Southern Calamary (*Sepioteuthis australis*) Fishery

Report to PIRSA

MA Steer, MT Lloyd and WB Jackson

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1. EXECUTIVE SUMMARY

1. This fishery assessment report updates the 2006 report and assesses the status of South Australia's calamary resource.

2. Calamary are harvested by the commercial and recreational sectors of the Marine Scalefish Fishery, and the South Australian prawn fisheries. Their respective contributions to the State-wide catch are: 62, 30 and 7.5% by total harvested weight and; 44, 21 and 35% by total number of individuals harvested.

3. Assessment of the status of calamary stocks relies heavily on the regional estimates of commercial catch and effort and associated derived estimates of CPUE. Estimates of targeted jig effort and associated CPUE provide the only estimates of relative abundance. The lack of quantitative catch and effort data from the recreational sector increases the uncertainty around estimates of total catch.

4. A total of 298.9 t of calamary were landed by the commercial sector in 2006. This was 59.0 t less than the previous year, representing a decrease of 16.5%.

5. Total targeted jig effort increased 10.4% from the previous year, but has remained below 8,000 fisher days per year, a level similar to that observed in the early 1990's when the fishery was developing.

6. CPUE in 2006 was 28.6 kg.fisher day^{-1}, which was 19.4% below CPUE in 2005. Despite this downward shift, catch rates remained moderately high in the major fishing regions, suggesting that calamary were relatively abundant in 2006.

7. The limit reference point for greatest 3-year trend in catch was breeched during 2006. State-wide commercial catch declined at a rate of 82.9 t per year, but the significance of this decline is uncertain due to high inter-annual variability in total catch.

8. The estimated calamary catch from the Gulf St. Vincent prawn sector in the 2005/06 fishing season was 227,202 animals with an estimated total weight of 13.0 t, 56.8% less than in 2004/05. Trawl effort had also declined 28.3%. It was estimated that trawlers caught calamary at a rate of 1.54 animals/min in 2005/06, 39.8% less than in 2004/05.

9. Commercial catch rates from the inshore MSF were strongly correlated with estimates of pre-recruit abundance two months prior, suggesting that the use of fishery-independent trawl data may provide a means of forecasting inshore recruitment. It is also a relative cost-effective method and has potential as an integrated fisheries management tool.

10. Continued fishery-independent trawl surveys are required to assess the stability of the established pre-recruit index as it is currently based on a limited time-series.

11. This report provides evidence that South Australia's calamary fishery is being harvested within sustainable limits.

2. INTRODUCTION

2.1. Overview

This is the seventh assessment of the South Australian calamary fishery since 1997. This is a 'living' document that constitutes part of the ongoing assessment of South Australia's Marine Scalefish Fishery by SARDI Aquatic Sciences. The aim of this report is: (1) to present information on the fishery and biology of the species and; (2) to synthesise the information into an assessment of the status of the stocks up to the time for which data are available. This report presents commercial fishery data and biological data collected up to December 2006.

This report is partitioned into eight chapters. The introduction, outlines the structure and content of the report, provides a description of the calamary fishery, a summary of the management regulations that relate to it, a summary of information on the recreational catch and effort for calamary in South Australia, as well as a review of the population dynamics and life history of the species.

Chapter three summarises commercial fishery data from 1984 to the end of 2006, presented as State-wide and regional trends of fishery catch and effort. This includes a detailed assessment of the regional estimates of catch and effort for the two main gear types of squid jigs and haul nets for each of the seven main fishery regions.

Chapter four summarises the data on the catch of calamary taken as 'by-product' by South Australia's Western King prawn fisheries and presents the results of structured, fishery-independent, trawl surveys.

Chapter five presents the results of a fishery-independent research program that was initiated in November 2004 and completed in December 2006. The primary objectives of this research were to describe the spatial and temporal patterns in calamary population structure and the seasonality of maturation and reproduction.

Chapter six synthesises the fishery-independent data and assesses the feasibility of using it, along with environmental information, as a means of forecasting recruitment strength in the commercial marine scalefish calamary fishery.

In Chapter seven, the performance of the fishery is assessed against the recently revised performance indicators that are specified in the minutes of the Marine Scalefish Fishery Management Committee meeting No. 99.

The final chapter summarises the data that were presented in chapters three to seven, describes the current status of the fishery, identifies the uncertainty associated with the assessment and identifies future research needs.

2.2. Description of fishery

Over the past three decades, worldwide squid landings have increased dramatically (Food and Agriculture Organisation (FAO) FishStat, 2004). This has been largely a result of fishers satisfying the market's high demand for seafood in the face of declining finfish stocks (Caddy and Rodhouse 1998). Consequently, many commercial fishers have redistributed their effort by expanding trawling grounds, maximising cephalopod by-catch, or directly targeting squid with purpose-built equipment (Rathjen 1991).

The southern calamary (*Sepioteuthis australis*) is the most common squid species in southern Australian inshore waters. It is a key component of the marine ecosystem as a primary consumer of crustaceans and fishes, and as a food source for a variety of predatory species (Coleman 1984; Gales et al. 1994). Like many other inshore squid species, calamary is of increasing commercial significance, contributing to multi-species, marine fisheries in all southern Australian states, particularly South Australia and Tasmania.

The South Australian fishery began developing in the early-mid 1970's when calamary were taken as a by-product of the net sector of the Marine Scalefish fishery and the prawn fisheries. The majority of the catch was in poor condition and was sold as bait, but a proportion was sold to the public in response to increasing commercial demand and market prices. The late 1970's saw an increase in catch and effort and by 1979/80 total catch had increased 4–fold to 193 t, with an estimated value of A$540,000. South Australia's Department of Primary Industries stated that *S. australis* was accepted on world markets and identified the Mediterranean countries as a potential export market. However, there was limited fisheries research to support such initiatives (Smith 1983). To date, southern calamary has been sold on local and national markets and there has been little international export interest.

Calamary are taken by commercial fishers in most shallow, coastal waters of South Australia using a variety of techniques. Most of the catch is landed by the hand jig and haul net sectors, however gill nets and dab nets are also used. Conventional 5–6 m fibreglass or aluminium vessels with high-powered (>60 hp) motors are typically used by the commercial and recreational fishers. However, recreational fishers also take calamary from jetties, breakwaters and other shore-based platforms. Prawn trawlers operating in deeper waters (> 10 m) of South Australia's

Gulf St. Vincent, Spencer Gulf and Far West Coast continue to take incidental catches of calamary, although the magnitude of this catch is largely unknown.

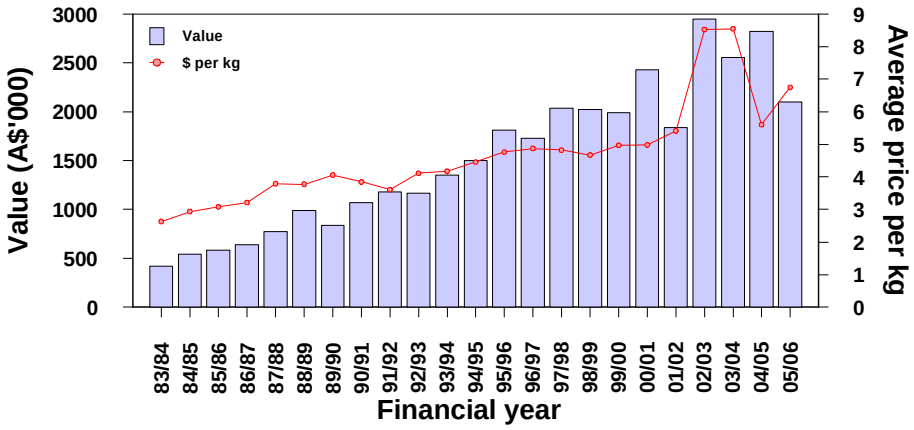

Figure 2.1. Annual market value and price per kg of the South Australian southern calamary fishery since 1983/84 financial year.

In June 2006, 349 fishers held a commercial marine scalefish fishing licence. Annual commercial landings of calamary by this sector peaked in 2000/01 at ~500 t that was worth an estimated A$2.5 million, making it Australia's largest calamary fishery (Fig. 2.1). Furthermore, calamary had become South Australia's third most valuable Marine Scalefish (MSF) species behind King George whiting (*Sillaginodes punctata*) and snapper (*Pagrus auratus*). Since then, the average price of calamary has increased by approximately A$3 per kg and, despite lower catches in 2002/03, the total value peaked in that year at an estimated A$3.0 million. All licensed MSF fishers are permitted to catch calamary, however many do not consider them a priority and concentrate their effort on other species. High market value (5–15 A$/kg), relatively low set-up costs, and open access to all fishers with a Marine Scalefish or rock lobster licence suggest that there is considerable latent effort and potential for the fishery to rapidly expand. This concern is exacerbated by the fishing effort from the recreational sector of the MSF and the prawn trawl fishery.

2.3. Recreational fishery

Since the production of the Marine Scalefish Green Paper (Jones et al. 1990) the understanding of the recreational catch and effort for calamary in South Australia has been substantially enhanced through the completion of two surveys: a creel survey through 1994 – 96 (McGlennon and Kinloch 1997); and the National Recreational and Indigenous Fishing Survey (NRIFS) for the period of May 2000 – April 2001 (Henry and Lyle 2003). A detailed breakdown of the results from these two surveys was presented in the previous calamary stock assessment report (Steer et

al. 2006). In the last survey, it was found that recreational fishers harvested a similar quantity of calamary to that of the commercial sector and accounted for approximately 48% of the State's catch (Henry and Lyle 2003). There has not been any on-going monitoring, which means that is unknown whether there have been any substantial changes in recreational catch and effort over the past six years, or whether recreational catches have reflected those of the commercial fishery.

2.4. Management regulations

In 1992, fisheries management raised concerns about the increasing popularity of calamary fishing by recreational and commercial fishers and the potential vulnerability of the spawning stocks (Marine Scalefish White Paper 1992). There were also reports of the illegal sale of calamary. These influences resulted in the implementation of recreational bag and boat limits in 1995 (i.e. 15 per bag/45 per boat per day). Input controls such as spatial and temporal closures and gear restrictions (minimum mesh size (30 mm) and lengths (600 m)) apply to the net sector, however these are generic measures rather than being specific to calamary (see Table 2.1). Restrictions currently prevent netting in all metropolitan waters and in waters greater than five metres deep, as well as in numerous bays and marine protected areas. Jigging is permitted in most State waters, with the exception of several aquatic reserves. In 2004, a permanent (effective until 31st December 2006) cephalopod fishing closure was implemented in False Bay, northern Spencer Gulf, to protect the annual spawning aggregation of the giant Australian cuttlefish *Sepia apama*. It is not known whether this spatial closure also provides some regional protection for spawning calamary.

Table 2.1. Chronology of management measures introduced into the Marine Scalefish fishery (1970 – 2004) adapted from Kumar et al. (1995) and Noell et al. (2006).

Date	Management policy
1970	Number of licences limited and classified (ie. A & B class)
Early 1970s	Commercial net fishery restricted to waters less than 5 m
1977	Freeze on commercial marine scalefish licences
1977–1982	Show cause provision – licence holders required to demonstrate a minimum level of involvement to qualify for renewal
1979	Removal of many licenses and owner-operated policy introduced
1980	Netting arrangements • Limit on total net length to 600 m for A class licence holders and 400 m for B class licence holders • Net could not be joined with another net • Net endorsements non-transferable • Freeze on issue of additional permits for use of nets • B class licence holders no longer entitled to use nets other than bait nets
1982	Non-transferability of net endorsements except in the case of family transfer
September 1982	Reclassification system of licenses (ie. M & B class)
1983	Inshore Fisheries Advisory Committee established; further aquatic reserves and restricted netting areas introduced
1992	New management controls introduced for snapper, King George whiting and calamary
September 1994	Licence amalgamation scheme initiated
November 1994	Net closures in regional centres implemented
May 1995	Recreational nets banned, more net closures for commercial fishers (area and season)
September 1995	Recreational bag and boat limits imposed for calamary
1998	First cuttlefish closure of Spencer Gulf spawning aggregation area implemented
2004	Full-time cephalopod fishing closure implemented in False Bay, Spencer Gulf
2005	Voluntary net buyback scheme. This culminated in the removal of 24 licences and 61 net endorsements. Additional areas closed to net fishing.

2.5. Performance Indicators and Limit reference points

In the last stock assessment for calamary, the performance of the fishery was assessed against the prescribed performance indicators and limit reference points outlined in the Management Plan for the Marine Scalefish Fishery (Noell et al. 2006). Since then, there has been a review of limit reference points that resulted in their further development. It was subsequently suggested that species-specific limit reference points would be more appropriate and that there should be a continuing emphasis on improving these limits as more information becomes available. It was agreed (MSFMC, Feb 2006) that the general limit reference points specified in the Fishery Management Plan (Noell et al. 2006), which apply to total commercial catch, targeted effort and targeted CPUE be replaced with the following:

- the 3rd highest and 3rd lowest values over the reference period (except the 3rd lowest value is not used to assess targeted effort);
- the greatest % interannual variation (±) over the reference period; and
- the greatest three, four or five year slope (or trend) (±) over the reference period, depending on the species.

The reference period for this assessment is the 22-year period from 1984 – 2005, inclusive. Due to the sub-annual lifespan of calamary the greatest three-year slope (trend) over the reference period was considered more appropriate than four- and five-year periods.

2.6. Biology of southern calamary

2.6.1. Distribution

The southern calamary (family: Loliginidae) is endemic to southern Australian and northern New Zealand waters. In southern Australia, its range is from Dampier in Western Australia to Moreton Bay in Queensland, including Tasmania. *S. australis* inhabits coastal waters and bays, usually in depths of less than 70 m (Winstanley et al. 1983).

2.6.2. Genetic stocks

Three different calamary 'genetic-types' were identified from southern Australian and northern New Zealand waters based on allozyme electrophoresis (Triantafillos and Adams 2001). In the 1990s all three genetic types were collected from South Australian waters and were categorised as 'peripheral', 'central' or 'hybrid' types. The 'peripheral' and 'hybrid' types were almost exclusively found around offshore islands of the Far West coast (e.g., Pearson and Flinders Islands), whereas the 'central' type dominated the gulf waters. Approximately 90% of South Australia's calamary catch is derived from gulf waters and further genetic analyses have confirmed that 99.5% of this catch consists of the 'central' genetic type.

2.6.3. Movement and Migration

Calamary are unevenly distributed with respect to size. Two fishery-independent studies have proposed generalised movement models where small (<30 mm mantle length (ML)) and large (>150 mm) individuals are predominately found in shallow, inshore waters, whereas the deeper, offshore waters are occupied by small to medium individuals (Smith 1983; Triantafillos 2001). Such spatial segregation is common within the loliginids, as is having offshore nursery and inshore spawning grounds (Sauer 1995). The distribution and abundance patterns of adult calamary in Gulf St. Vincent were found to be highly variable, varying both temporally and spatially but conforming to a seasonal, systematic pattern that was consistent amongst years (Triantafillos 2001). Adult abundance typically increased for six months, peaked and declined for the remainder of the year. The timing of the peak varied among regions, following an anti-clockwise direction around Gulf St. Vincent, from Kangaroo Island in late spring to Edithburgh

during late winter (Fig. 2.3). Spawning behaviour and the spatially different seasonal patterns in water clarity may account for this anti-clockwise progression (Triantafillos 2001).

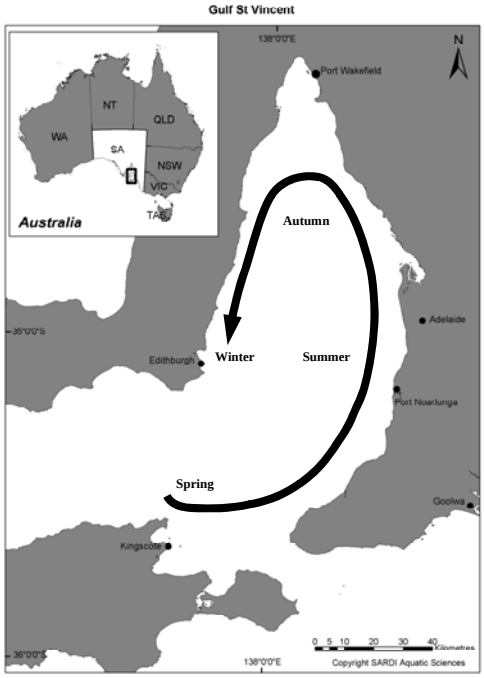

Figure 2.3. The seasonal anti-clockwise progression of adult abundance in South Australia's Gulf St. Vincent (adapted from Triantafillos 1997).

Acoustic telemetry has recently been used to track the movement of squid on Tasmanian spawning grounds (Pecl et al. 2006). Forty-six individuals were fitted with acoustic transmitters and tracked for up to 129 days. A total of 83 passive acoustic receivers were systematically deployed around known spawning areas. Results indicated that individuals travel 100s of km over the spawning period visiting several different spawning beds within a defined area.

