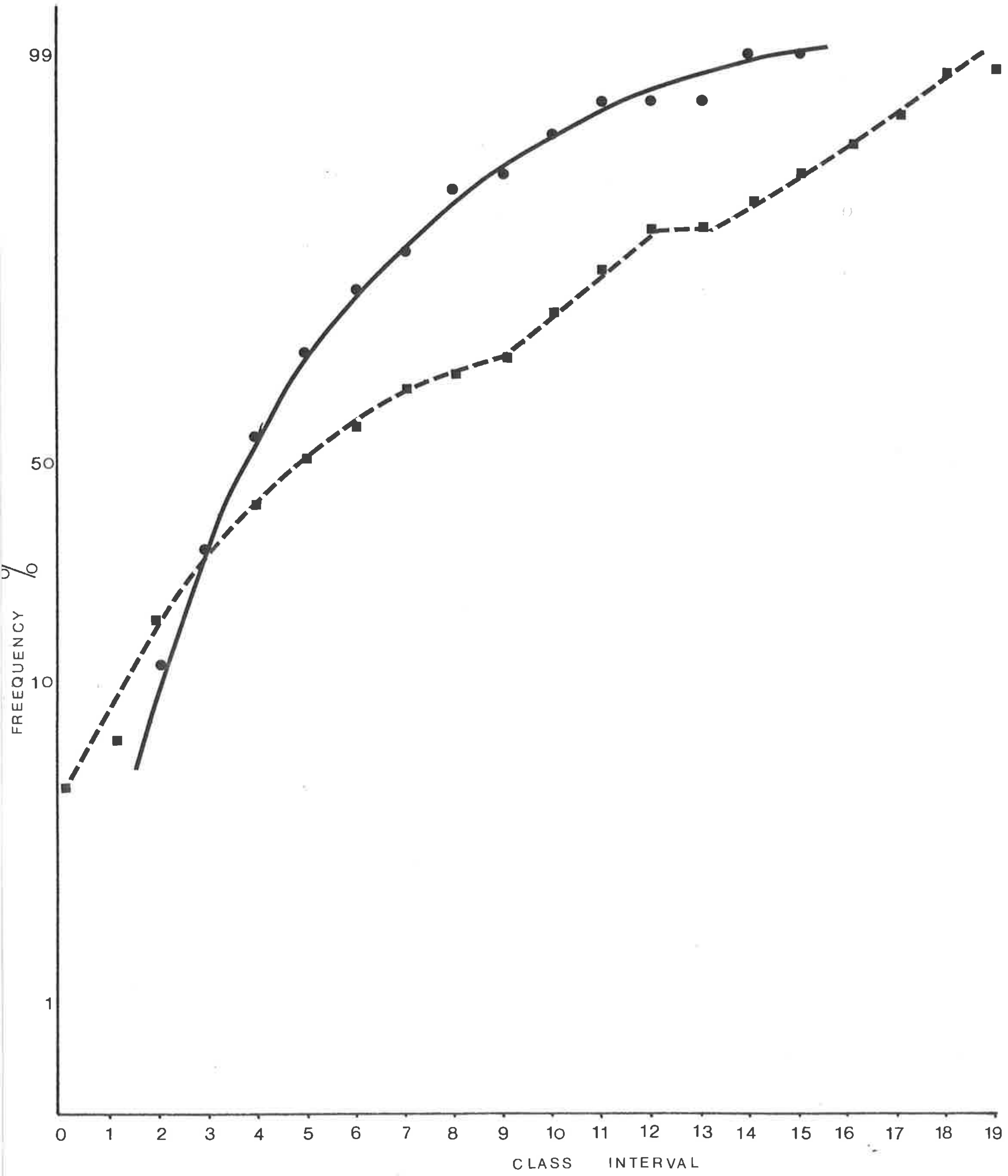
Nominal class interval	Class Interval	Frequency	Cumulative Frequency	% Cumulative Frequency
0	0-9	0	0	0
1	10-19	0	0	0
2	20-29	11	11	11.46
3	30-39	18	29	30.21
4	40-49	24	53	55.21
5	50-59	17	70	72.92
6	60-69	10	80	83.33
7	70-79	5	85	88.54
8	80-89	5	90	93.75
9	90-99	1	91	94.79
10	100-109	2	93	96.88
11	110-119	1	94	97.92
12	120-129	0	94	97.92
13	130-139	0	94	97.92
14	140-149	1	95	98.96
15	150-159	0	95	98.96
16	160-169	1	96	100.00%
17	170-179			
18	180-189			
19	190-199			

2) Effort (hrs trawled)

Nominal class Interval	Class Interval	Frequency	Cumulative Frequency	% Cumulative Frequency
0	0-249	3	3	3.13
1	250-449	2	5	5.21
2	500-749	13	18	18.75
3	750-999	11	29	30.21
4	1000-1249	11	40	41.67
5	1250-1449	10	50	52.08
6	1500-1749	7	57	59.38
7	1750-1999	8	65	67.71
8	2000-2249	2	67	69.79
9	2250-2499	4	71	73.96
10	2500-2749	7	78	81.25
11	2750-2999	6	84	87.50
12	3000-3249	4	88	91.67
13	3250-3499	0	88	91.67
14	3500-3749	2	90	93.75
15	3750-3999	2	92	95.83
16	4000-4249	1	93	96.88
17	4250-4499	1	94	97.92
18	4500-4749	1	95	98.96
19	4750-4999	0	95	98.96
20	5000-5249	1	96	100.00%

FIGURE C1

FREQUENCY DISTRIBUTION (PLOTTED ON PROBABILITY SCALE) OF CATCH PER UNIT EFFORT (●) AND EFFORT (■) DATA.


99
50
10
1
FREEQUENCY %
0
1
2
3
4
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CLASS INTERVAL

APPENDIX D

Mean weekly water temperatures in upper Spencer Gulf

Data on the mean weekly water temperature in upper Spencer Gulf were obtained from records of the cooling-water intake water temperature, at the Sir Thomas Playford power station near Pt. Augusta, and are shown in Table D1.

Mean monthly water temperatures at Pt. Augusta are shown in Table D2.

TABLE D1

WEEKLY MEAN WATER TEMPERATURE AT PT. AUGUSTA

Week No.	temperature ^{o}C										
	Year 1966	67	68	69	70	71	72	73	74	75	76
1		23.9	22.2	23.9	19.9	24.3	23.4	22.7	23.9	22.3	-
2		22.8	21.7	23.9	23.1	22.4	21.0	23.4	26.0	21.6	23.9
3		24.4	24.4	22.8	22.2	23.4	21.8	22.4	27.3	23.3	21.5
4		23.3	26.1	24.4	23.1	22.7	22.3	22.0	23.3	23.1	21.7
5		21.7	26.1	25.6	24.1	23.4	25.3	23.8	25.4	24.6	23.7
6		24.4	21.7	26.4	27.7	24.4	23.4	25.9	22.9	25.1	25.3
7		25.0	26.1	25.0	23.3	24.3	21.0	26.3	22.4	26.3	25.1
8		23.3	23.9	23.3	21.6	25.4	24.8	26.3	22.5	24.6	24.2
9		21.1	21.1	25.6	24.2	25.2	22.8	24.2	28.3	22.8	24.7
10		21.7	23.3	23.3	22.8	24.4	21.8	23.4	24.5	22.3	25.4
11		22.8	23.9	21.7	23.1	24.2	20.2	20.4	24.2	24.0	22.5
12		22.2	22.2	21.1	20.9	23.6	20.8	21.7	23.6	19.6	20.3
13		21.1	20.0	20.6	20.1	23.8	20.0	19.8	23.8	20.5	23.4
14		21.1	21.1	22.2	19.8	24.3	20.3	20.4	21.1	19.0	20.4
15		18.9	19.4	21.7	19.7	21.1	18.5	21.4	19.1	19.4	20.2
16		19.4	20.0	17.8	20.7	17.8	19.2	18.1	21.3	21.0	18.5
17		19.4	16.7	18.9	17.9	17.3	17.3	17.6	19.8	19.6	18.1
18		17.2	17.2	18.2	17.5	18.7	16.7	17.8	19.1	18.8	15.9
19		18.3	15.6	17.6	16.9	21.1	15.2	15.7	16.6	18.6	15.2
20		15.6	15.6	15.8	17.2	15.6	15.5	17.3	17.3	17.8	15.8
21		16.1	17.2	15.2	15.9	13.9	14.5	14.9	16.1	17.1	14.6
22		13.9	13.3	14.1	15.9	14.2	15.6	15.5	14.4	18.6	14.4
23		14.4	13.3	12.8	15.0	14.7	13.8	14.2	14.4	17.4	14.1
24		16.7	15.6	13.5	15.2	14.0	14.6	13.2	14.0	13.0	14.0
25		15.0	14.4	14.3	13.3	13.6	12.9	13.6	12.9	13.2	13.3
26		12.8	11.7	13.8	14.4	13.4	12.6	13.2	14.0	13.7	13.4
27		11.1	12.2	14.1	13.9	13.1	12.3	14.5	12.7	13.4	13.5
28		12.2	12.8	14.8	13.3	14.0	12.9	15.5	12.7	14.2	12.5
29		13.9	13.3	14.8	13.1	12.6	12.9	15.1	12.8	14.4	12.6
30		12.2	11.7	14.9	12.7	13.6	12.6	15.2	14.1	16.6	13.0
31		12.2	12.2	15.0	12.9	13.8	12.3	16.1	14.8	14.1	13.4
32		11.7	12.2	14.3	13.2	13.9	12.9	15.3	14.7	14.4	13.2
33		12.8	13.3	16.7	13.1	14.3	12.8	14.9	14.6	13.6	13.3
34		16.1	12.8	17.1	13.1	10.7	13.3	14.9	14.6	14.2	14.1
35		14.4	14.4	16.9	14.1	14.8	13.6	14.8	15.6	13.6	15.7
36		12.8	15.6	15.3	15.0	15.5	13.2	17.3	15.6	19.9	15.7
37		15.6	16.7	15.9	14.4	17.0	14.3	17.1	17.5	18.8	15.8
38		17.8	15.6	18.8	14.8	16.4	15.6	-	15.9	19.9	16.6
39		15.6	15.0	22.2	15.8	17.9	17.1	20.5	15.6	19.1	17.2
40		17.8	14.4	20.6	18.6	18.7	17.3	23.3	16.8	18.1	17.2
41		22.2	17.2	19.9	18.7	18.4	15.6	24.9	19.1	18.3	16.5
42		20.6	20.6	22.7	17.1	20.2	18.6	20.0	17.2	19.0	16.0
43		20.0	20.0	22.2	19.4	19.6	21.2	20.3	21.9	17.3	18.7
44		18.3	20.0	20.8	19.6	21.3	21.3	19.7	19.7	17.6	19.9
45		22.2	21.1	20.9	21.1	18.4	19.8	20.0	20.3	18.9	20.6
46		19.4	21.7	21.9	18.7	20.8	21.4	20.2	22.4	22.9	21.6
47		-	18.9	21.3	22.6	19.7	20.7	-	21.0	22.7	20.5
48		18.9	20.6	20.3	22.2	19.9	23.0	21.5	21.4	23.2	21.8
49		22.8	20.0	23.5	23.1	22.8	22.6	24.4	23.4	27.1	22.7
50		20.6	21.7	21.8	23.1	21.1	23.4	24.6	23.2	24.6	-
51		23.3	21.7	22.6	22.6	-	24.6	24.1	24.0	22.0	-
52	23.9	23.3	21.7	21.1	20.9	-	25.4	22.5	21.7	-	-