2.6.4. Age and Growth

To date, three techniques have been used to determine age and growth of southern calamary: (1) length frequency analysis (Smith 1983), (2) direct measurements from tag-recapture experiments (Smith 1983), and (3) statolith increment analysis (Triantafillos 2001; Pecl 2001; Moltschaniwskyj et al. 2003). One study has validated the one-day equals one-ring relationship in statoliths (Fig. 2.4) for summer-reared calamary (Pecl 2000; 2004). Triantafillos (2001) compared all three techniques and found clear differences in growth estimates, with statolith analysis considered the most accurate. Length-frequency analysis under-estimated growth rates and over-estimated

longevity and was considered inappropriate for estimating calamary growth. Length-frequency analysis cannot resolve the large variation in growth rates and delineate 'micro-cohorts', which are characteristic of most populations (Caddy 1983; Jackson et al., 2000; Jackson and Pecl 2003).

Significant gender differences in growth rates were found for South Australian calamary, where males grew faster and attained larger sizes (Triantafillos 2001). This pattern was consistent among locations and hatching seasons. Water temperature also significantly affected growth rates, where individuals that hatched in autumn grew the slowest and those hatched in spring the fastest. Such plastic growth is well documented for cephalopods and is suggested to be governed by a combination of factors including; temperature (Forsythe 1993), prey availability (Brodziak and Macy 1996), population density (Dawe 1988), sexual maturation (Moltschaniwskyj 1995) and genetics (Triantafillos 2004). Calamary growth was best characterised by non-asymptotic power functions and their longevity was found to be sub-annual, with them living a maximum of 280 days (Triantafillos 2001). These results are similar to the estimated age and growth functions for Tasmanian calamary (Pecl 2000). Furthermore, the growth patterns are similar to the majority of other large loliginids worldwide, which all conform to the 'live-fast, die-young' lifestyle (Jackson and Choat 1992; Arkhipkin 1995; Jackson 2004).

Figure 2.4. A transverse section of a calamary statolith, illuminated with transmitted light and magnified 400x. Note the fine alternating dark and light bands for which one sequence of a dark and light band represents one day.

2.6.5. Reproductive Biology

Like all cephalopods, southern calamary have separate sexes (gonochoristic). Maturation in females is principally a process of oocyte development, through the accumulation of large quantities of lipoprotein yolk, and the enlargement of accessory reproductive organs, namely the nidamental and oviducal glands. In mature males, spermatozoa are packaged into spermatophores that are stored in a spermatophoric (Needham's) sac. Courtship and mating is

behaviourally complex, but essentially involves the transfer of mature spermatophores from the male to the female using a modified arm (hectocotylus). Females store sperm inside their buccal membrane in spermathecae and are capable of mating multiple times with numerous males before fertilising the eggs and spawning.

Macroscopic examination of reproductive organs from wild-caught female calamary suggests a reproductive mode that involves multiple spawning events, where females lay a series of clutches over an extended spawning season (Pecl 2000; Triantafillos 2001). These findings were consistent with those for other loliginids (eg *Loligo vulgaris reynaudii, L. forbesi*) and were largely based on observations of: low gonadosomatic indices; the heavier weight of the ovary relative to the oviduct; sustained feeding activity of mature animals; and the relatively poor correlation between body size and oviduct fullness (reviewed in Rocha et al. 2001). Further histological analysis by Pecl (2001) revealed continuous egg production in mature individuals, a characteristic synonymous with other multiple spawning cephalopods (Lewis and Choat 1993; Moltschaniwskyj 1995). Such serial spawning confounds fecundity estimates as it is difficult to accurately quantify the number and sizes of clutches laid by individual females, the duration between clutches and the number of residual, unspawned eggs at death.

Calamary egg masses are typical of loliginid squid, where females package <10 longitudinally-aligned eggs within a protective, digitate strand. Females have the capacity to store sperm from a variety of males. Therefore, an individual egg strand may display considerable genetic diversity through multiple paternities (van Camp et al. 2005). Each female is capable of laying a series of egg strands, individually attaching each one to a common holdfast to form a discrete egg mass (Fig. 2.5). Numerous females can contribute to a single egg mass (Jantzen and Havenhand 2002), and therefore increase both its overall size and density. There is evidence to suggest that calamary preferentially attach eggs to seagrass (eg., *Amphibolis* spp.) and macroalgae (eg., *Cystophora* spp., *Sargassum* spp.), however they are also known to lay eggs on low relief rocky reefs and on sand (Triantafillos 2001). Visual surveys of egg masses, back-calculated hatching dates and the presence of reproductively-mature adults indicate spawning occurs in inshore waters throughout the year, a strategy which provides a 'conveyor belt' of recruits (Jackson and Pecl 2003; Moltschaniwskyj and Pecl, 2006). Most animals caught offshore are sexually immature, which supports the hypothesis that such waters act as a nursery ground. Size-at-maturity varied among individuals, ranging from 132 to 215 mm ML for females and 117 to 185 mm ML for males, whilst age-at-maturity ranged from 148 to 201 days for females and 151 to 164 days for males (Triantafillos 2001).

The temporal and spatial distribution of spawning activity conformed to the anti-clockwise trend observed for adult abundance in GSV; egg densities were highest in the southeast in spring and in the west the following winter (Triantafillos 2001). Spawning aggregations, however, were found to be an order of magnitude larger on the eastern side of Gulf St. Vincent than on the western side. It was hypothesised that this pattern is a consequence of the adults requiring a certain temperature range and clear water for their visually-orientated, mating behaviour (see Jantzen and Havenhand 2003a; 2003b), egg deposition and subsequent embryonic development (Triantafillos 2001).

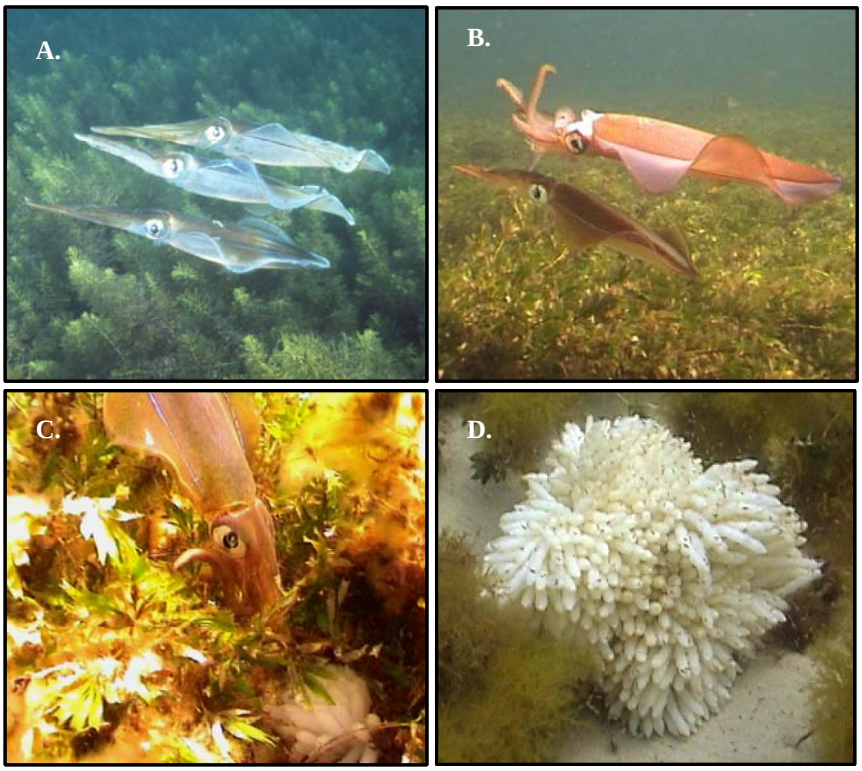

Figure 2.5. A. Southern calamary, *Sepioteuthis australis*. B. Typical mating position. C. Female depositing eggs. D. Calamary egg mass composed of numerous egg strands (Photos courtesy of Dr. T. Jantzen, Flinders University, South Australia).

2.6.6. Early Life History

Loliginid squid differ fundamentally from fish, as they do not have a true larval phase (Young and Harman 1988). Instead, they undergo direct embryonic development within well-protected egg capsules to hatch as structurally and functionally adept 'paralarvae' (Boyle et al. 2001; Steer et al. 2002). Consequently, some of the risks associated with a planktonic life history phase are reduced, resulting in a higher rate of early survivorship compared with marine fishes (Caddy 1983). Embryonic development is a lengthy process that comprises up to 30% of the total life

span (Boletzky 1987). Development rates range from 61 days at 13°C (Steer et al. 2003b) to 31 days at 20°C with hatching rates declining significantly with increasing temperature (Triantafillos 2001). This suggests that water temperatures greater than 20°C approximate the upper thermal limit for egg development. An extensive Tasmanian field study quantified embryo mortality rates to range between 2 to 25% (Steer 2004). The observed rates were highly variable, both spatially and temporally, and were relatively unaffected by natural temperature fluctuations, which remained within the range of 11 to 21°C. Changes in salinity were also found to be highly deleterious for *Loligo gahi* embryos (Cinti et al. 2004). As such, this suggests that rapid changes as a result of heavy rainfall and subsequent runoff may contribute to mortality of the eggs of *S. australis* (Steer et al. 2002). Furthermore, the structure of calamary egg masses were found to constrain development, with embryos located deep within an aggregated mass suffering higher rates of mortality and abnormal development than those located around the periphery (Gowland et al. 2002; Steer et al. 2002; 2003b; 2006). This was attributed to the inability of the deeper embryos to adequately respire and eliminate metabolic wastes.

Calamary egg masses are conspicuous and potentially vulnerable to predation, however there is little evidence of predation in the field. Egg masses harbour a variety of commensal species, namely gastropods, isopods, amphipods and echinoderms but these species were preferentially fed on the associated epibiota rather than the actual egg mass (Steer pers. obs.). A series of feeding studies done in the laboratory and field found that calamary egg masses deterred a variety of predatory invertebrates, suggesting that the protective layers of the strand have chemical properties that render them unpalatable (Benkendorff 1999). Incidental accounts of egg predation have been documented for other loliginid species. For example, small sparids (*Spondyliosoma emarginatum*) have been observed to nibble the tips of *L. vulgaris reynaudii*'s egg strands (Sauer and Smale 1993) and capitellid polychaetes consume the protective layer of *L. opalescens* eggs (Qian and Chia 1991). Nevertheless, in general, egg predation appears to be negligible.

Embryos hatch at night, reducing the risk of predation on the hatchlings by visual predators. Once hatched, paralarvae are photopositive and actively swim to the surface (Smith 1983), however it is unknown how long they remain there. Plankton tows in Gulf St. Vincent in December 1998 and 2000, suggested that newly hatched paralarvae remain on the spawning grounds and become benthic when they reach approximately 8 mm mantle length (Triantafillos 2001). New hatchlings rely on endogenous yolk reserves for a few days and then switch to exogenous feeding. Small paralarvae (~7 mm mantle length (ML)) have been observed to feed on mysid shrimp and other zooplankton associated with low relief seagrass beds (Smith 1983).

Although their dietary preferencess are unknown, mysid shrimp and crab zoea have been successfully used to rear hatchlings in captivity (Steer pers. obs.).

Tasmanian calamary hatchlings ranged in size from 4.3 to 7.3 mm ML (Steer et al. 2003a), slightly larger than those from South Australia (mean 4.75 mm ML, Triantafillos 2001), and were inversely related to incubation temperature. Comparative analysis of hatchling and adult statoliths, determined that smaller hatchlings were less likely to recruit, suggesting that an element of size-mediated mortality operates during the early life history (Steer et al. 2003a).

3. COMMERCIAL FISHERY STATISTICS

When catch data from the commercial sector were first collected there was no discrimination between calamary from other local cephalopods, namely arrow squid (*Nototodarus gouldi*) and the giant cuttlefish (*Sepia apama*). This was rectified in 1983/84 with the implementation of the GARFIS catch and effort database system that required fishers to log specific details such as species caught, species targeted, weight of catch, method of capture and Marine Fishing Area fished. Currently, trends in spatial and temporal commercial catch, effort and catch per unit of fishing effort (CPUE) data are the only indicators of stock biomass for this fishery. Jig data are considered a more accurate estimate of calamary abundance than the haul net data for several reasons. Firstly, jigging specifically targets calamary providing a relatively robust estimate of targeted effort. Determining targeted effort in the haul net sector is problematic as the majority of fishers can be non-specific in their targeted species and are capable of catching a number of other species such as King George whiting (*Sillaginoides punctata*), garfish (*Hyporhamphus melanochir*), Australian herring (*Arripis georgiana*) and snook (*Sphyraena novaehollandiae*). Secondly, jigging occurs over a much broader spatial and temporal scale than haul netting providing a more comprehensive insight into the patterns of distribution and abundance. The resolution within the jig sector is, therefore, far more detailed than that of the haul net sector. For these reasons, estimates of targeted effort, as defined by the number of boat days targeted on southern calamary multiplied by the number of personnel involved, and the associated estimates of CPUE from the jig sector are heavily relied on in this stock assessment.

3.1. State-wide trends

The total catch of calamary was 298.9 t in 2006, combined across all gear types, including both targeted and non-targeted catch. This was 59.0 t less than the previous year, representing a decrease of 16.5% (Fig. 3.1a). This is the second consecutive year where total catch has declined, and the first time that it has fallen below 300 t since 1990. Over the past three years total annual catch has dropped 165.8 t, representing a 35.7% decline. Total effort in 2006 was 8,534 fisher days, 7.4% higher than 2005. Despite this marginal increase, total effort has remained below the long-term average of ~10,000 fisher days for the past two years (Fig. 3.1b). Total catch rate in 2006 was 29.4 kg.fisher day^{-1}, 19.2% less than the previous record year of 36.4 kg.fisher day^{-1}, but is still relatively high for this fishery (Fig. 3.1b).

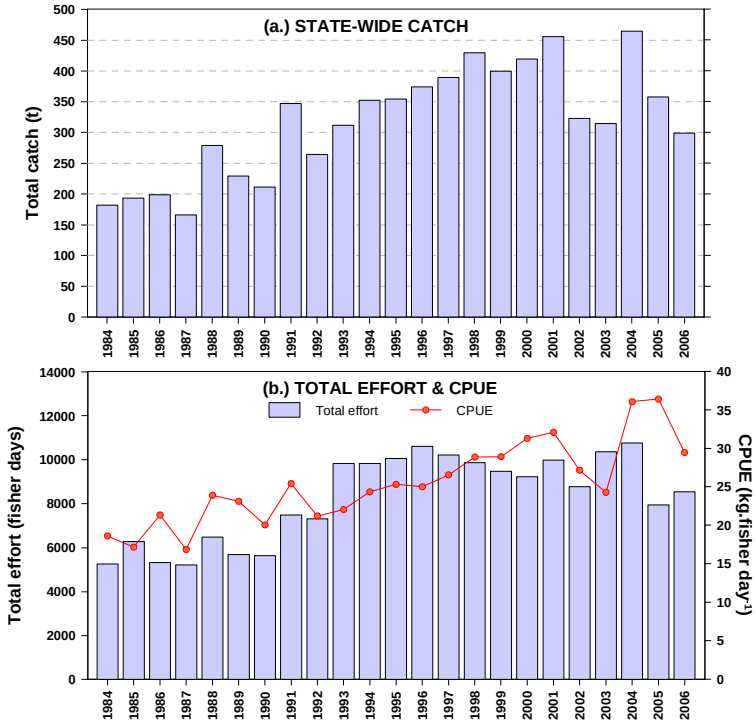

Figure 3.1. (a.) Total State-wide catch of southern calamary from 1984 to 2006. (b.) Annual estimates of targeted effort and associated catch per unit effort from 1984 to 2006.

Prior to 1992 the jig and haul net sectors contributed equally to annual catches. Since then, jigs have become the preferred gear type and over the past 11 years have accounted for >65% of the total annual catch. Targeted jig catch in 2006 was 226.4 t, 11.0% less than the previous year and 32.9% less than the 2004 record catch of 337.2 t (Fig. 3.2a). Targeted jig effort in 2006 was 7,913 fisher days, 744 fisher days (10.4%) more than the previous year (Fig. 3.2b). Over the past two years, targeted jig effort has remained below 8,000 fisher days per year, returning to levels similar to those observed in the early 1990's when the fishery was developing (Fig. 3.2b). With the exception of 2001 and 2002, targeted jig catch rates had steadily increased from 19.6 kg.fisher day^{-1} in 1990 to a record level of 35.5 kg.fisher day^{-1} in 2004, where it remained in 2005 (Fig. 3.2b). This represented an increase of 59%, at an average rate of 0.76 kg.fisher day^{-1}.year^{-1}. Catch rates dropped 19.4% to 28.6 kg.fisher day^{-1} in 2006.

Total haul net catches peaked in 1991 and 2001 at 171.3 and 163.1 t, respectively (Fig. 3.2c). Total haul net catch in 2006 was the lowest on record at 70.2 t. Historically, targeted haul net catch rarely exceeded 25% of the total haul net catch, however over the past three years it has consistently contributed to >50%. Haul net targeted effort peaked at 1,259 fisher days in 2004, but has since declined to 614 fisher days in 2006 (Fig. 3.2d). Although, there has been a 51.2% reduction in targeted haul net effort over the past three years, catch rates have been high, exceeding 40 kg.fisher day^{-1} each year (Fig. 3.2d).