TABLE D2

MEAN MONTHLY WATER TEMPERATURES AT PT. AUGUSTA

Temperature °C

Month	Year									
	1967	68	69	70	71	72	73	74	75	76
Jan	23.2	24.1	24.1	22.5	23.2	22.8	22.9	25.2	23.0	22.7
Feb	23.1	23.3	24.8	24.2	24.5	23.5	25.3	24.3	24.7	24.8
Mar	22.0	22.4	21.7	21.7	24.0	20.7	21.3	24.0	21.6	22.9
Apr	19.7	20.1	20.2	20.1	20.1	18.8	19.9	20.3	19.8	19.3
May	16.8	16.4	16.2	16.9	16.7	15.8	16.5	17.3	18.2	15.2
Jun	14.6	13.7	13.7	14.8	14.0	13.5	13.9	13.9	14.3	13.8
Jul	12.4	12.5	14.7	13.3	13.3	12.7	15.1	13.1	14.7	12.9
Aug	13.2	12.6	15.8	13.1	13.2	12.8	15.3	14.7	14.1	13.5
Sep	15.2	15.5	17.8	14.8	15.9	14.2	17.4	16.0	18.3	16.2
Oct	19.2	17.4	21.5	15.5	19.0	18.0	21.8	17.2	18.4	17.1
Nov	19.7	20.5	21.0	20.5	20.0	20.8	20.4	20.8	21.1	20.6
Dec	22.5	21.1	21.9	22.4	22.0	23.3	23.9	23.0	24.2	-

APPENDIX E

Length/weight relationship of *P. latisulcatus*

The weights of each prawn to the nearest .1 gm and the carapace length to the nearest 1mm. are shown in Table E1.

TABLE E1

LENGTH/WEIGHT RELATIONSHIP OF *P. LATISULCATUS*

Carapace length (nearest mm) ♂	Weight (nearest 0.1 gm) ♂
30	16.8
31	
32	20.3 20.4
33	26.0
34	20.3 23.4 26.6
35	23.2 23.2 23.2 25.7 26.1 26.1
36	21.1 22.1 24.7 24.8 24.9 25.7 25.7 26.3 26.3 26.9
37	27.0 27.2 27.2 28.1 28.2 28.9 29.2 35.9
38	27.2 28.1 28.8 29.5 29.7 29.9 29.9 30.2 30.2 30.9 32.3
39	28.8 30.3 31.4 31.5 31.6 31.6 31.6 31.6 31.6 31.7
40	31.8 32.1 32.2 32.3 32.4 32.5 32.5 32.6 32.6 32.7 35.4
41	32.9 35.5 36.3 36.4 36.4 36.7 36.8 36.8 36.9 37.0 37.1 37.2 37.5 38.9 39.4
42	34.6 37.2 38.5 39.0 39.3 39.8 40.7
43	39.3 39.4 39.5 40.5 40.9 41.8
44	43.5 43.9 44.2 45.8 45.8 46.4

Carapace length (nearest mm) ♀	Weight ♀ (nearest 0.1 gm)
36	24.6 24.7
37	28.4
38	28.8
39	30.9 31.2
40	26.9 30.2 31.4
41	31.2 35.4 36.7 38.0 38.4
42	35.4 36.4 38.1
43	36.3 38.2 38.9 39.0 39.1 37.2 39.2
44	38.0 38.9 38.9 39.0 40.9 41.6
45	40.9 42.8 44.4 45.8
46	40.3 41.4 41.6 42.8 43.0 44.8 45.7 47.5
47	45.0 46.7 46.8 46.8 47.8 47.8 48.4 49.9
48	43.8 47.8 48.6 49.2 50.1 53.6 57.5
49	50.0 50.3 50.4 54.1 54.9 54.9 54.9
50	56.9 57.4 57.9 59.5 60.2
51	56.2 57.5 58.1 58.8 58.8 59.0 59.1
52	62.5 63.4 63.4 64.5 64.5
53	64.5 66.0 66.1
54	67.6
55	64.6 69.9 70.5 71.2 72.0
56	74.1 75.2
57	76.3 77.5 79.4 80.0
58	83.3 84.5 86.2
59	88.9 89.1

APPENDIX F

Catch per unit effort (numbers trawled per hour) in the Spencer Gulf Fishery

The numbers of prawns trawled per hour of fishing in the Spencer Gulf Fishery are shown in Table F1.

Observed and predicted catch per unit effort, and catchability ratios in the Spencer Gulf prawn fishing are shown in Tables F2 to F10.

TABLE F1 CATCH PER UNIT EFFORT (NUMBERS TRAWLED PER HOUR) IN THE SPENCER GULF FISHERY

	1968	1969	1970	1971	1972	1973	1974	1975	1976
Jan	3030	3163	3356	2044	3526	3600	2437	2444	3207
Feb	2500	2533	2840	4687	4447	5747	4721	2267	3780
Mar	4914	2494	4550	5358	4278	4969	5593	2778	4481
Apr	5096	2807	3943	4181	3012	3277	4265	1772	2721
May	4347	2360	2443	2125	1817	2365	2221	1129	
Jun	2362	1406	2390	1656	1566	1703	1277	835	
Jul	1689	2121	1091	1049	1591	1379	1136	640	
Aug	1594	1310	873	1085	1290	1456	1459	544	
Sep	2037	1540	889	1080	876	1651	1439	550	
Oct	1535	1378	1127	1411	1229	2051	1336	683	
Nov	2534	1573	1378	2176	1687	2069	1801	889	
Dec	2458	1992	2197	2841	1763	2272	1894	1007	