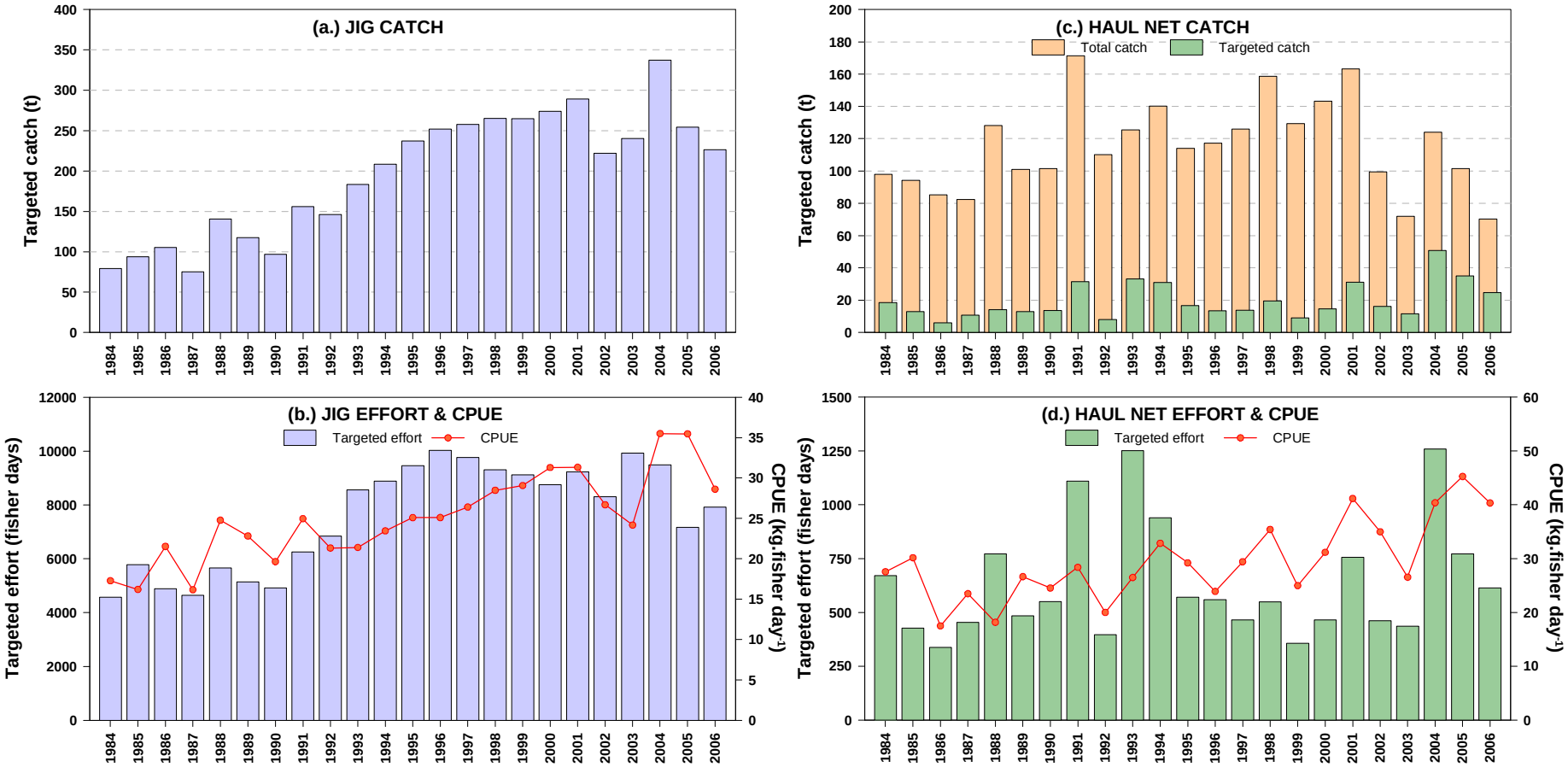

Figure 3.2. State-wide totals (a.) Historical record of targeted catch of calamary by the commercial jig sector; (b.) historical record of targeted effort and CPUE of the jig sector; (c.) historical record of total catch in the haul net sector; (d.) historical record of targeted effort and CPUE in the commercial haul net sector

3.2. Regional trends

South Australia's calamary fishery is partitioned into seven regional fishing areas that account for 98% of the State's catch (Fig. 3.3). Over the past five years South Central Gulf St. Vincent, Northern Spencer Gulf and North West Gulf St. Vincent combined contributed 65 – 75% of the State's total commercial catch. South Central Gulf St. Vincent has usually been the most productive region, producing >22% of the State-wide catch. However, it was overshadowed by North West Gulf St. Vincent in both 2005 and 2006 (Table 3.1). North West Gulf St. Vincent is the only region where the haul net sector consistently landed more calamary than the jig sector. This is the result of greater targeted effort in the haul net sector compared with the other regions.

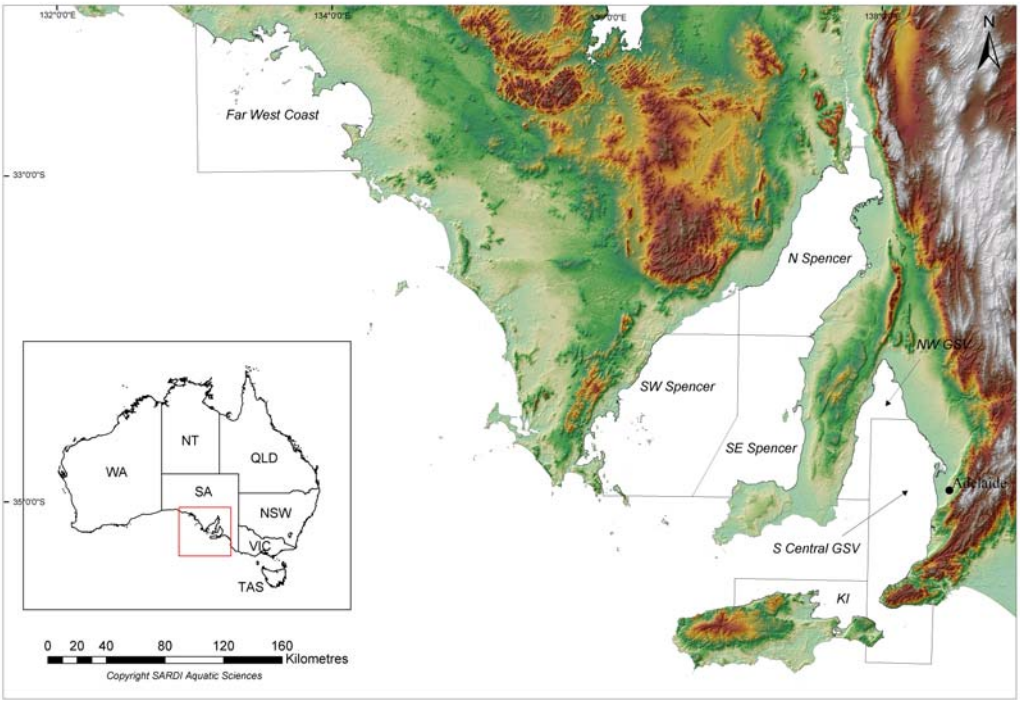

Figure 3.3. Map of South Australia identifying the seven main fishing regions for southern calamary.

Table 3.1. Summary of total southern calamary catch by gear type over the past five years for each of the seven regions.

2002

Region	Jig (t)	Haul net (t)	Other	Total
FW	14.9	0.0	0.0	14.9 (4.6)
KI	1.3	0.5	0.2	2.0 (0.6)
NSG	45.4	36.5	0.1	82.0 (25.4)
NWGSV	17.9	44.5	0.3	62.8 (19.4)
SESG	22.8	6.8	0.3	29.9 (9.2)
SCGSV	87.4	10.5	0.3	98.3 (30.4)
SWSG	27.0	0.2	0.2	27.4 (8.5)
Other	5.1	0.4	0.5	6.0 (1.9)
Total (% of total)	221.9 (68.7)	99.4 (30.7)	1.9 (0.6)	323.2

2003

Region	Jig (t)	Haul net (t)	Other	Total
FW	15.8	0.0	0.1	15.9 (5.1)
KI	3.9	0.9	0.6	5.4 (1.7)
NSG	54.3	24.6	0.1	79.0 (25.1)
NWGSV	18.7	27.6	0.5	46.8 (14.9)
SESG	30.6	9.5	0.1	40.2 (12.8)
SCGSV	70.9	8.5	0.1	79.6 (25.3)
SWSG	41.1	0.1	0.6	41.8 (13.3)
Other	5.0	0.1	0.6	5.7 (1.8)
Total (% of total)	240.2 (76.4)	71.4 (22.7)	2.7 (0.9)	314.3

2004

Region	Jig (t)	Haul net (t)	Other	Total
FW	15.8	0.0	0.0	15.8 (3.4)
KI	6.1	1.6	0.5	8.2 (1.8)
NSG	43.7	27.8	0.1	71.5 (15.4)
NWGSV	43.5	67.9	0.6	112.0 (24.1)
SESG	65.5	9.0	0.1	74.6 (16.0)
SCGSV	121.4	16.2	0.1	137.6 (29.6)
SWSG	38.4	0.2	0.4	39.0 (8.4)
Other	4.7	1.2	0.1	6.0 (1.3)
Total (% of total)	339.0 (73.0)	123.9 (26.7)	1.7 (0.4)	464.7

2005

Region	Jig (t)	Haul net (t)	Other	Total
FW	5.4	0.0	0.0	5.4 (1.5)
KI	3.0	0.9	0.4	4.2 (1.2)
NSG	34.7	18.4	0.0	53.2 (14.9)
NWGSV	55.6	57.2	0.6	113.4 (31.7)
SESG	37.0	7.4	0.0	44.5 (12.4)
SCGSV	88.3	16.3	0.0	104.6 (29.2)
SWSG	25.8	0.0	0.2	26.0 (7.3)
Other	5.2	1.3	0.0	6.6 (1.8)
Total (% of total)	255.0 (71.2)	101.5 (28.4)	1.3 (0.4)	357.9

2006

Region	Jig (t)	Haul net (t)	Other	Total
FW	8.6	0.0	0.0	8.6 (2.9)
KI	2.5	1.2	0.1	3.9 (1.3)
NSG	43.2	17.9	0.1	61.3 (20.5)
NWGSV	32.8	45.0	0.3	78.1 (26.1)
SESG	25.7	0.0	0.0	25.7 (8.6)
SCGSV	75.6	5.9	0.6	82.2 (27.5)
SWSG	35.6	0.0	0.2	35.9 (12.0)
Other	3.1	0.0	0.2	3.3 (1.1)
Total (% of total)	227.2 (76.0)	70.2 (23.5)	1.4 (0.5)	298.9

3.2.1. Far West Coast (GARFIS Block 8, 9, 10)

Commercial netting restrictions were implemented in Denial and Smoky Bay in 1958. Thus, the catch from this region has been taken exclusively by the jig sector (Fig. 3.4a). Targeted calamary catch peaked in 1996 at 36.3 t, doubling the catch of the previous year and contributing 9.7% of the Statewide catch (Fig. 3.4a). A second smaller peak of 32.9 t was observed in 2001. Since then catches declined by half and remained relatively stable until 2004. In 2005, catch declined a further 65.9% to 5.4 t, the lowest ever recorded in this region. Targeted calamary catch increased by 59.2% to 8.5 t in 2006. Currently this region contributes 2.9% of the State's annual catch. Annual targeted jig effort peaked in 2001 at 1,227 fisher days before declining by 51% to 596 fisher days in 2002 (Fig. 3.4b). Jig effort marginally increased in 2003 and 2004 before dropping to a record low of 290 fisher days in 2005. Jig effort remained relatively low in 2006 at 386 fisher days. CPUE increased systematically through the early-mid 1990s peaking in 1996 and again in 1999 at 34.1 and 31.7 kg.fisherday^{-1} respectively (Fig. 3.4b). Since then, CPUE has precipitously decreased to less than 25 kg.fisherday^{-1}, representing a 30.2% decline over eight years.

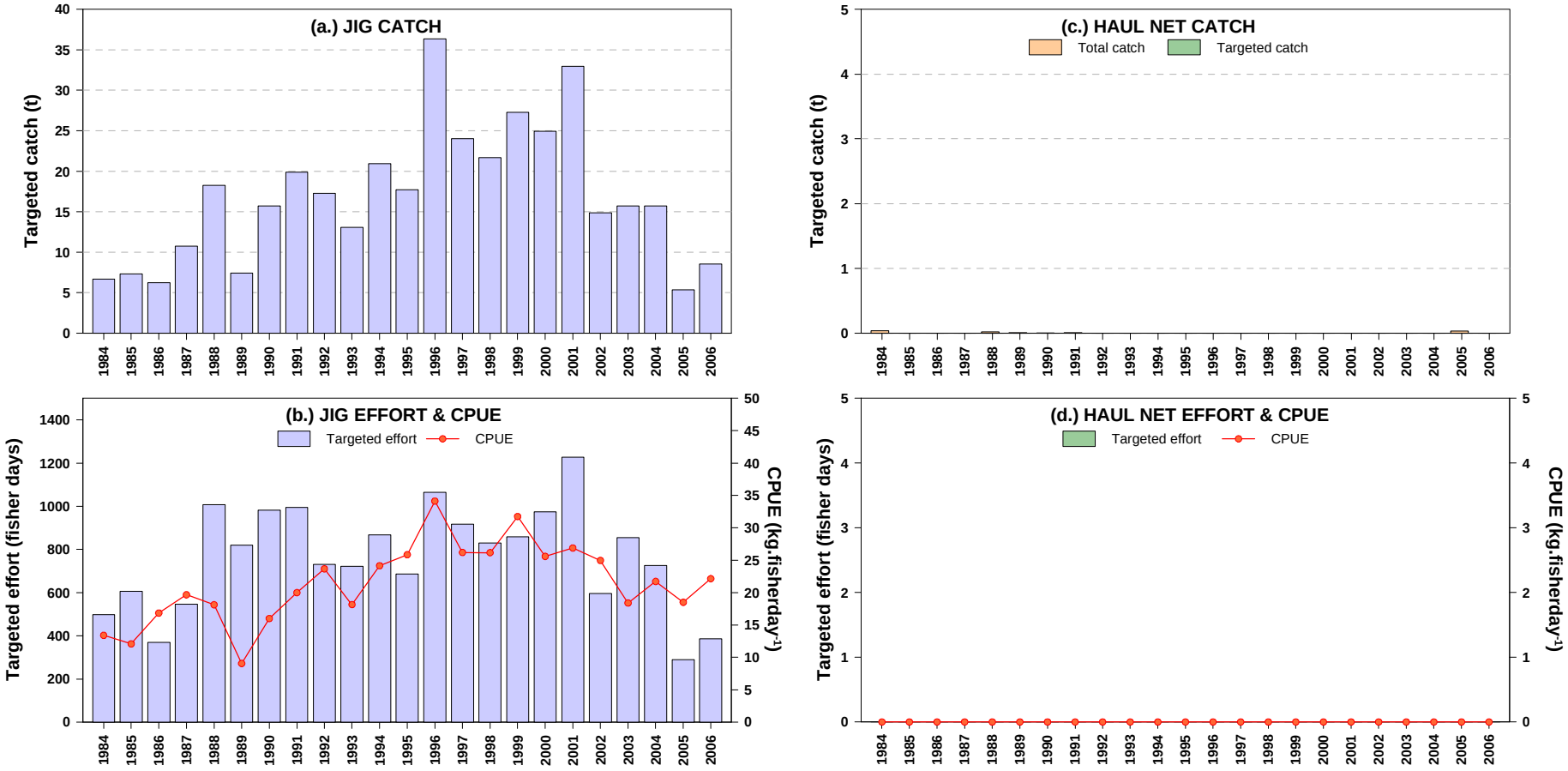

Figure 3.4. Far West Coast, (a.) Historical record of targeted catch of calamary by the commercial jig sector; (b.) historical record of targeted effort and CPUE of the jig sector; (c.) historical record of total catch in the haul net sector; (d.) historical record of targeted effort and CPUE in the commercial haul net sector.

3.2.2. South West Spencer Gulf (GARFIS Block 29, 30, 31)

The South West Spencer Gulf calamary fishery is relatively small contributing <15% of the State's annual catch (Table 3.1). With the exception of 2002, annual targeted jig catch increased systematically from a low of 19.1 t in 1998 to a peak of 41.1 t in 2003 (Fig. 3.5a). Catch in 2004 remained high having declined marginally by 6.6% to 38.4 t but dropped a further 28.6% to 27.4 t in 2005. Total targeted jig catch increased 30.1% to 35.6 t in 2006. Annual targeted jig effort peaked in 1996 and again in 2003 at 1,612 and 1,529 fisher days, respectively (Fig. 3.5b). Targeted jig effort in 2006 was 1,187 fisher days, 22.4% lower than the previous peak in 2003. CPUE peaked in 1991 at 30.5 kg.fisherday^{-1} before declining to a historic low of 17.4 kg.fisherday^{-1} in 1994 (Fig. 3.5b). CPUE has systematically increased to exceed 30 kg.fisherday^{-1} in 2006 for the first time in 15 years.