OBSERVED AND PREDICTED CATCH PER UNIT EFFORT, AND CATCHABILITY RATIOS IN THE SPENCER GULF PRAWN FISHERY

TABLE F2 - 1968

MONTH	C_{obs}	$C_t e^{-Zt}$	$\frac{q_t}{q_o}$	$\frac{q_t}{q_o} C_t d^{-Zt}$
Jan	3030			
Feb	2500			
Mar	4914			
Apr	5096	5096	1.0000	5096
May	4347	4612	0.7860	3671
Jun	2362	4174	0.6316	2636
Jul	1689	3777	0.5478	1873
Aug	1594	3418	0.5551	1898
Sep	2037	3094	0.7444	2303
Oct	1535	2800	0.8501	2380
Nov	2534	2534	1.0000	2534
Dec	2458	2293	1.0264	2354

TABLE F3 - 1969

Jan	3163			
Feb	2533			
Mar	2494			
Apr	2807	2807	1.0000	2807
May	2360	2584	0.7955	2055
Jun	1406	2378	0.6402	1523
Jul	2121	2189	0.7055	1544
Aug	1310	2015	0.7723	1556
Sep	1540	1855	0.8829	1638
Oct	1378	1707	1.0577	1806
Nov	1573	1572	1.0359	1628
Dec	1992	1447	1.0748	1555

TABLE F4 - 1970

MONTH	C_{obs}	$C_o e^{-Zt}$	$\frac{q_t}{q_o}$	$\frac{q_t}{q_o} C_t e^{-Zt}$
Jan	3356			
Feb	2840			
Mar	4550	4550	1.0000	4550
Apr	3943	3916	0.9334	3656
May	2443	3369	0.7827	2637
Jun	2390	2899	0.6675	1935
Jul	1091	2495	0.5746	1434
Aug	873	2147	0.5614	1205
Sep	889	1848	0.6675	1233
Oct	1127	1590	0.8613	1370
Nov	1378	1369	0.9505	1301
Dec	2197	1178	1.0276	1211

TABLE F5 - 1971

Jan	2044			
Feb	4687			
Mar	5358	5358	1.0000	5358
Apr	4181	4881	0.8583	4189
May	2125	4446	0.7102	3157
Jun	1655	4050	0.5693	2306
Jul	1049	3689	0.5284	1949
Aug	1085	3361	0.5223	1755
Sep	1081	3061	0.6710	2054
Oct	1411	2789	0.6922	1930
Nov	2176	2540	0.8543	2170
Dec	2841	2314	0.9933	2298

TABLE F6 - 1972

MONTH	C_{obs}	C_o	$\frac{q_t}{q_o}$	$\frac{q_t}{q_t}C_o e^{-Zt}$
Jan	3526			
Feb	4447	4447	1.0000	4447
Mar	4278	4054	0.8969	3636
Apr	3012	3695	0.8186	3025
May	1817	3369	0.6774	2282
Jun	1566	3071	0.5495	1688
Jul	1591	2800	0.4999	13999
Aug	1290	2552	0.5062	1292
Sep	876	2326	0.5906	1374
Oct	1229	2121	0.7833	1661
Nov	1687	1933	0.9008	1742
Dec	1763	1762	1.0103	1780

TABLE F7 - 1973

Jan	3600			
Feb	5747	5747	1.0000	5747
Mar	4969	5064	0.8681	4396
Apr	3277	4463	0.8160	3642
May	2365	3933	0.6723	2644
Jun	1703	3466	0.5409	1875
Jul	1379	3055	0.6043	1846
Aug	1456	2692	0.6144	1654
Sep	1651	2372	0.7130	1691
Oct	2051	2091	0.8859	1852
Nov	2069	1842	0.8499	1566
Dec	2272	1624	0.9564	1553

TABLE F8 - 1974

MONTH	C_{obs}	$C_o e^{-Zt}$	$\frac{q_t}{q_o}$	$\frac{q_t}{q_o} C_o e^{-Zt}$
Jan	2437			
Feb	4721			
Mar	5593	5593	1.0000	5593
Apr	4265	4946	0.8662	4285
May	2221	4375	0.7384	3231
Jun	1277	3869	0.5636	2181
Jul	1136	3422	0.5162	1767
Aug	1459	3026	0.6083	1841
Sep	1439	2677	0.6760	1809
Oct	1336	2367	0.7326	1734
Nov	1802	2094	0.8856	1854
Dec	1894	1852	0.9660	1788

TABLE F9 - 1975

Jan	2444			
Feb	2267			
Mar	2778	2778	1.0000	2778
Apr	1772	2409	0.9204	2217
May	1129	2090	0.8472	1770
Jun	835	1812	0.6376	1156
Jul	640	1572	0.6616	1040
Aug	544	1363	0.6254	853
Sep	550	1182	0.8520	1007
Oct	684	1025	0.6566	878
Nov	889	889	0.9796	871
Dec	1007	771	1.0948	844

TABLE F10

SUMS OF SQUARES OF THE DIFFERENCE BETWEEN OBSERVED AND PREDICTED CATCH PER UNIT EFFORT

	$(O - P_{\text{constant } q})^2$	$(O - P_{\text{variable } q})^2$	% reduction in sums of squares
1968	13786539.73	1454843.82	89.45%
1969	2002880.82	886415.52	55.74%
1970	6882455.8	1709269.4	75.16%
1971	29992808.61	4261714.75	85.79%
1972	11204854.14	1117680.30	90.03%
1973	12310956.75	1636509.05	86.71%
1974	22185586.04	2688734.14	87.88%
1975	4393733.75	1240727.11	71.76%
Mean % reduction			80.73%
All years combined	102759814.3	14995894.1	85.40%

APPENDIX G

Rainfall and evaporation over nursery areas of *Penaeus latisulcatus*

Table G1 shows the rainfall in mm from eight localities in the Northern Spencer Gulf region from 1967 to 1975.