This region has experienced dramatic reduction in haul net catch and effort as a result of the introduction of permanent netting closures implemented in September 1995 and again in 2000 (Table 2.1). Prior to these restrictions between 12–34% of the total catch was landed by the haul net sector, of which <6.5% was targeted catch (Fig. 3.5c). Since then, haul net catch has been negligible, rarely exceeding 2% of the total, with no fishers targeting calamary (Fig. 3.5d).

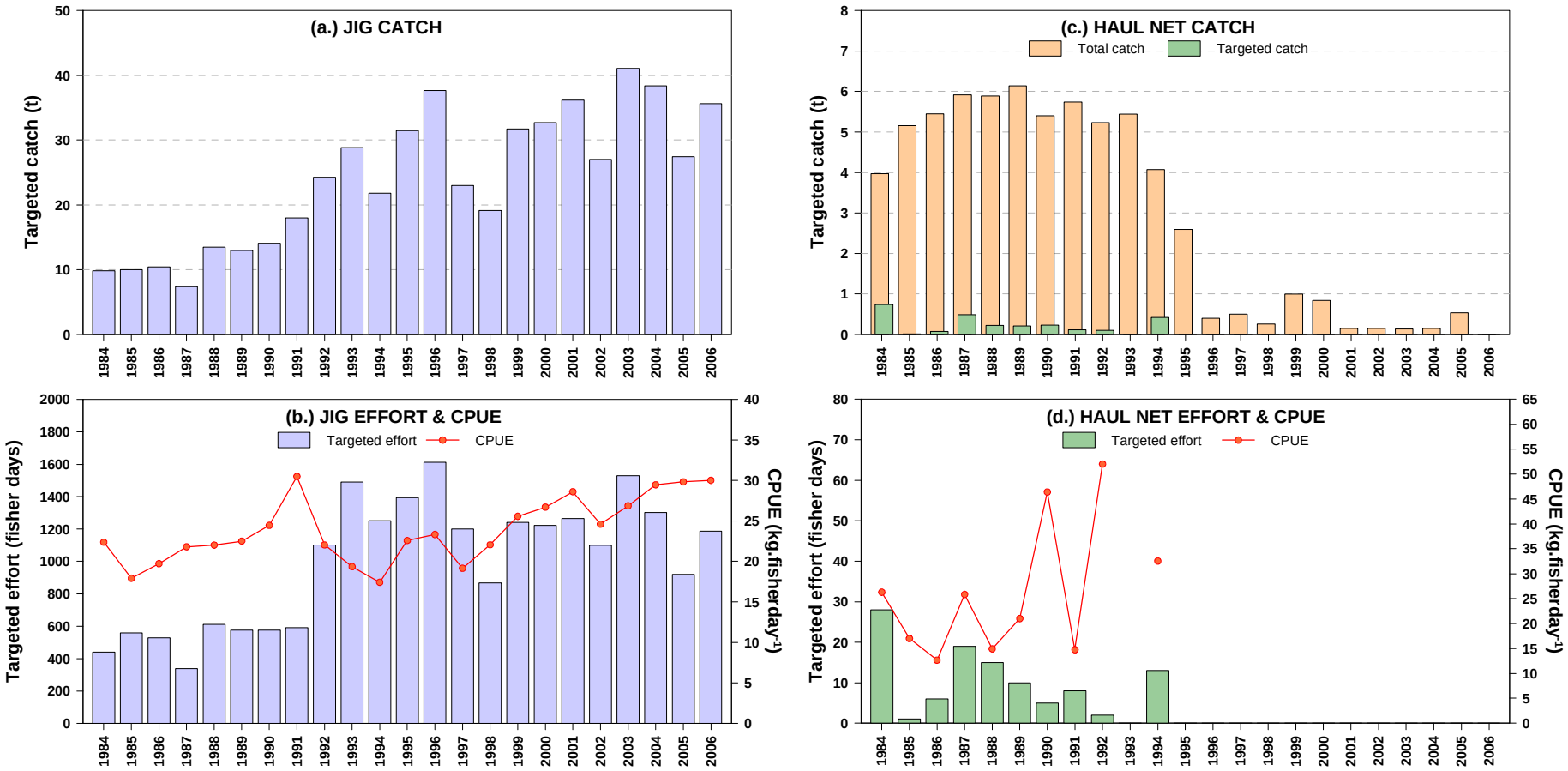

Figure 3.5. South West Spencer Gulf, (a.) Historical record of targeted catch of calamary by the commercial jig sector; (b.) historical record of targeted effort and CPUE of the jig sector; (c.) historical record of total catch in the haul net sector; (d.) historical record of targeted effort and CPUE in the commercial haul net sector.

3.2.3. Northern Spencer Gulf (GARFIS Block 21, 22, 23)

The Northern Spencer Gulf calamary fishery is one of the largest in South Australia contributing up to 25.1% of the State-wide catch (Table 3.1). In the past four years the jig sector has contributed >60% of the annual total catch. Prior to this, it was shared equally with the haul net sector. Annual targeted jig catch first exceeded 30 t in 1993, slipping once to 27.3 t in 1996 (Fig. 3.6a). Subsequent jig catches increased steadily to peak at 54.2 t in 2003 before dropping 19.7% to 43.5 t in 2004 and a further 21.1% to 34.3 t in 2005. Catch had rebounded to 43.1 t in 2006, representing a 25.7% increase. Annual targeted jig effort also peaked in 2003 with fishers expending 1,997 fisher days, considerably more than the 1,000 – 1,400 fisher days that were usually targeted on calamary in this region (Fig. 3.6b). Annual targeted effort in 2004 – 2006 was within the usual range. Targeted jig CPUE peaked at 34.4 kg.fisherday^{-1} in 1999 and has remained at a relatively high level (>32 kg.fisherday^{-1}) with the exception of 2002 and 2003 when catch rates decreased to 26.3 and 27.1 kg.fisherday^{-1}, respectively (Fig. 3.6b).

Total catches in the haul net sector have been highly variable over the years with three obvious peaks, the first in 1988 at 66.6 t, followed by 58.7 t in 1991 and 53.3 t in 2001 (Fig. 3.6c). Total catch decreased substantially after the most recent peak to 17.9 t, representing a 66.3% decline over five years and producing the lowest catch on record for this gear type in this region. The majority (~90%) of total calamary catch in the haul net sector is non-targeted with fishers either incidentally netting calamary whilst targeting other marine scalefish or non-specifically targeting "any species". Targeted haul net catch peaked in 1988 and 2004 at 5.9 and 4.7t, respectively, coinciding with periods of increased fishing intensity when annual targeted effort uncharacteristically exceeded 175 fisher days (Fig 3.6d). Despite increased fishing effort during these years, catch rates were moderate at approximately 27 kg.fisherday^{-1} (Fig. 3.6d). Catch rates have remained moderate in 2006 at 23.9 kg.fisherday^{-1}, substantially lower than the high of 58.3 kg.fisherday^{-1} in 2001. This represents a drop of 59.0% over the last five years.

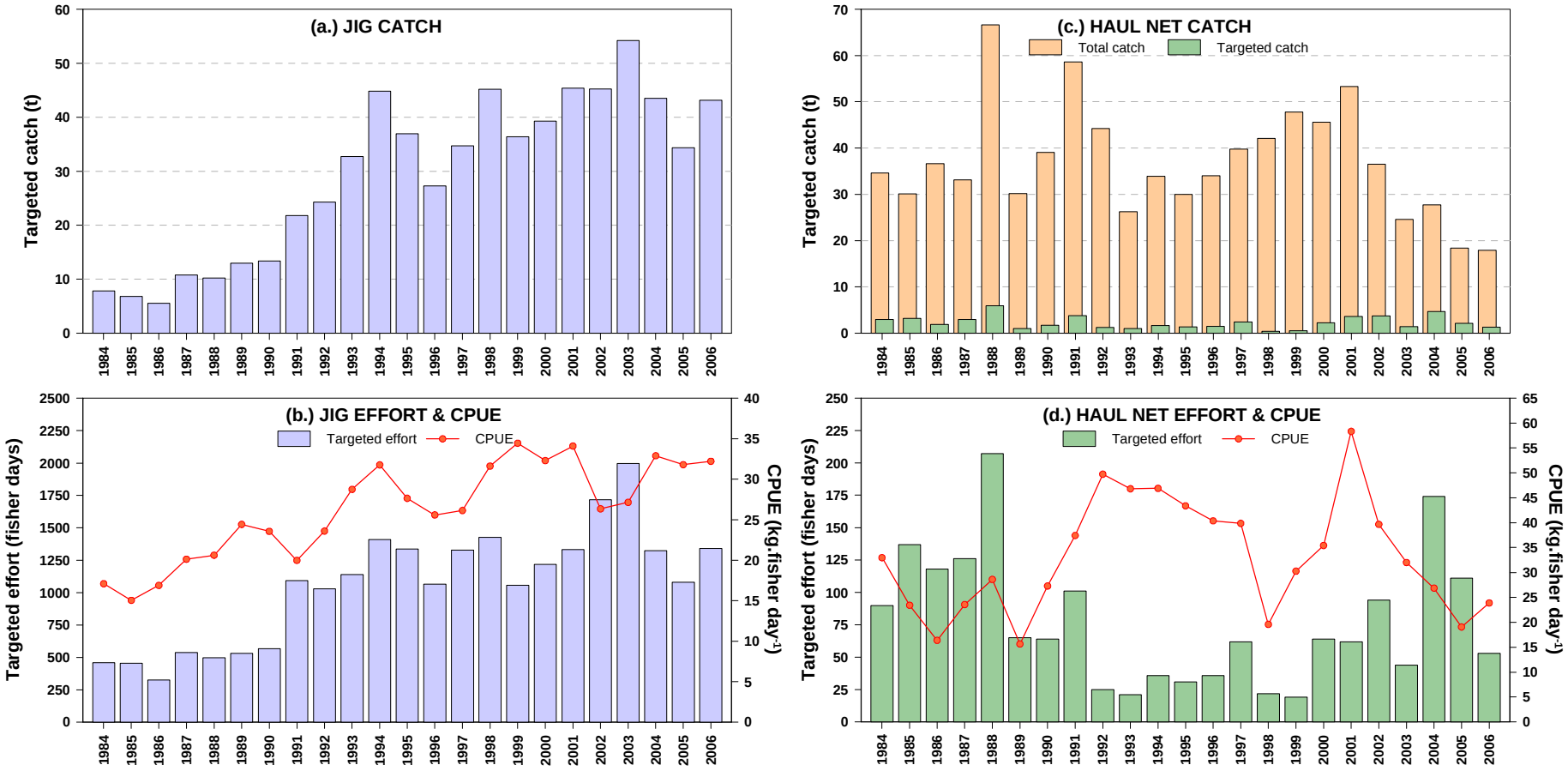

Figure 3.6. Northern Spencer Gulf, (a.) Historical record of targeted catch of calamary by the commercial jig sector; (b.) historical record of targeted effort and CPUE of the jig sector; (c.) historical record of total catch in the haul net sector; (d.) historical record of targeted effort and CPUE in the commercial haul net sector.

3.2.4. South East Spencer Gulf (GARFIS Block 32, 33)

Between 1988 and 1991 annual catch in South East Spencer Gulf was shared equally between the haul net and jig sectors, but has since been dominated by the jig sector, accounting for 71.2% in 1991 to 99.9% in 2006. Annual targeted jig catch rapidly increased from 24.1 t in 1992 to 55.8 t in 1997 (Fig. 3.7a). Catches remained above 54 t until 2002 when they declined below 23 t for the first time since 1991. Jig catch remained low at 30.5 t in 2003 before increasing to a record level of 64.1 t in 2004. Catch dropped to 25.6 in 2006, representing a 60.1% drop in two years. Jig effort followed a similar trend, rapidly increasing from 878 fisher days in 1992 to 1,745 fisher days in 1997, after which it remained stable, except for a substantial decline in 2002 when it dropped to 1,187 fisher days (Fig. 3.7b). Jig effort dropped below 1,000 fisher days in 2005 for the first time since 1992 and remained at this level in 2006. Catch rates fell significantly in 2001 and 2002 to below 20 kg.fisherday^{-1}, a level that had not been observed since 1987 (Fig. 3.7b). Despite a reduction in targeted jig effort in 2005, catch rates recovered to >35 kg.fisherday^{-1}, but subsequently dropped 25.3% to 27.6 kg.fisherday^{-1} in 2006.

Total haul net catches peaked in 1991 and 2001 at 19.5 and 16.3 t, respectively (Fig. 3.7c). Each of these years included a greater proportion of targeted catch (~30%) than the majority of other years. From 2002 to 2005 targeted haul net catch has been minimal contributing <2% of the total catch, which is largely a result of negligible effort, with fishers expending <12 days a year targeting calamary (Fig. 3.7d). There was no recorded calamary catch in the haul net sector in 2006 presumably as a consequence of the voluntary net buyback and additional area net closures implemented in this region in August 2005.

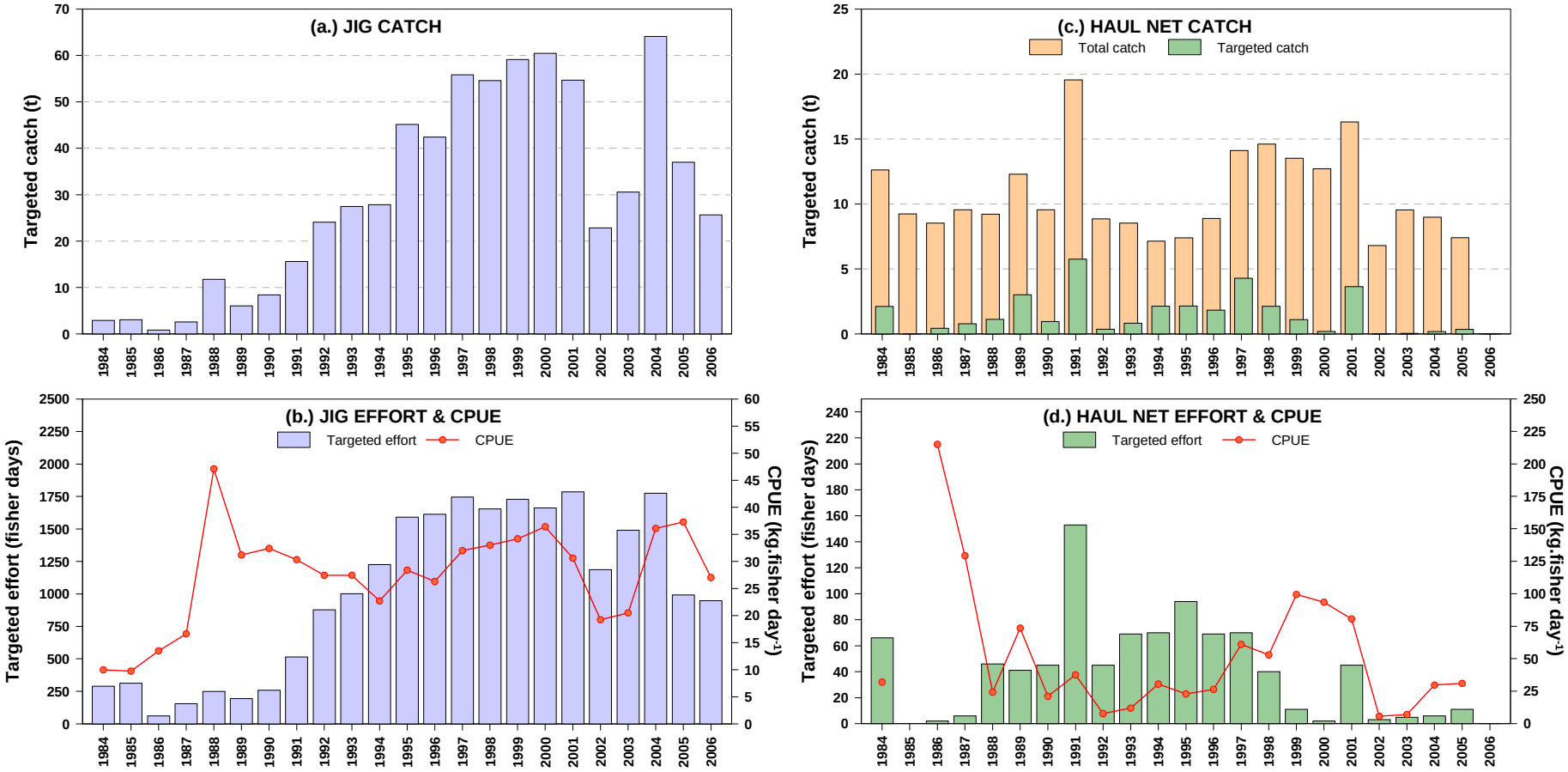

Figure 3.7. South East Spencer Gulf, (a.) Historical record of targeted catch of calamary by the commercial jig sector; (b.) historical record of targeted effort and CPUE of the jig sector; (c.) historical record of total catch in the haul net sector; (d.) historical record of targeted effort and CPUE in the commercial haul net sector.