Evaporation at Baroota (fig 22) is shown in Table G2.

Table G3 shows the rainfall in mm at Carnarvon (fig 6) on Shark Bay.

TABLE G1 RAINFALL OVER NORTHERN SPENCER GULF

Rainfall (mm)

1967	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Moonta	11	61	2	5	17	4	42	68	16	17	0	6
Wallaroo	16	59	1	7	16	4	27	65	17	5	0	5
Pt. Broughton	18	54	1	0	10	4	37	32	27	6	0	8
Pt. Pirie	38	50	2	3	13	4	25	27	15	3	2	4
Pt. Germein	24	41	0	0	25	12	19	28	16	5	0	6
Baroota	31	45	1	1	19	8	22	28	17	4	1	5
Pt. Augusta	18	49	0	3	16	5	14	18	18	8	1	4
Whyalla	30	55	3	15	15	5	19	13	14	2	0	5
1968												
Moonta	38	48	22	48	80	74	56	54	17	39	32	36
Wallaroo	24	66	20	31	71	79	56	44	12	34	26	27
Pt. Broughton	34	39	19	29	95	65	49	38	9	42	36	17
Pt. Pirie	48	12	4	32	72	72	33	54	12	44	51	12
Pt. Germein	55	13	4	42	57	57	31	55	11	39	49	7
Baroota	39	36	44	44	69	72	31	55	28	38	60	14
Pt. Augusta	32	35	7	56	41	71	31	17	14	16	33	3
Whyalla	63	21	15	26	29	71	38	18	10	16	42	5
1969												
Moonta	12	63	28	17	81	28	69	36	59	5	31	24
Wallaroo	8	65	26	16	86	27	54	34	52	5	21	31
Pt. Broughton	9	33	22	15	84	34	59	25	72	2	21	9
Pt. Pirie	10	39	13	21	99	33	43	24	62	15	35	6
Pt. Germein	11	36	17	28	111	25	47	45	49	16	20	4
Baroota	50	20	19	26	136	22	38	26	57	26	27	21
Pt. Augusta	26	10	33	9	35	17	40	11	22	39	11	4
Whyalla	17	56	44	20	37	14	39	38	30	7	27	8

Rainfall mm												
1967	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Moonta	13	5	5	37	37	30	28	50	70	7	27	30
Wallaroo	12	0	3	28	32	22	36	49	58	2	28	15
Pt. Broughton	18	0	1	36	36	28	24	15	92	6	18	22
Pt. Pirie	33	0	8	19	30	25	17	54	72	13	55	23
Pt. Germein	24	0	10	13	20	24	17	41	53	14	52	31
Baroota	17	0	16	12	21	30	17	49	79	42	120	54
Pt. Augusta	28	0	11	3	15	10	5	22	70	22	27	23
Whyalla	48	0	11	18	26	11	5	26	54	10	15	26
1971												
Moonta	5	0	50	48	66	52	44	45	39	9	47	30
Wallaroo	4	1	86	76	58	46	38	41	50	4	46	14
Pt. Broughton	2	1	36	118	59	65	74	29	51	10	57	14
Pt. Pirie	1	1	21	64	44	69	52	38	47	6	37	36
Pt. Germein	0	5	33	69	39	61	61	37	33	3	48	45
Baroota	0	6	21	74	21	77	75	34	45	4	48	42
Pt. Augusta	4	0	16	39	7	52	47	19	23	1	35	32
Whyalla	0	0	31	37	21	35	39	26	20	1	42	20
1972												
Moonta	45	62	0	29	11	14	55	71	22	14	8	2
Wallaroo	24	36	0	30	6	13	56	69	23	7	5	5
Pt. Broughton	11	47	0	16	2	8	51	57	22	16	7	6
Pt. Pirie	32	16	1	39	5	8	49	66	15	14	24	11
Pt. Germein	26	38	0	19	3	3	39	53	10	17	15	17
Baroota	33	27	0	30	8	4	52	39	11	24	20	11
Pt. Augusta	36	13	1	4	2	4	12	42	10	17	8	7
Whyalla	31	37	1	5	4	4	12	36	11	27	19	12

Rainfall mm

1973	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Moonta	8	66	38	28	42	86	57	63	22	43	15	24
Wallaroo	15	90	34	67	43	65	59	69	29	64	13	24
Pt. Broughton	23	96	27	18	21	61	54	60	28	73	10	12
Pt. Pirie	25	150	13	32	25	61	30	66	33	159	36	28
Pt. Germein	25	130	8	35	48	53	29	67	30	132	30	24
Baroota	34	139	12	37	48	55	36	89	34	113	32	28
Pt. Augusta	28	93	8	36	25	39	29	64	31	70	52	38
Whyalla	29	112	25	22	29	43	21	57	25	76	54	21
1974												
Moonta	18	37	7	45	87	11	37	20	40	97	9	4
Wallaroo	19	46	19	27	81	15	88	23	48	96	9	4
Pt. Broughton	49	71	5	72	110	12	82	12	52	89	5	1
Pt. Pirie	101	35	3	83	147	22	19	25	54	107	4	4
Pt. Germein	86	40	1	88	123	19	79	32	56	88	5	10
Baroota	103	23	1	72	116	31	75	33	64	111	7	1
Pt. Augusta	99	59	2	48	123	20	26	28	43	79	12	0
Whyalla	115	89	3	34	94	10	37	16	44	79	12	2
1975												
Moonta	13	3	26	9	37	2	73	24	69	79	19	17
Wallaroo	17	2	46	20	48	7	59	31	68	72	13	14
Pt. Broughton	13	2	23	19	32	1	45	27	65	92	18	13
Pt. Pirie	18	4	40	23	32	0	37	44	59	91	23	19
Pt. Germein	10	5	19	18	28	1	29	34	40	84	15	14
Baroota	30	2	16	20	32	1	34	49	32	112	11	26
Pt. Augusta	4	5	10	9	16	0	30	29	27	64	8	29
Whyalla	8	4	14	19	27	1	24	23	37	77	12	12

TABLE G2

MONTHLY EVAPORATION (mm) AT BAROOTA (fig. 22), NORTHERN SPENCER GULF

	J	F	M	A	M	J	J	A	S	O	N	D
1967	301	254	229	173	113	82	95	105	146	203	297	304
1968	302	262	230	186	87	62	63	97	140	230	249	319
1969	347	222	226	166	124	72	73	114	97	221	252	278
1970	283	278	214	167	104	116	118	107	151	247	262	284
1971	319	273	236	181	95	59	82	92	121	237	208	286
1972	258	276	246	198	133	120	114	109	211	223	262	347
1973	338	226	240	183	133	65	79	98	166	197	231	277
1974	264	201	208	86	78	69	79	87	120	164	228	295
1975	303	278	223	194	143	86	133	98	134	156	265	287

TABLE G.3

RAINFALL OVER CARNARVON, SHARK BAY

Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
1960	2	88	78	2	29	3	95	2	8	1	0	0	308
1961	14	35	24	25	9	46	10	22	1	3	0	0	189
1962	157	9	0	2	64	10	21	1	1	11	0	*	276
1963	157	67	*	41	143	45	96	5	2	0	*	0	556
1964	0	0	93	2	1	56	59	21	5	2	1	0	240
1965	2	0	25	4	25	161	99	45	3	3	4	*	371
1966	0	0	1	8	3	27	18	9	5	3	*	1	75
1967	117	29	14	4	44	46	8	36	*	1	0	0	299
1968	6	0	6	18	13	55	18	3	3	5	0	1	128
1969	0	0	0	9	36	39	3	*	4	0	1	1	93
1970	1	149	0	32	60	25	7	4	9	2	0	4	293
1971	42	3	21	0	17	18	140	38	1	10	1	1	292
1972	0	0	0	0	71	97	107	21	3	4	0	0	303
1973	1	1	3	4	22	23	44	19	4	1	*	*	122
1974	19	2	20	12	70	31	180	32	1	28	0	*	395
1975	0	110	24	89	14	67	41	10	10	38	81	1	485
1976	6	-	-	-	-	-	-	-	-	-	-	-	-

* = Rainfall between 0.1 and 0.4 mm

APPENDIX H

Osmotic Concentrations in the Haemolymph of juvenile *Penaeus Latisulcatus*

The replicate haemolymph freezing point depressions (Δ) of each juvenile prawn are represented in each row of table H1. The salinity and freezing point depression of the medium in which the various groups of prawns were held in the laboratory are also recorded. Rows marked * represent the replicate Δs of the haemolymph of wild prawns. All other determinations were made on cultured prawns.

TABLE H1

FREEZING POINT DEPRESSIONS (Δ) OF THE HAEMOLYMPH OF JUVENILE *PENAEUS LATISULCATUS*

Salinity of medium	Δ of medium °C	replicate Δs of haemolymph					mean Δ of haemolymph for each prawn
		2	3	4	5	6	
10‰	0.535	1.240	1.255	1.240	1.240	1.225	1.240
		1.365	1.260	1.270	1.270	1.265	1.270
		1.300	1.295	1.300	1.300	1.295	1.298
15‰	0.786	1.320	1.325	1.325	1.325	1.320	1.323
		1.255	1.260	1.255	1.255	1.260	1.257
		*1.325	1.330	1.330	1.330	1.330	1.329
19.6‰	0.990	1.275	1.185	1.295	1.305	1.185	1.249
		1.325	1.275	1.275	1.275	1.300	1.290
		1.330	1.210	1.210	1.400	1.340	1.298
		1.300	1.280	1.295	1.280	1.295	1.290
		1.360	1.355	1.355	1.345	1.360	1.355
		1.165	1.165	1.185	1.165	1.270	1.190
		1.380	1.585	1.370	1.370	1.370	1.415
		1.445	1.445	1.430	1.400	1.400	1.424
20‰	1.010	1.440	1.420	1.420	1.420	1.420	1.424
		1.445	1.435	1.420	1.400	1.435	1.437
		1.395	1.400	1.395	1.380	1.380	1.390
24.5‰	1.230	1.475	1.490	1.490	1.475	1.475	1.481
		1.495	1.500	1.490	1.490	1.490	1.493
		1.350	1.370	1.350	1.350	1.350	1.354
		1.655	1.600	1.580	1.580	1.600	1.603