3.2.5. North West Gulf St. Vincent (GARFIS Block 34, 35)

The North West Gulf St. Vincent calamary fishery contributes approximately 25% of the State-wide catch (Table 3.1). 2005 was the first year where the haul net and jig sectors contributed equally to the total catch, as historically this was the only region where haul nets were consistently the dominant gear type. Catches were also shared relatively equally between the two gear types in 2006. Targeted jig catch substantially increased in 2004 and 2005 (Fig. 3.8a). Prior to 2004, catches had been relatively stable varying around 20 t, with the exception of a small peak (32.9 t) in 2001. In 2004, jig catch increased by 132% to 43.5 t and increased a further 27.4% to 55.4 t in 2005, the highest catch recorded in this fishing region. Targeted jig catch dropped 40.9% to 32.7 t in 2006, but is still considered relatively high for this fishing area. The most recent peak coincided with a peak in targeted effort at 1,181 fisher days, 8.6% greater than the previous year (Fig. 3.8b). Catch rates have steadily climbed from 5.2 kg.fisherday^{-1} in 1983 to a peak of 43.0 kg.fisherday^{-1} in 2001 (Fig. 3.8b). Catch rates during this period continued to climb despite that targeted effort levels dropped below 630 fisher days, suggesting that either the efficiency of the jig fishers improved or they fished previously unexploited parts of the stocks. High catch rates were not maintained in 2002 and 2003 dropping below 32 kg.fisherday^{-1}, but increased to a record level of 46.9 kg.fisherday^{-1} (Fig. 3.8b). Catch rates dropped back to 33.6 kg.fisherday^{-1} in 2006.

Total haul net catch dropped to a 15-year minimum in 2003, but increased to 67.9 t in 2004 before sequentially dropping to 45.0 t in 2006, representing a 33.7% decline over two years (Fig. 3.8). In comparison to the other regions, a large proportion of calamary caught by haul nets in this region was targeted, which may explain why catches have been considerably greater than those of the jig sector. Over the past six years targeted haul net effort in this region accounted for 79.0% of the total targeted haul net effort in the South Australian calamary fishey. Despite considerable inter-annual variability, there has been a long-term trend of increasing CPUE since 1986, culminating into the peak catch rate of 52.0 kg.fisherday^{-1} in 2005 (Fig. 3.8d). Catch rates dropped 19.1% to 42.0 kg.fisherday^{-1} in 2006, but remained the third highest on record.

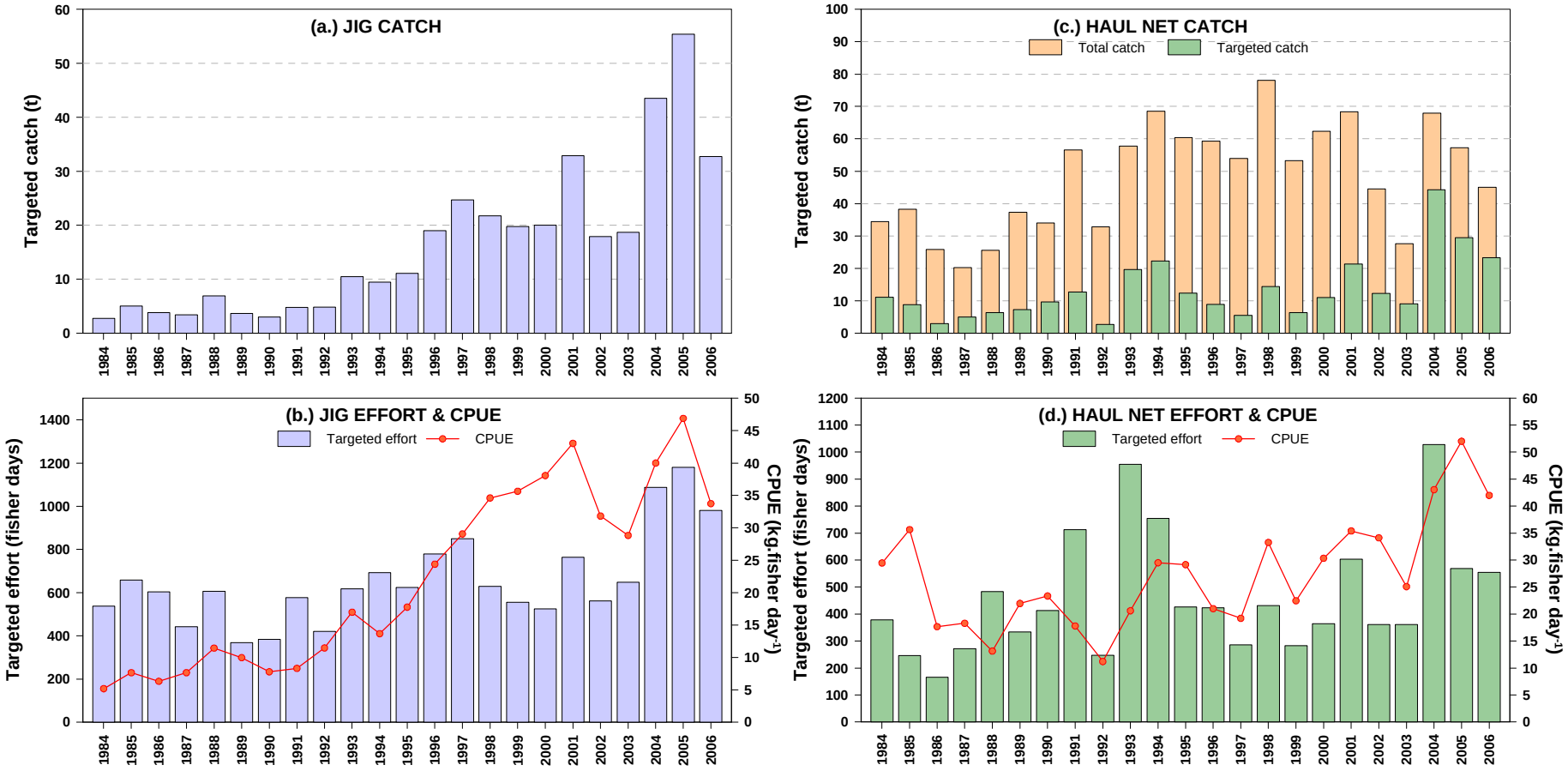

Figure 3.8. North West Gulf St. Vincent (a.) Historical record of targeted catch of calamary by the commercial jig sector; (b.) historical record of targeted effort and CPUE of the jig sector; (c.) historical record of total catch in the haul net sector; (d.) historical record of targeted effort and CPUE in the commercial haul net sector.

3.2.6. Kangaroo Island (GARFIS Block 41, 42)

The Kangaroo Island calamary fishery is the smallest in South Australia rarely contributing >2.0% of the State-wide catch (Table 3.1). Annual targeted jig catch has fluctuated from peak catches of ~8 t in 1984 and 1998 to historic lows of 0.1 and 1.3 t in 1989 and 2002, respectively (Fig. 3.9a). A total of 2.5 t of calamary was landed by the jig sector in 2006. Targeted jig effort displayed a similar trend, peaking in 1984 at 396 fisher days and again in 1998 at 460 fisher days (Fig. 3.9b). Jig fishers expended 229 days targeting calamary in 2006, equal to the previous year. Despite the same amount of targeted effort, catch rates dropped 14.1% to 11.0 kg.fisherday^{-1} in 2006 (Fig 3.9b). There has been a general downward trend in CPUE since 1998.

The most recent peak to exceed 3.0 t in total haul net catch was in 1994, after which catches have decreased by >50% (Fig. 3.9c). Haul net fishers expended few (<10) days targeting calamary over the past three years. This, however, follows a 12-year period during which there was no targeted effort (Fig. 3.9d).

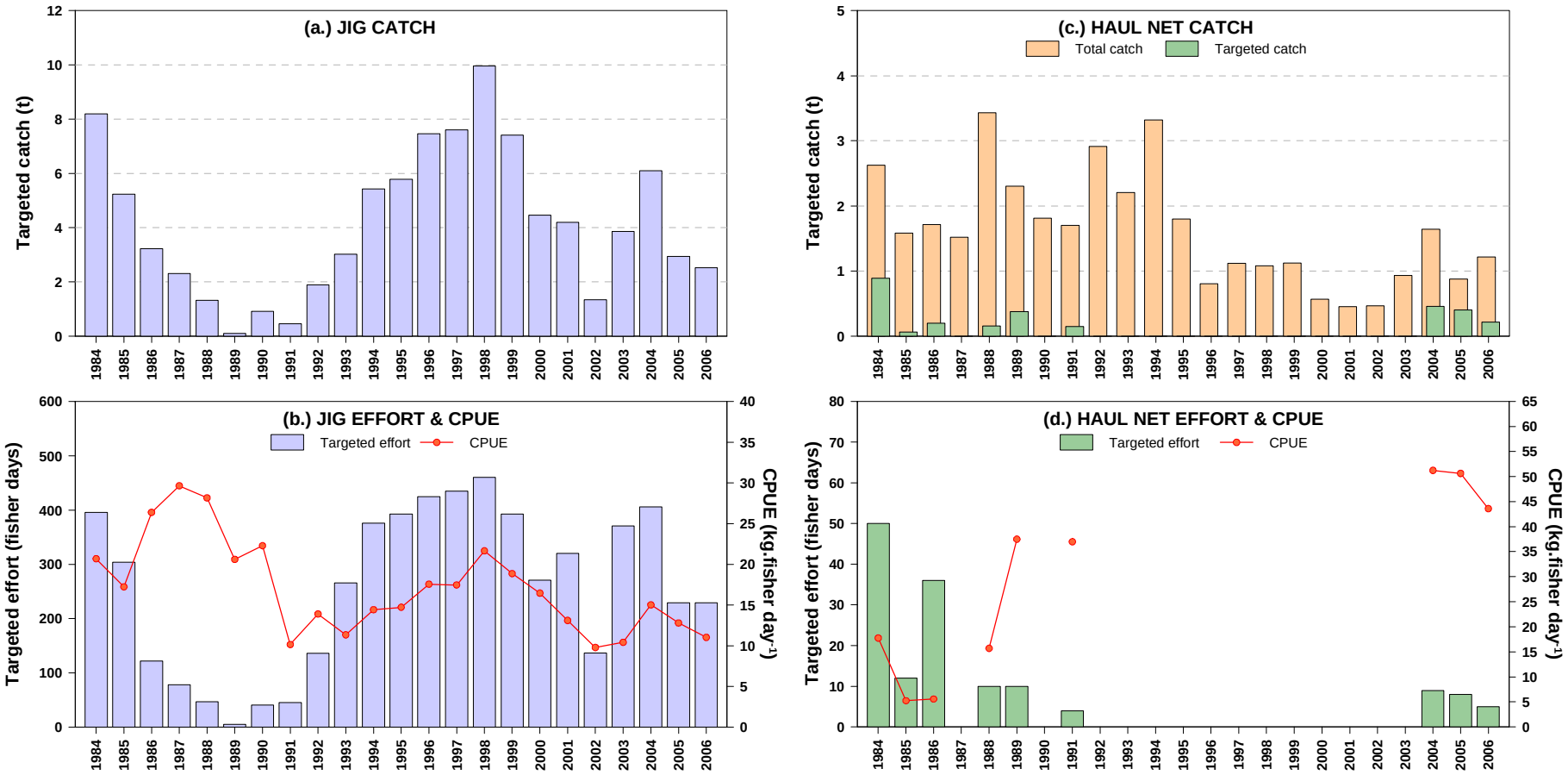

Figure 3.9. Kangaroo Island (a.) Historical record of targeted catch of calamary by the commercial jig sector; (b.) historical record of targeted effort and CPUE of the jig sector; (c.) historical record of total catch in the haul net sector; (d.) historical record of targeted effort and CPUE in the commercial haul net sector.

3.2.7. South Central Gulf St. Vincent (GARFIS Block 41, 42)

The South Central Gulf St. Vincent calamary fishery has been the most productive in South Australia since 1984 and in 2006 contributed to 27.5% of the State-wide catch (Table 3.1). The highest recorded catch was 121.4 t in 2004, annual catches in this region were generally around 70 to 90 t (Fig. 3.10a). CPUE also peaked in 2004 at 45.3 kg.fisherday^{-1}, almost double that of the previous year (Fig. 3.10b). Catch rates dropped to 30.0 kg.fisherday^{-1} in 2006 representing a 33.8% decline over the past two years.

Total haul net catch has rarely exceeded 30% of the jig catch. Targeted haul net catches peaked in 1991 and 1993 at 9.0 and 11.7 t, respectively and were a function of large increases in effort (Figs. 3.10c and d). Annual haul net effort has remained less than 60 fisher days since 1995 and there has been no apparent trend in CPUE (Fig. 3.10d).

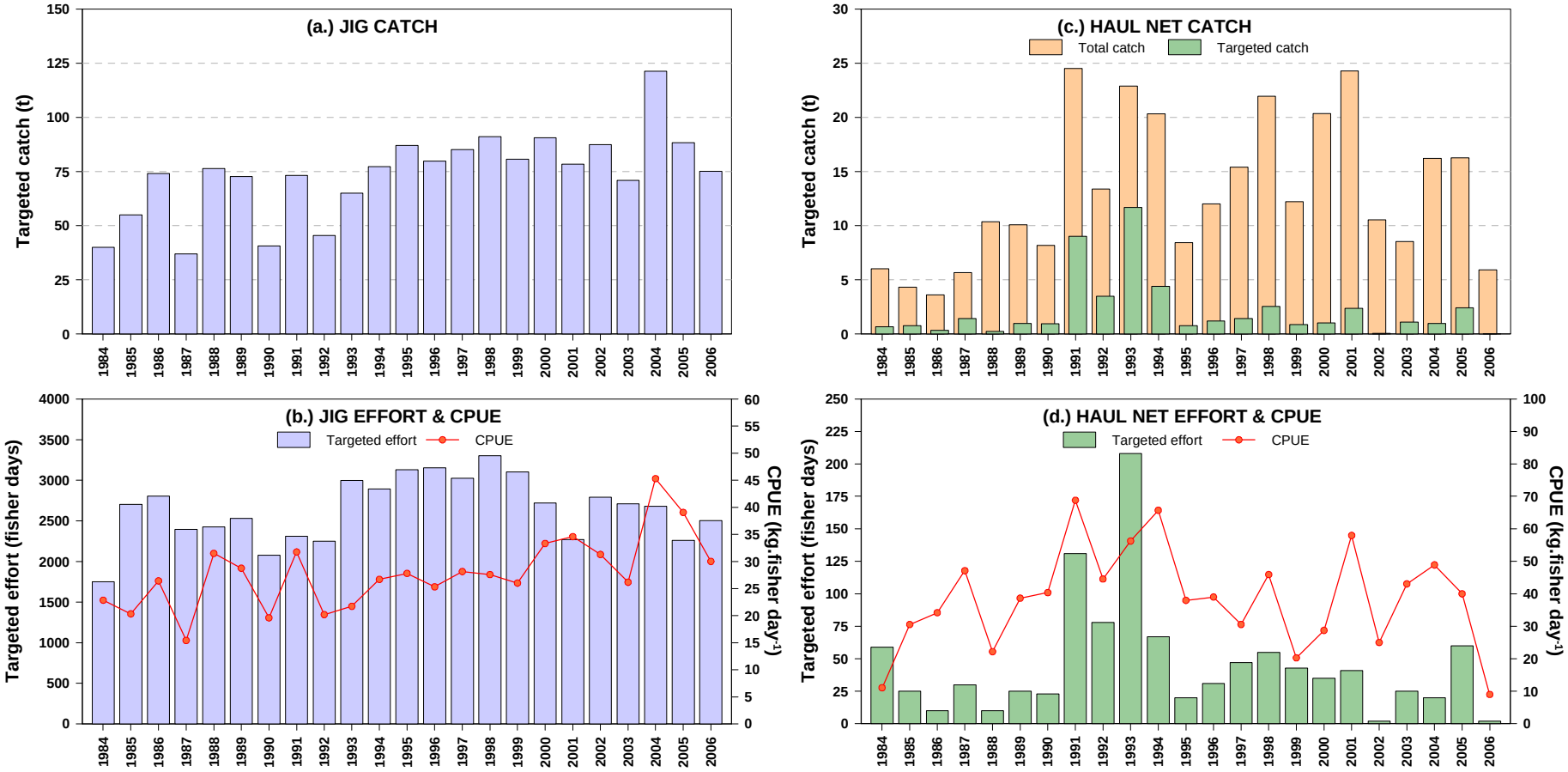

Figure 3.10. South Central Gulf St. Vincent (a.) Historical record of targeted catch of calamary by the commercial jig sector; (b.) historical record of targeted effort and CPUE of the jig sector; (c.) historical record of total catch in the haul net sector; (d.) historical record of targeted effort and CPUE in the commercial haul net sector.

3.3. Long-term trends in licence holders

High levels of latent effort are a consistent feature in the Marine Scalefish fishery, which is typical of most multi-species, multi-gear fisheries. This is particularly evident in the southern calamary fishery where in 2006, only 40.1% of commercial fishers who were legally permitted to catch calamary (i.e. those possessing either a 'M' or 'B' class marine scalefish licence, or a rock lobster licence) reported landings, of whom 35.5% targeted calamary. Fisheries management has aimed at reducing commercial effort by reducing the number of marine scalefish licence holders. The policies to achieve this have included: (1) an ongoing non-transfer of 'B' class licences; (2) non-transfer of licences with net endorsements between 1983 and 1993; (3) a licence amalgamation scheme introduced in 1994 for all 'M' class licence holders; and (4) a voluntary net buyback scheme introduced in 2005. These policies appear to have been successful, as the total number of marine scalefish licences has decreased from 695 in 1984 to 349 in July 2006, representing a 49.8% reduction (Fig. 3.11a).

Flow-on effects from the decrease in number of licence holders have been seen in the snapper and King George whiting fisheries, where the total numbers of licensed fishers taking these species declined by 27 and 45%, respectively (Fowler et al 2005; McGarvey et al 2005). A similar decline was evident in the calamary fishery, where the total number of licensed fishers who took calamary dropped from 312 in 1984 to 226 in 2006, representing a 27.6% reduction over 23 years (Fig. 3.11a).

Despite a reduction in the total number of licence holders that took calamary, there was a 20% increase in the number of licence holders that targeted calamary, which increased from 167 in 1984 to 200 in 2006 (Fig. 3.11a). This trend relates to two opposing dynamics. The first is the gradual, but consistent decline in the number of fishers using haul nets to catch calamary up to 2005 after which it declined rapidly as a result of the voluntary net-buy back scheme (Fig. 3.11b). Traditionally these fishers have comprised the bulk of non-targeted catch and effort. Secondly, there was an increased trend in the number of fishers that targeted calamary with squid jigs, particularly between 1990 and 1996 after which there was a strong decline (Fig. 3.11b).

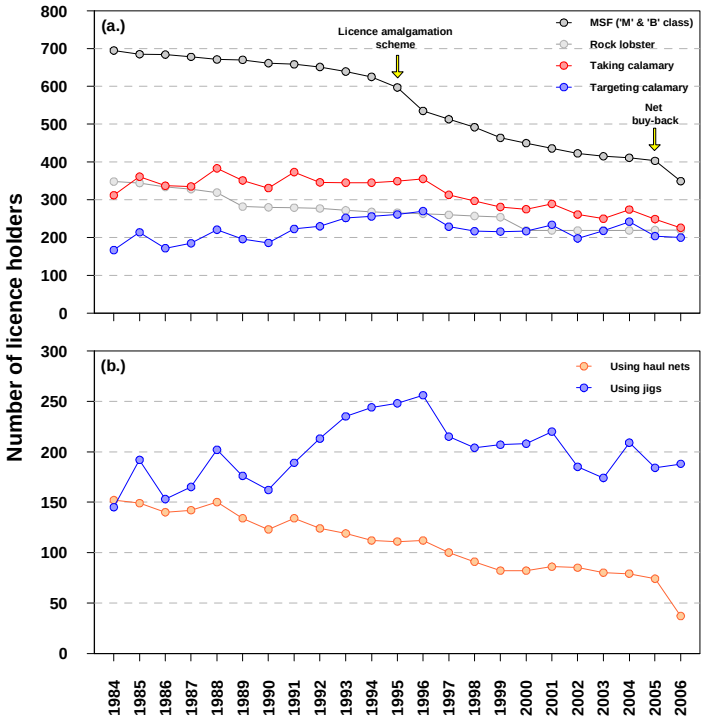

Figure 3.11. (a.) Number of Marine Scalefish and Rock Lobster licence holders that are legally permitted to retain and sell calamary and those licence holders that successfully caught calamary in each year. (b.) Number of licence holders that successfully caught calamary each year separated by the main gear types.

More than 50 'scalefish' species can be harvested by commercial fishers in South Australian waters. Of these, less than 10 are consistently targeted, with King George whiting being the State's most valuable species. Marine Scalefish fishers have considerable flexibility in their target species and can adapt their fishing practices according to circumstances, such as market demand, seasonality, local abundance, relative abundance of other species, prevailing weather conditions and personal preference. Conversely, some fishers specialise in targeting one particular species. In the calamary fishery, the top ten fishers, who represent ~4% of the MSF licence holders, land 31% of the State's annual calamary catch (Fig. 3.12). Such dominance by only a few fishers further highlights the considerable latent effort in this fishery. Calamary are an attractive target species as they are highly aggregative during seasonal spawning and are relatively easy and cost-effective to catch. As a result, fishers who preferentially target other species may shift their emphasis towards calamary, which may be considered a more viable financial alternative.

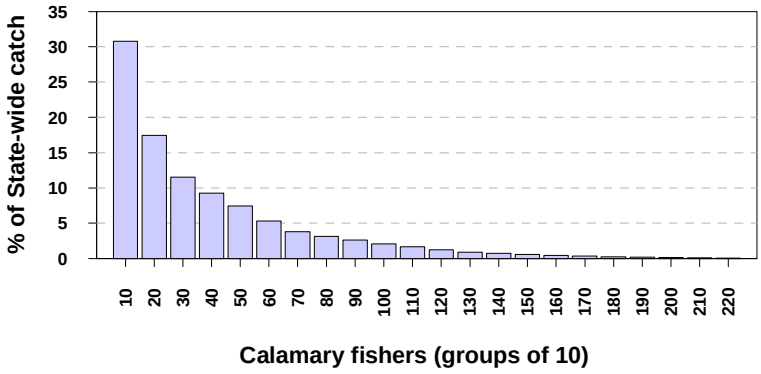

Figure 3.12. The contribution of the State-wide commercial calamary catch by commercial fishers in 2006. Fishers are ranked from most to least productive and presented in groups of 10.

4. CALAMARY BY-PRODUCT IN THE SA PRAWN FISHERIES

There are three separately managed, commercial prawn fisheries in South Australia: Spencer Gulf, Gulf St. Vincent and the West Coast (Fig. 4.1). The Spencer Gulf prawn fishery is the largest in terms of total area, production and number of vessels (39) followed by Gulf St. Vincent and West Coast fisheries with 10 and three vessels, respectively. All three fisheries target the western king prawn *Melicertus latisulcatus*, but are permitted to retain and sell calamary as a 'by-product' species. In Gulf St. Vincent and Spencer Gulf there are generally six fishing periods within a season, with each period lasting a maximum of 18 nights from the last to the first quarter of the moon in November, December, March, April, May and June (Dixon et al. 2005a).

Prior to 2002 there was no legislative requirement for fishers to report landed by-product. In 2002, commercial logbooks in the Spencer Gulf fishery were modified to include by-product information and it became mandatory to report the retained portion of any daily catches. More recently, the Australian Government Department of the Environment and Water Resources (DEWR) determined that the South Australian prawn fisheries must monitor and assess by-catch to comply with the *Environment Protection and Biodiversity Conservation (EPBC) Act* (Anon 2004). Consequently commercial logbooks were amended in the remaining two fisheries to include mandatory reporting of retained by-product, from December 2005. However, the reported catch of the species under-represents the total catch (Dixon et al. 2005a), because not all is retained as fishers discard the small animals and those in poor condition.

The impact of the commercial prawn fishery on calamary stocks has been suggested to be significant (Triantafillos and Fowler 2000). However, there has been no on-going formal quantification to substantiate this. There have been a few estimates of the catch that have ranged from 1.0 to 3.1 million animals per annum (Smith 1983; Triantafillos 1997), and 46.6 t taken by the Spencer Gulf prawn fishery in 2000/01 (Carrick 2003). These estimates have resulted from the scaling up of single trawl catches to a total catch across the whole fishery, and so do not consider spatial and temporal variation in catch rates. Structured, fishery-independent, trawl surveys are carried out by SARDI to assess the status of the prawn population in each of the three prawn fisheries and to develop harvest strategies for each fishing period. By-product was quantified as part of the Gulf St. Vincent fishery-independent surveys in 2004/05 from which it was estimated that approximately 0.5 million calamary totalling 28.7 t were caught during the fishing season (Steer et al. 2006). There remains an on-going commitment to quantify by-product within GSV to satisfy the Commonwealth's EPBC requirements. These surveys will be further refined and expanded to include the remaining fisheries in coming years. Data obtained

from these surveys will potentially quantify the prawn sector's contribution to State-wide total calamary catch.

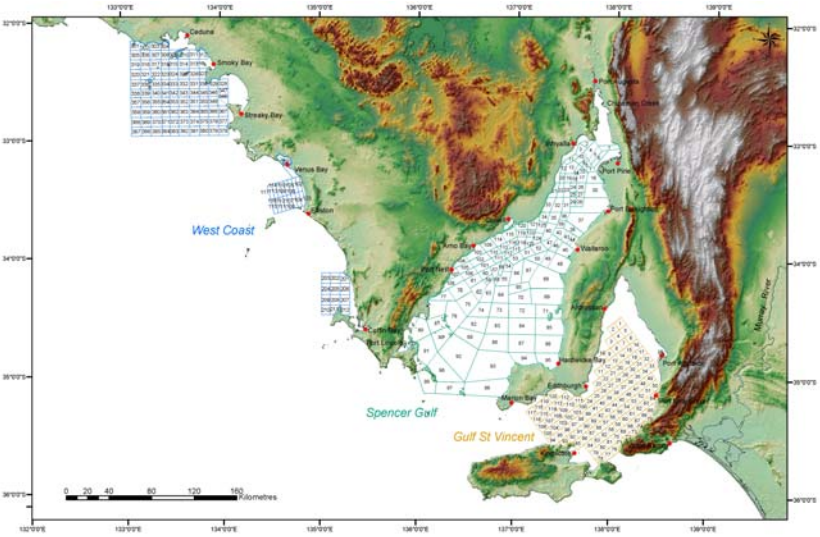

Figure 4.1. Location of the three South Australian prawn fisheries; West Coast, Spencer Gulf and Gulf St. Vincent. (Map sourced from Dixon and Roberts 2006).

4.1. Spencer Gulf calamary by-product

Over the past four fishing seasons, annual retained calamary catch by the Spencer Gulf prawn sector has ranged between 21 and 31 t (Fig. 4.2). Reported calamary catch has declined over the past three seasons, however these reported catches under-represent the total calamary catch and mortality in this sector as not all calamary caught are retained. Reported calamary catch declined 17.7% from 2004/05 to 2005/06.

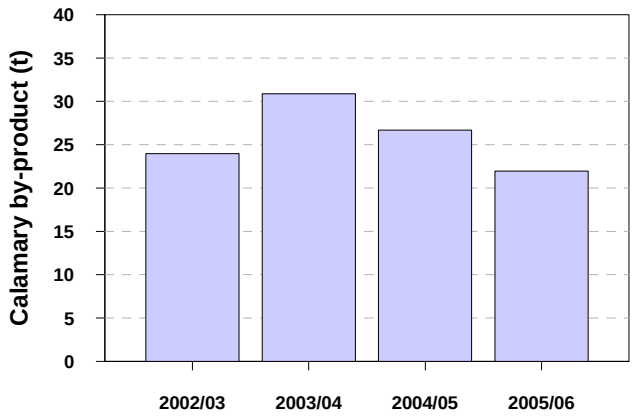

Figure 4.2. Annual reported calamary catch from the Spencer Gulf prawn fishery.

4.2. Gulf St. Vincent calamary 'by-product' scientific surveys

Trawl surveys were carried out in Gulf St. Vincent (Fig. 4.3) between the last quarter and new moon in December, March, April and May of the 2004/05 and 2005/06 fishing seasons by the prawn fishing fleet. Each survey involved either five or 10 commercial vessels trawling over one or two nights, with approximately 12, 30–minute trawl shots carried out by each vessel per night. Up to 110 trawl sites were sampled per month, 52 of which were dedicated 'by-product' sites where all trawled calamary were collected, bagged and frozen for future processing. The latter were spatially structured so that they were distributed evenly throughout the gulf (Fig. 4.3). All sites were semi-fixed, with skippers beginning a survey shot as close as possible to a fixed Global Positioning System (GPS) waypoint. Trawl distance was calculated from GPS marks recorded at the beginning and end of each trawl shot. Most vessels were fitted with double-rigged, demersal, otter-trawl gear with a 27.5 m headline and a cod-end mesh size of 4.5 cm (stretched).

A maximum of 30 calamary were haphazardly sampled from each 'by-product' shot to obtain biological information. From each individual, the dorsal mantle length (ML), total body weight (g) and sex were recorded. Lipinski's (1979) universal maturity scale (Table 5.1) was used to categorise calamary as juveniles (Stage 0), sub-adults (Stage I, II and III) and adults (Stage IV, V and VI). Statoliths were removed for age analysis. The remaining animals were counted and collectively weighed. During the 2005/2006 surveys, scientific observers counted and weighed calamary, using calibrated marine scales, for each shot, where possible. To assess the accuracy of these data, 136 samples were collected and re-counted and weighed in the laboratory. Results indicated that data collected at sea did not significantly differ from data collected in the laboratory, in count (Two tailed paired T-test; $t = -0.26$, $df = 136$, $p = 0.79$) and weight ($t = 1.76$, $df = 136$, $p = 0.08$).

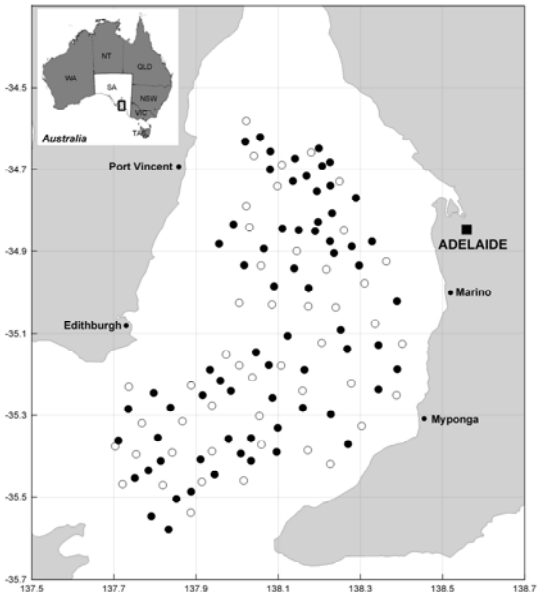

Figure 4.3. A map of Gulf St. Vincent identifying trawl survey shots. Open circles indicate survey shots where calamary were specifically collected.

4.2.1. Distribution and abundance

A total of 29,663 calamary were caught from 538 survey shots. Catch rates varied between 0 and 196 calamary.km^{-1}. Numerical and biomass catch rates were positively correlated (Spearman Rank $r = 0.56$, $n = 538$, $p < 0.001$). Calamary were widely distributed throughout the offshore waters of Gulf St. Vincent and displayed a transient pattern of abundance with catch rates varying both spatially and temporally (Fig. 4.4). The statistical distribution of catch rates was positively skewed, indicating that calamary were patchily distributed throughout the gulf, particularly in March and April when catch rates were highest.

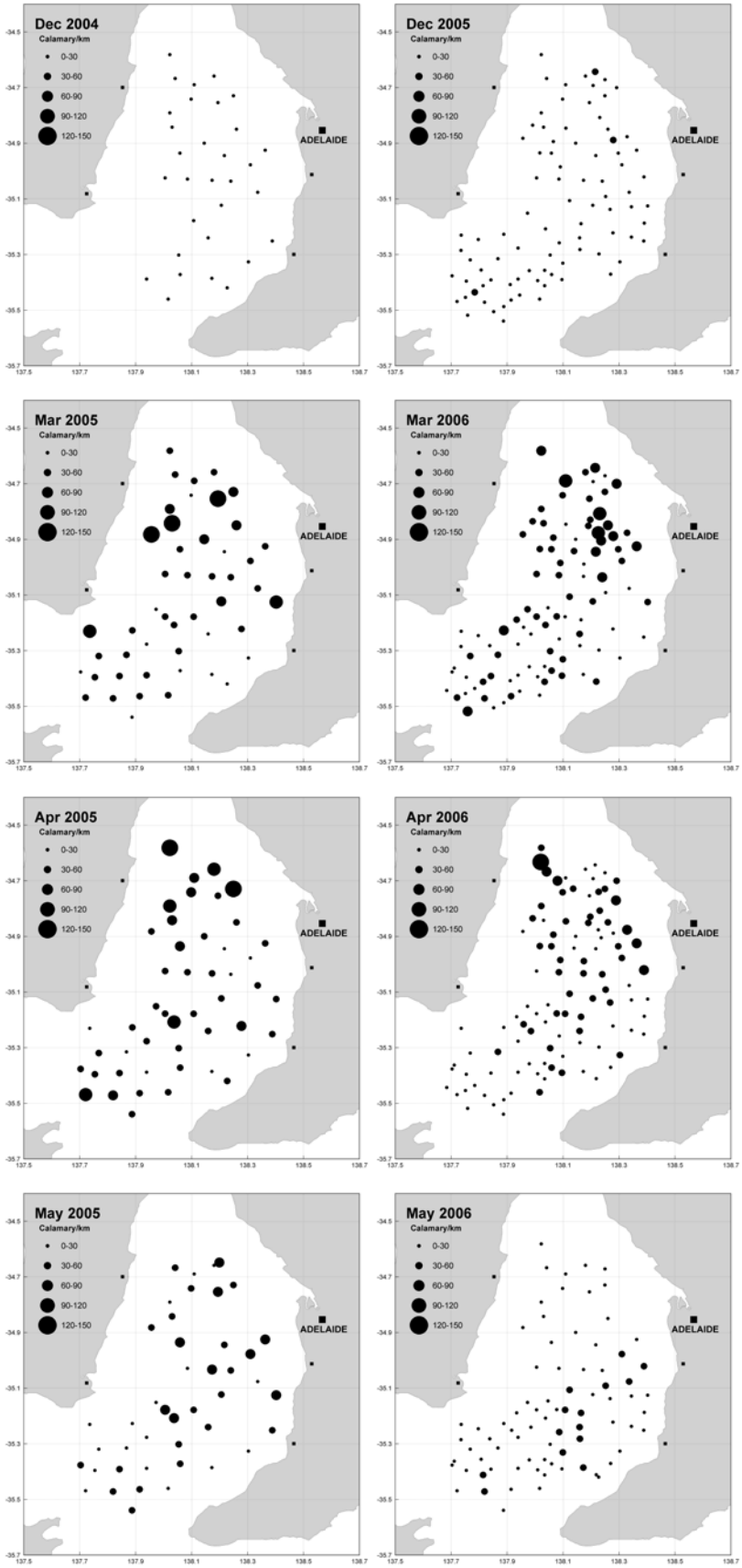

Figure 4.4. Distribution and abundance of calamary caught in Gulf St. Vincent during the 2004/05 and 2005/06 survey seasons.