Salinity of medium	Δ of medium	replicate Δs of haemolymph					Mean Δ of haemolymph for each prawn
		2	3	4	5	6	
47.5‰	2.475	2.140	2.140	2.135	2.135	2.135	2.137
		2.160	2.155	2.165	2.165	2.165	2.162
		2.150	2.110	2.110	2.110	2.110	2.118
		2.120	2.100	2.000	2.010	2.010	2.048
		*2.170	2.170	2.170	2.170	2.170	2.170
54.0‰	2.795	2.430	2.430	2.430	2.435	2.445	2.434
		2.365	2.330	2.315	2.315	2.315	2.328
		*2.400	2.405	2.410	2.390	2.405	2.402
59.0‰	3.125	2.550	2.550	2.550	2.550	2.550	2.550
		2.620	2.625	2.625	2.620	2.620	2.622
		2.505	2.500	2.500	2.510	2.500	2.503
63.0‰	3.280	2.700	2.825	2.800	2.740	2.700	2.753
		2.950	2.950	2.905	2.900	2.900	2.921
		*2.705	2.705	2.705	2.705	2.705	2.705
		*2.800	2.805	2.815	2.805	2.815	2.808
67.5‰	3.540	3.020	3.020	3.020	3.020	3.020	3.020
		3.140	3.140	3.140	3.140	3.140	3.140
		2.945	2.945	2.945	2.945	2.945	2.945
70.0‰	3.700	3.325	3.325	3.325	3.330	3.330	3.327
		3.325	3.325	3.330	3.335	3.335	3.330
		*3.2-3	3.260	3.260	3.265	3.265	3.265

Salinity of medium	Δ of medium	replicate Δs of haemolymph					Mean Δ of haemolymph for each prawn
		2	3	4	5	6	
27.5‰	1.450	1.460	1.460	1.445	1.460	1.445	1.454
		1.460	1.460	1.445	1.445	1.460	1.454
		1.670	1.590	1.600	1.590	1.670	1.624
		1.570	1.520	1.565	1.570	1.570	1.559
		1.510	1.535	1.460	1.470	1.455	1.486
		1.720	1.715	1.700	1.725	1.700	1.712
30.0‰	1.580	1.540	1.540	1.535	1.540	1.540	1.539
		1.750	1.700	1.690	1.680	1.645	1.693
35.0‰	1.820	1.680	1.680	1.660	1.675	1.675	1.674
		1.645	1.640	1.645	1.635	1.645	1.642
36.0‰	1.900	1.800	1.830	1.830	1.830	2.000	1.858
		1.750	1.755	1.750	1.750	1.750	1.751
		1.645	1.645	1.650	1.650	1.650	1.648
		*1.735	1.740	1.740	1.735	1.735	1,737
		*1.800	1.800	1.805	1.805	1.805	1.803
		*1.755	1.755	1.755	1.755	1.755	1.755
		*1.890	1.690	1.695	1.695	1.690	1.692
		*1.770	1.765	1.775	1.765	1.765	1.768
40‰	2.105	1.995	1.995	1.990	1.995	1.995	1.994
		2.030	2.030	2.030	2.020	2.030	2.028
		2.050	2.030	2.030	2.030	2.030	2.034
		1.880	1.880	1.880	1.880	1.880	1.880
		1.920	1.900	1.900	1.900	1.900	1.904
		*1.970	1.970	1.970	1.990	1.970	1.974
		*1.895	1.925	1.955	1.960	1.920	1.931
42.5‰	2.230	1.875	1.870	1.870	1.875	1.870	1.872
		1.995	2.000	2.005	2.000	2.000	2.000
		2.045	2.045	2.040	2.040	2.040	2.042
		*1.975	1.985	1.985	1.985	1.985	1.983
		*1.955	1.963	1.965	1.955	1.960	1.960

APPENDIX I

CONCENTRATION OF IONS IN THE HAEMOLYMPH OF JUVENILE *PENAEUS LATISULCATUS*

In the following tables the concentrations of Sodium, Potassium, Calcium and Magnesium in the haemolymph of juvenile *P. latisulcatus* are recorded. Concentrations are in parts per million (ppm - equivalent to mg/ml) and each row in the tables represents the concentrations of each ion in the haemolymph of each individual prawn.

TABLE I.1

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 11.5‰

Prawn Number	Concentration (mg/ml)			
	Na$^+$	K$^+$	Ca^{++}	Mg^{++}
1	5622.4	288.650	648.333	135.038
2	6149.5	365.205	843.360	149.596
3	6751.9	311.491	607.169	191.262
4	4367.4	200.298	747.980	133.030
5	5145.5	332.324	567.009	189.254
6	6852.3	264.805	582.571	173.692
7	6526.0	378.006	561.738	236.944
8	6149.5	591.356	596.376	204.063
9	8734.8	622.891	656.867	137.548
10	7781.0	326.551	458.577	149.345

TABLE I.2

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 12.5‰

Prawn Number	Na$^+$	K$^+$	Ca^{++}	Mg^{++}
11	6827.2	356.671	822.143	80.320
12	7730.8	389.301	604.978	109.436
13	5296.1	358.177	490.365	102.659
14	7053.1	274.845	712.661	101.906
15	6626.4	558.224	712.404	118.974
16	7228.8	331.320	607.548	116.966

TABLE I3

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 16.0‰

Prawn Number	Na^+	K^+	Ca^{++}	Mg^{++}
17		396.329	639.159	143.823
18	7128.40	459.832	623.739	177.708
19	6977.80	361.189	1186.862	131.775
20	9061.10	359.181	939.335	58.734
21	6124.40	307.726	810.716	125.500
22	7479.00	341.862	478.791	111.193
23	7279.00	377.253	511.687	55.973
24	7028.00	319.061	484.959	130.520
25	5095.30	542.662	442.811	310.087

TABLE I4

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 28.5‰

	Na^+	K^+	Ca^{++}	Mg^{++}
26	9633.4	129.014	302.957	69.778
27	6049.1	484.932	1092.352	174.194
28	10014.9	404.361	927.454	190.760
29	8107.3	386.791	778.100	109.436
30	7580.2	202.557	504.259	61.244
31	9512.9	369.723	939.493	181.724
32	9337.2	308.730	915.146	184.485
33	6174.6	327.304	792.658	165.158
34		499.992	1041.650	161.644
35	10190.6	511.789	1112.934	231.673
36	8810.1	674.186	940.246	367.966
37	7103.3	430.967	914.644	232.426
38	7304.1	587.340	917.656	242.717
39	7881.4	399.090	869.715	185.740