Average monthly peak catch rates varied between fishing seasons (season*month interaction: $F_{3, 530} = 4.279$, $p = 0.033$) (Fig. 4.5a). Calamary were least abundant in December in both years. Peak catches occurred in April 2005 and in March 2006 at 54.3 and 39.1 calamary km^{-1}, respectively. Catch rates were lower in 2005/06, particularly towards the end of the fishing season, where mean calamary abundance significantly declined in April and May by 45.3% and 47.0%, respectively. A similar trend was evident when only the sub-adult component of the population was considered (season*month interaction: $F_{3, 336} = 10.343$, $p < 0.001$) (Fig. 4.5b).

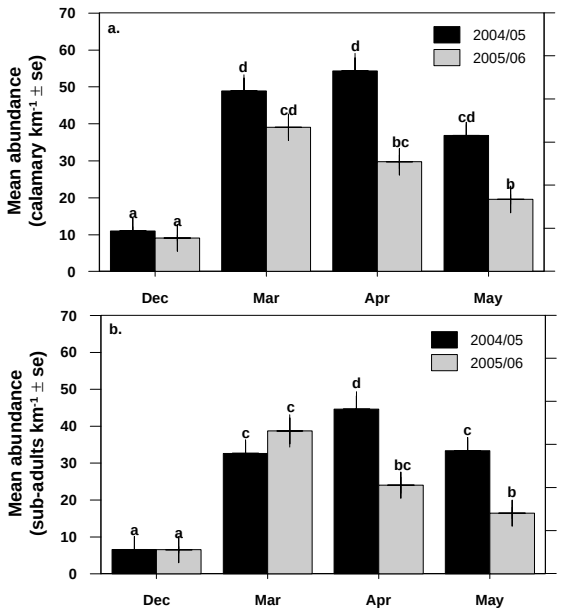

Figure 4.5. Changes in (a.) mean total calamary abundance and (b.) mean sub-adult abundance over the trawl survey period for the 2004/05 and 2005/06 fishing seasons. Letters indicate the results of Tukey's HSD post hoc test (means with the same letter are not significantly different)

4.2.2. Catch composition

Biological parameters were measured for 9,464 individuals. Of these, there were 822 juveniles, 4,250 females and 4,392 males that all ranged in size from 22 mm to 255 mm ML. Sub-adults dominated the catch representing 84.7% of the sampled population; juveniles comprised 8.7% and adults 6.6%. Adults made their highest proportional contributions in December but were largely absent in March and April in both fishing seasons (Fig. 4.6). Juveniles were most evident in December, March and April. The size structures of the sub-adults were temporally stable throughout both fishing seasons (Fig. 4.6).

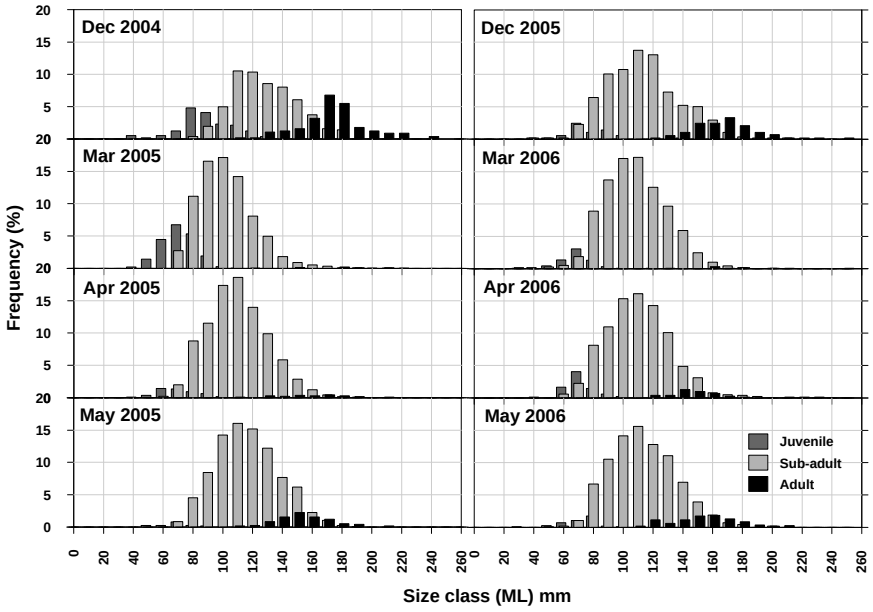

Figure 4.6. Monthly catch composition of calamary trawled in Gulf St. Vincent during the 2004/05 and 2005/06 fishing seasons.

4.2.3. Estimating calamary by-catch in GSV

Through regular by-product surveys, it was possible to obtain spatial (fishing block) and temporal (monthly) calamary mean catch rates. These catch rates were applied to the prawn fishery's commercial effort data, which reports area fished and duration of trawl shots (mins), to provide an estimate of the total calamary caught by the GSV prawn fishery in each fishing season. Estimates of total calamary catch, both in terms of numbers and weight, were calculated by adding monthly block estimates to incorporate the spatial and temporal variation in catch rates. The error variances were propagated throughout the calculation. Calculating estimated total calamary catch this way can be considered more accurate than generally applying a grand mean catch rate to total fishing effort.

The estimated calamary catch from the GSV prawn fishery in 2005/06 was 227,202 animals with an estimated total weight of 13.0 t (Table 4.1, 4.2), 56.8% less than in 2004/05. Trawl effort had also declined 28.3% from 205,479 mins in 2004/05 to 147,295 mins in 2005/06. It was estimated that trawlers caught calamary at a rate of 1.54 animals/min in 2005/06, 39.8% less than 2.56 animals/min estimated for the previous fishing season (Fig. 4.7).

Table 4.1. Commercial prawn fishery effort, estimated catch rate from by-product surveys and estimated total calamary catch (numbers of animals ± standard error) from the GSV prawn fishery in 2005/06. * indicates an absence of data and the incorporation of the survey block's mean catch rate.

Survey block	Data	December	March	April	May	June
1	effort (mins)	3435	190	280	80	-
	calamary/min	0.90 (0.15)	3.60 (0.50)	2.60 (0.40)	0.78 (0.10)	2.1 (0.24)*
	total	3104.86 (511.49)	677.70 (91.70)	729.80 (121.40)	62.04 (8.00)	-
2	effort (mins)	15	505	150	1495	2735
	calamary/min	0.58 (0.08)	2.24 (0.12)	2.25 (0.19)	0.97 (0.11)	1.66 (0.13)*
	total	8.69 (1.24)	1130.64 (58.37)	338.00 (28.43)	1445.17 (169.17)	4526.70 (354.36)
3	effort (mins)	75	570	7547.5	11532.5	21187.5
	calamary/min	0.22 (0.03)	2.12 (0.39)	1.83 (0.29)	0.84 (0.19)	1.43 (0.19*)
	total	16.25 (2.17)	1210.3 (219.47)	13786.77 (2227.2)	9687.30 (2252.34)	30389.5 (4019.10)
4	effort (mins)	-	90	330	90	-
	calamary/min	0.42 (0.13)	1.14 (0.38)	1.16 (0.27)	1.16 (0.27)	0.99 (0.14)*
	total	-	102.50 (34.29)	383.78 (90.47)	104.30 (24.64)	-
5	effort (mins)	7610	720	675	4950	-
	calamary/min	0.70 (0.17)	4.04 (0.43)	2.476 (0.33)	1.53 (0.15)	2.26 (0.22)*
	total	5366.86 (551.71)	2908 (147.30)	1669.14 (127.08)	7575 (787.28)	-
Hole	effort (mins)	1585	11045	9262.5	8567.5	3490
	calamary/min	0.54 (0.07)	2.24 (0.20)	2.16 (0.19)	1.93 (0.16)	1.74 (0.12)*
	total	849.11 (114.91)	24765.34 (2259.70)	19986.42 (1743.80)	16544.79 (1362.60)	6061.16 (420.83)
IS	effort (mins)	2775	865	37195	6845	1402.5
	calamary/min	0.45 (0.11)	2.23 (0.45)	0.74 (0.14)	1.20 (0.18)	1.24 (0.17)*
	total	1237.74 (312.10)	1922.61 (386.40)	27630.57 (5184.9)	8207.66 (1225.26)	1742.64 (242.29)
				Total effort (mins)	**147,295**	
				Estimated total calamary catch (# animals)	**227,202.43 (8,156.80)**	

Table 4.2. Commercial prawn fishery effort, estimated catch rate from by-product surveys and estimated total calamary catch (kgs ± standard error) from the GSV prawn fishery in 2005/06. * indicates an absence of data and the incorporation of the survey block's mean catch rate.

Survey block	Data	December	March	April	May	June
1	effort (mins)	3435	190	280	80	-
	kg/min	0.06 (0.01)*	0.19 (0.03)	0.137 (0.02)	0.06 (0.01)	0.11 (0.013)
	total	212.21 (37.85)	35.96 (5.88)	37.91 (6.04)	4.62 (0.79)	-
2	effort (mins)	15	505	150	1495	2735
	kg/min	0.06 (0.01)*	0.09 (0.01)	0.12 (0.01)	0.06 (0.01)	0.09 (0.01)
	total	0.85 (0.13)	44.89 (3.03)	18.39 (1.71)	86.84 (7.00)	237.63 (16.17)
3	effort (mins)	75	570	7547.5	11532.5	21187.5
	kg/min	0.02 (0.01)*	0.12 (0.03)	0.09 (0.01)	0.07 (0.02)	0.08 (0.01)
	total	1.21 (0.10)	70.61 (14.72)	658.62 (103.67)	782.63 (173.06)	1778.86 (231.84)
4	effort (mins)	-	90	330	90	-
	kg/min	0.04 (0.01)*	0.05 (0.02)	0.06 (0.01)	0.07 (0.02)	0.06 (0.01)
	total	-	4.54 (1.65)	18.27 (4.21)	6.24 (1.76)	-
5	effort (mins)	7610	720	675	4950	-
	kg/min	0.05 (0.01)*	0.16 (0.02)	0.11 (0.02)	0.08 (0.01)	0.10 (0.01)
	total	408.13 (101.83)	111.86 (11.47)	75.72 (12.17)	385.68 (62.16)	-
Hole	effort (mins)	1585	11045	9262.5	8567.5	3490
	kg/min	0.05 (0.01*)	0.10 (0.01)	0.12 (0.01)	0.13 (0.01)	0.10 (0.01)
	total	77.39 (9.05)	1135.34 (88.35)	1137.54 (76.61)	1106.22 (95.63)	355.18 (20.41)
IS	effort (mins)	2775	865	37195	6845	1402.5
	kg/min	0.03 (0.01)*	0.12 (0.02)	0.06 (0.01)	0.09 (0.01)	0.08 (0.01)
	total	87.91 (17.20)	104.74 (20.89)	2087.28 (419.05)	592.92 (98.50)	108.56 (13.45)
				Total effort (mins)	**147,295**	
				Estimated total calamary catch (kg)	**13,035.62 (566.18)**	

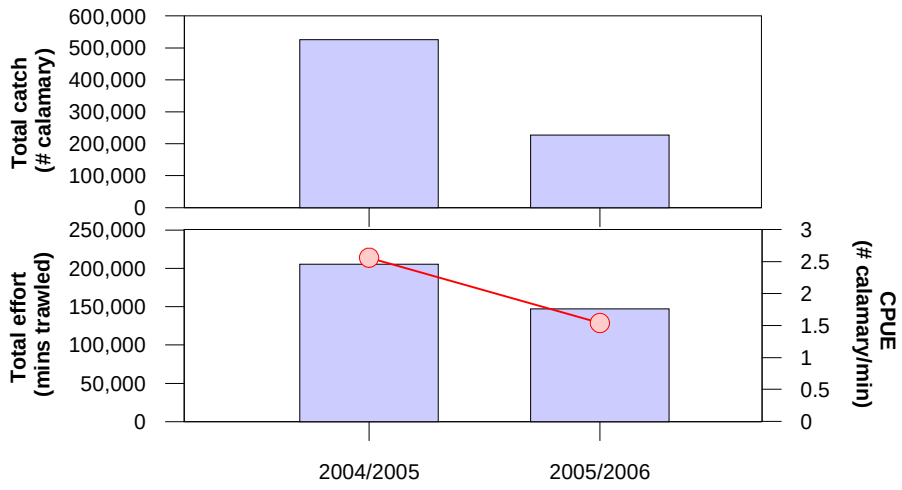

Figure 4.7. (a.) Annual calamary catch from the Gulf St. Vincent prawn trawl fishery estimated from structured fishery-independent trawl surveys. (b.) Annual trawl effort and associated estimate of CPUE.

4.3. West Coast calamary by-product

There is no time series of calamary data for this fishery as mandatory reporting of by-product species was implemented in December 2005. Given the oceanic environments in which this fishery operates (Dixon and Roberts 2006) it is unlikely that calamary, which are predominantly an inshore species, would contribute significantly to the catch. Oceanic arrow squid are more likely to constitute a greater proportion of the squid by-product.

5. POPULATION DYNAMICS AND REPRODUCTIVE ECOLOGY

Dynamics of the South Australian calamary population, like many other squid fisheries, are complicated by continuous recruitment to the inshore spawning grounds throughout the year (Moltschaniwskyj and Pecl 2007). Consequently, multiple 'micro-cohorts' may be present in the fishery at any one time. Fishing pressure is therefore not focussed on a single population cohort. In conventional fisheries assessment, there is an implicit assumption that the population is composed of relatively discrete cohorts of increasing size and age. The construction of age-length keys, through direct ageing, allows the exploitation rate of a single age group to be monitored over time. Although it is possible to resolve calamary micro-cohorts through statolith age estimates, estimates of recruitment, fishing mortality and natural mortality would be required for each of the discrete micro-cohorts (Boyle and Rodhouse 2005). This process is further obscured by the fact that this species has a sub-annual life cycle and exhibits extreme plasticity in growth rate. Consequently, the construction of a reliable age/length key is, therefore, fundamentally flawed.

Stochastic environmental variation on sub-annual species is a major impediment to the establishment of a reliable assessment and management procedure for cephalopods (Boyle and Rodhouse 2005). For annual species that exhibit a defined seasonal spawning period there is an increased risk of recruitment failure because spawning may coincide with poor environmental conditions. Fishers, who target seasonal spawning aggregations, remove animals before they successfully breed, increasing the risk of collapse. Through spawning year round, calamary have effectively spread the mortality risk, by increasing the probability that at least a proportion of eggs laid will encounter favourable conditions and successfully recruit (Moltschaniwskyj and Steer 2004). Despite this natural safeguard, calamary stocks are still at risk of recruitment failure, as present day fishers have a general understanding of their spawning dynamics and continue to target spawning aggregations. This section aims to describe the composition of the commercially fished population and the seasonality of maturation and reproduction.

5.1. Field sampling

A fisheries independent sampling regime was initiated in December 2004 to document changes in calamary population structure and reproductive ecology. Sampling was carried out on a monthly basis at four inshore locations within Gulf St. Vincent; Myponga, Marino, Port Vincent and Edithburgh (Fig. 4.3). These areas were selected as they were considered in previous independent surveys that were done throughout the 1990s (Triantafillos 2001). Within each location, five sites were sampled, that were typically less than 5 m deep and within 15 km of each

other. Efforts were made to jig at least 15 calamary at each site, however, variable weather conditions, local abundance and catchability meant that this target was not always reached. Additional samples, consisting mostly of juveniles and sub-adults, were obtained from the deeper, offshore waters of the gulf, as 'by-product' from commercial prawn trawlers (see Section 4.0).