TABLE I4 (CONTD)

Prawn number	Na^+	K^+	Ca^{++}	Mg^{++}
40	7981.8	348.137	1137.030	367.464
41	10567.1	394.572	1180.453	170.178
42	9839.2	472.884	1003.498	288.901
43	9688.6	461.840	1034.873	264.303
44	8609.3	330.065	699.035	241.462
45	10993.8	333.328	680.963	224.645
46	9989.8	352.655	1026.849	146.082

TABLE I5

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 31.5‰

Prawn number	Na^+	K^+	Ca^{++}	Mg^{++}
47	10014.9	386.791	741.454	150.349
48	10165.5	526.347	1116.197	71.033
49	10115.3	334.583	1149.018	115.118
50	8709.7	518.315	841.603	251.000
51	10065.1	312.746	814.997	162.146
52	10265.9	529.108	873.229	182.728
53	9789.0	463.095	861.908	121.735
54	9337.2	403.859	1050.937	154.365
55	9111.3	389.050	801.694	185.999
56	9186.6	448.788	853.400	156.122

TABLE I6

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 34.5‰

Prawn Number	Na^+	K^+	Ca^{++}	Mg^{++}
57	10943.6	285.387	1700.023	107.428
58	8835.2	426.951	679.708	92.870
59	8960.7	436.238	864.193	251.000

TABLE 16 (CONTD)

Prawn number	Na^+	K^+	Ca^{++}	Mg^{++}
60	9538.0	530.112	830.308	182.477
61	10240.8	356.428	932.465	145.580
62	7089.0	319.978	633.840	90.072
63	10165.5	504.761	1012.032	271.080
64	11730.6	544.921	927.804	232.408

TABLE 17

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 39.0‰

Prawn Number	Na^+	K^+	Ca^{++}	Mg^{++}
65	12926.5	561.487	1262.384	457.871
66	11094.2	473.385	1069.634	357.674
67	8508.9	472.131	717.801	265.307
68	8283.0	459.581	731.679	521.076
69	10592.2	467.362	904.126	387.042

TABLE 18

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 39.5‰

Prawn Number	Na^+	K^+	Ca^{++}	Mg^{++}
70	1094.2	411.640	820.087	740.45
71				793.411
72	11671.5	426.951	1015.664	222.135
73	12725.7	466.358	895.131	284.885
74	9211.7	395.827	1004.099	794.164
75	10265.9	333.328	881.767	158.632
76	8182.6	413.899	764.832	169.927
77	12750.8	607.671	1630.773	530.363
78	11197.8	539.650	950.386	217.366

TABLE I9

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 41.5‰

Prawn number	Na$^+$	K$^+$	Ca^{++}	Mg^{++}
79	11972.7	423.939	1026.458	168.170
80	12123.3	587.842	900.528	238.952
81	12675.5	480.163	870.459	168.672
82		622.480	1043.934	251.000
83	8985.8	544.670	922.887	358.930
84	9236.8	417.413	1085.311	119.962
85	10968.7	498.486	968.119	249.494
86	11797.0	528.355	867.118	217.115
87	12575.1	653.102	895.902	
88	9989.8	521.829	1224.091	
89	10793.0	724.135	1088.652	410.134
90	11144.4	314.503	786.163	189.505

TABLE I.10

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 44.0‰

Prawn number	Na$^+$	K$^+$	Ca^{++}	Mg^{++}
91	11395.4	431.469	947.045	186.242
92	11044.0	594.117	876.884	419.170
93	12248.8	537.813	1338.970	382.775
94	11194.6	489.450	1064.237	158.883
95	8257.9	451.298	964.521	563.746
96	12876.3	538.144	1091.479	246.984
97	12073.1	476.147	895.388	223.139
98	12725.7	463.597	945.760	140.560
99	12098.2	694.015	997.674	600.141
100				271.182

TABLE I.10 (CONTD)

Prawn number	Na^+	K^+	Ca^{++}	Mg^{++}
101	13503.8	734.677	1121.548	293.670
102	10692.6	489.450	1079.657	199.294
103	12625.3	663.142	1006.155	317.504
104	11094.2	565.754	1222.549	322.535

TABLE I.11

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 50.5‰

Prawn Number	Na^+	K^+	Ca^{++}	Mg^{++}
105	11922.5	579.057	1184.971	646.074
106	12399.4	499.992	1188.368	155.118
107	11711.9	596.627	1009.753	184.736
108	11646.4	630.261	1171.663	794.164
109	12324.1	606.918	874.057	171.935
110	12499.8	555.463	1191.709	150.600
111	11646.4	608.926	897.187	169.425
112	10315.1	621.721	930.340	144.325
113	12801.0	587.842	1050.102	163.401
114	11044.0	724.637	1198.648	306.471

TABLE I.12

IONIC CONCENTRATIONS IN THE HAEMOLYMPH OF JUVENILE *P. LATISULCATUS* EXPOSED TO 65.5‰

Prawn number	Na^+	K^+	Ca^{++}	Mg^{++}
115	13303.0	573.786	1423.266	793.913
116	15762.8	604.910	1225.633	770.319
117	14332.1	675.441	1093.535	229.414
118	12750.8	851.894	1058.583	794.164

TABLE I.12 (CONTD)

Prawn Number	Na^+	K^+	Ca^{++}	Mg^{++}
119	13654.4	576.296	1081.713	275.347
120	14156.4	637.289	794.901	794.164
121	12826.1	702.298	1102.016	268.319
122	11420.5	599.639	1005.384	141.313
123	11771.9	524.088	1215.096	230.669
124	11746.8	1042.905	1120.263	794.164