Each individual was measured (ML), weighed (to 0.1 g), sexed, and assigned a maturity stage based on the criteria specified in Table 5.1. Gonad weight, including the associated reproductive structures, was recorded for each jigged animal. Gonadosomatic indices (GSI) were calculated for both males and females using the following equation:

$$GSI = (GW/(BW - GW)) * 100,$$

where GW is the weight of the entire gonad (including all accessory reproductive structures) and BW is total body weight. Statoliths were retained from each individual for age investigations.

Statoliths were whole-mounted in Crystal Bond® thermoplastic cement with the ventral dorsal dome projecting over the edge of the glass slide. The statolith was then ground along a transverse plane, using wet 30 μm lapping film, until the plane passed through the statolith nucleus. The ground surface was polished with 0.05 μm alumina powder on suede polishing cloth. The extent and intensity of grinding was continually monitored using a binocular light microscope. The polished surface was mounted so that the rostrum aligned perpendicular to the slide's surface. The statolith was ground and polished to a section thin enough for examination. Age estimates were determined by counting alternating light and dark increments in the statoliths under a high power microscope (400x), illuminated with transmitted light (Fig. 2.4). Each sequence of a dark and light increment outside of the natal ring was assumed to represent one day's growth (Jackson 1994; Pecl 2004). Counts were made by two independent, experienced readers. If counts between readers differed by >10% a third count was done and the outlier discarded. Statoliths were rejected if counts continued to differ by >10% or if the natal ring could not be identified.

The distribution and abundance of calamary eggs was also investigated at each of the four Gulf St. Vincent locations. Egg surveys were based on the methods described in Moltschaniwskyj et al. (2003). At each site 20 belt transects of dimensions 10 x 2 m were haphazardly laid out over the substratum and the area carefully searched for eggs. Each egg mass encountered was assigned a developmental stage according to the criteria specified in Table 5.2, and the length of the mass recorded to the nearest centimetre. Due to variation in the size of egg masses, the

number of egg strands was considered a better estimate of spawning intensity than the number of egg masses. The majority of egg masses consisted of more than 50 strands making it intractable to count individual strands underwater. Thus, in order to estimate the number of strands within an egg mass a total of 91 egg masses of different sizes and developmental stages were measured *in situ* and then collected between December 2004 and May 2005. The number of egg strands in each mass was counted. A Model II regression was used to generate a predictive relationship to calculate the number of strands from the length of an egg mass (*sensu* Moltschaniwskyj et al. 2003). Hatching or disintegrating egg masses (Stage IV) were not included in the analysis, as they could not be accurately measured. There was a significant positive linear relationship ($F = 500.6$; $df = 1, 90$; $p < 0.01$) with egg mass length explaining 85.0% of the variation in number of egg strands

Table 5.1. Decsription of maturation stages for female and male southern calamary (adapted from Lipinski's (1979) universal maturity scale for cephalopods).

	Maturity Stage	Gonad description
Females	I Developing	Sexual organs difficult to see. Oviducts and nidamental glands appear as fine translucent strips. Ovary is translucent and membranous.
	II Immature	Nidamental glands form clearly visible whitish strips. Oviduct meander and ovary are visible.
	III Preparatory	Nidamental glands are enlarged. Oviduct meander is extended. Immature oocytes visible inside the ovary.
	IV Maturing	Nidamental glands are large. Oviducts are fleshy and swollen. Oviducts contain numerous transparent oocytes.
	V Mature	As above, except the oocytes are translucent.
	VI Spent	No oocytes, or degenerated ones present in the oviduct. Nidamental glands reduced, mantle tissue flaccid. Animal condition is poor.
Males	I Developing	Sexual organs difficult to discern. Spermatophoric complex appears as a translucent spot.
	II Immature	Sexual organs are whitish and the separate parts of the spermatophoric complex are visible.
	III Preparatory	Spermatophoric complex is clearly visible. The spermatophore sac is long containing white particles.
	IV Maturing	Sexual organs, including testis, vas deferens and spermatophoric complex are whitish.
	V Mature	As above, except spermatophores are present in spermatophore sac.
	VI Spent	No spermatophores in spermatophoric sac or only degenerated ones. Animal condition is poor.

Table 5.2. Description of calamary egg mass stages as determined by Moltschaniwskyj et al. (2003).

Stage	Egg mass description
I	Newly laid eggs, very white and shiny, no fouling by algae
II	Eggs no longer shiny, little fouling evident, eggs not clearly obvious
III	Eggs clearly obvious, extensive fouling on egg mass, embryos pigmented
IV	Most of the mass had hatched and had started to disintegrate

5.2. Size structure

A Total of 2,114 calamary (1,477 males and 667 females) were jigged from inshore waters from December 2004 until December 2006. The size structure of calamary was broad with mantle lengths ranging from 74 to 394 mm and 96 to 295 mm for males and females, respectively (Fig. 5.1). In most months, two or more modes were apparent and there were no clear trends of modal progression. The size composition for females was relatively stable throughout the sampling period with the majority of animals approximately 200 mm size class.

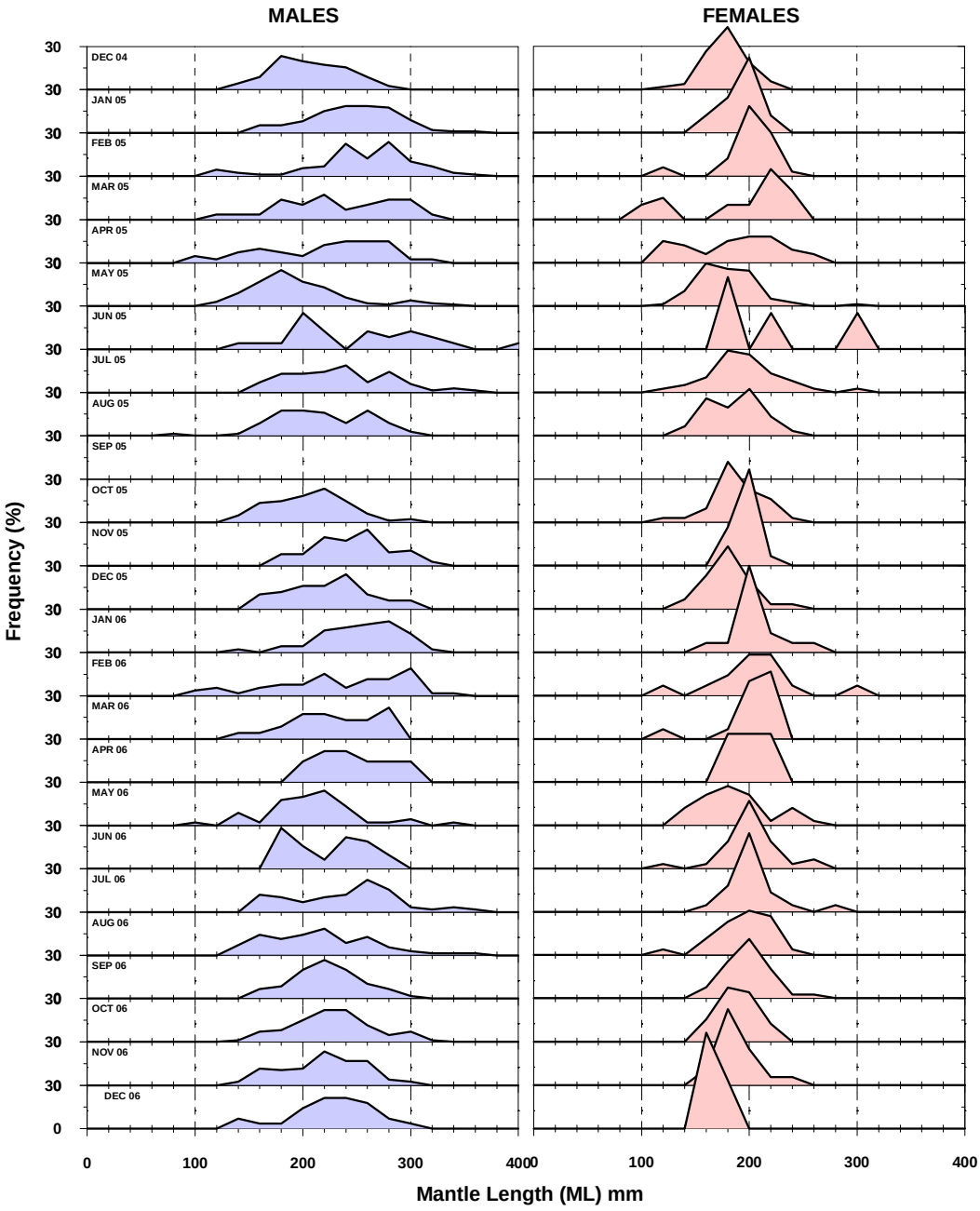

Figure 5.1. Monthly size frequency histogram for male (blue) and female (pink) southern calamary from fishery independent sampling from December 2004 to December 2006.

5.3. Age structure

Statoliths were processed from 440 individuals with an average of 18 sampled per month. Of these a total of 393 (89.3%) were successfully aged (n_{males} = 206, $n_{females}$ = 187). The relationship between age in days and total weight was best described by exponential functions for both males and females (Fig. 5.2). There was considerable variability in size for individuals of the same age. For example, at age 200 days, males differed by as much as 700 g and females by 400 g (Fig. 5.2). There was no significant gender difference in the rate of growth in weight ($F_{equal\ slopes}$ = 3.911; df = 1, 574; p = 0.05), however males were, on average, heavier at a given age ($F_{intercept}$ = 31.45; df = 1, 574; p < 0.05).

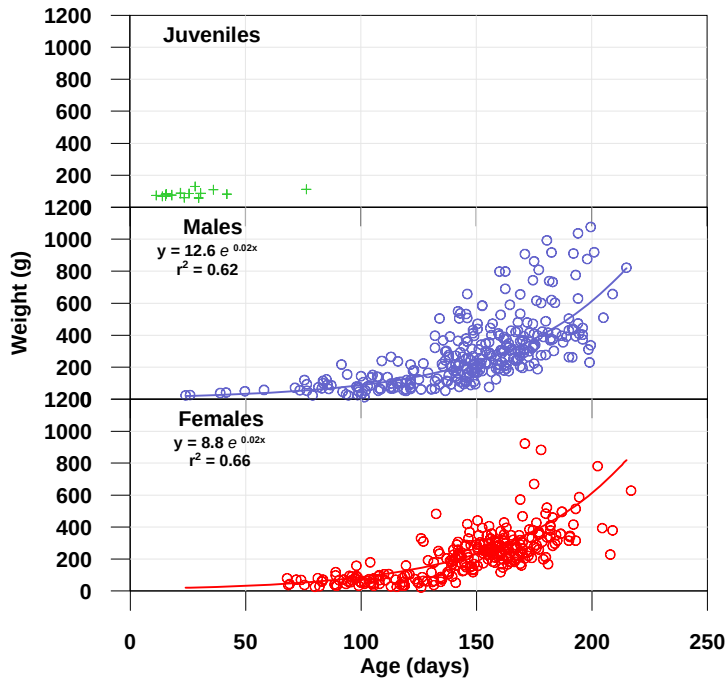

Figure 5.2. Calamary growth in total body weight of juveniles, males and females. Exponential curves fitted and associated parameters displayed.

The observed age range for calamary collected from fishery-independent jig sampling was 105 to 215 days for males, and 120 to 217 days for females. The mean age distribution across all months of capture did not exhibit much variation (Fig. 5.3). Considerable heterogeneity of variances were observed among months, therefore individual months were compared using Bonferroni adjusted pairwise t-tests assuming unequal variances. The mean age in December 2006 was significantly less than in January and March 2005 but not significantly different from each of the other months. The high degree of variance seen in some months (e.g. May 2005) suggests that individuals were caught from a mixture of cohorts (Fig. 5.3). The overall average age of calamary caught on the inshore spawning grounds was 162.6 ± 0.9 days, i.e., approximately five months.

Estimated hatch dates were back-calculated from age data for each monthly sample. The frequency distribution of estimated hatch dates clearly showed that calamary hatched throughout the year (Fig. 5.4).

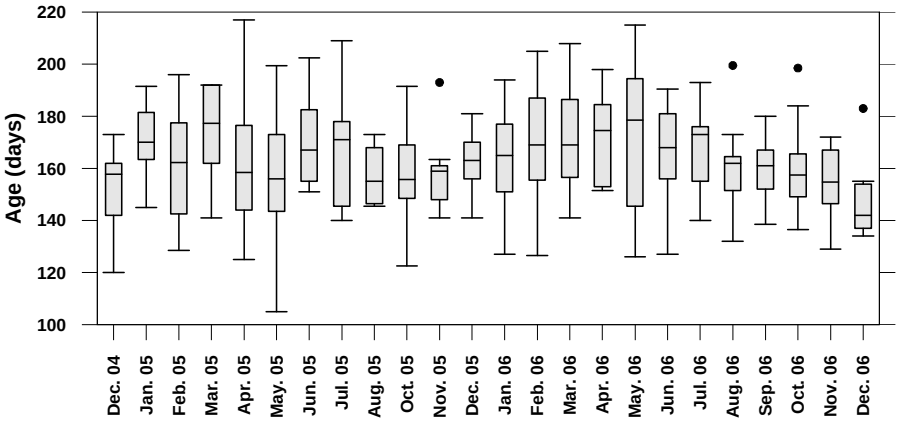

Figure 5.3. Age distribution of calamary for each month of capture.

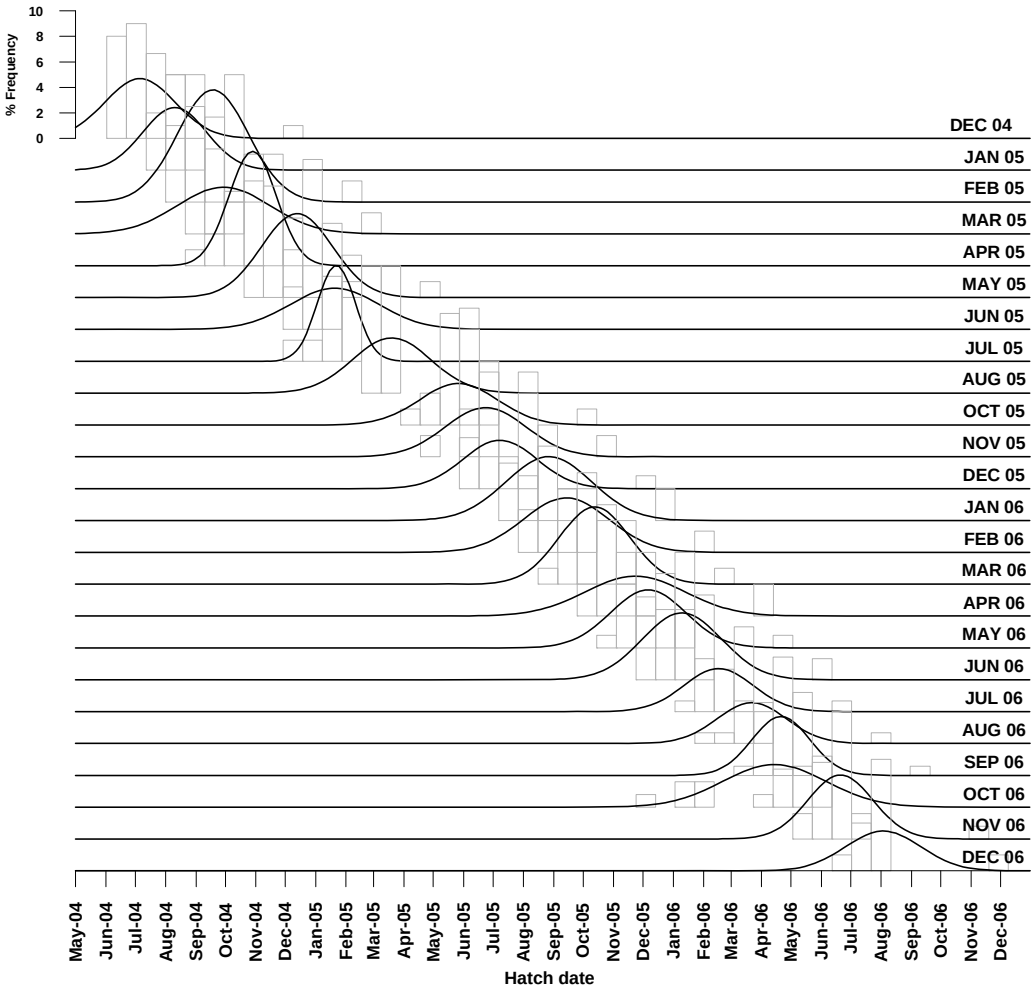

Figure 5.4. Frequency distributions of estimated hatch dates for calamary for each month of capture.

5.4. Size and age at first maturity

Males matured at a smaller size and earlier age than females. The smallest mature male was 88 mm ML and 84 days old, whereas the smallest mature female was 117 mm ML and 104 days old (Fig. 5.5). Size and age at first sexual maturity (50%) was 150 mm ML and 124 days for males and 163 mm ML and 139 days for females.

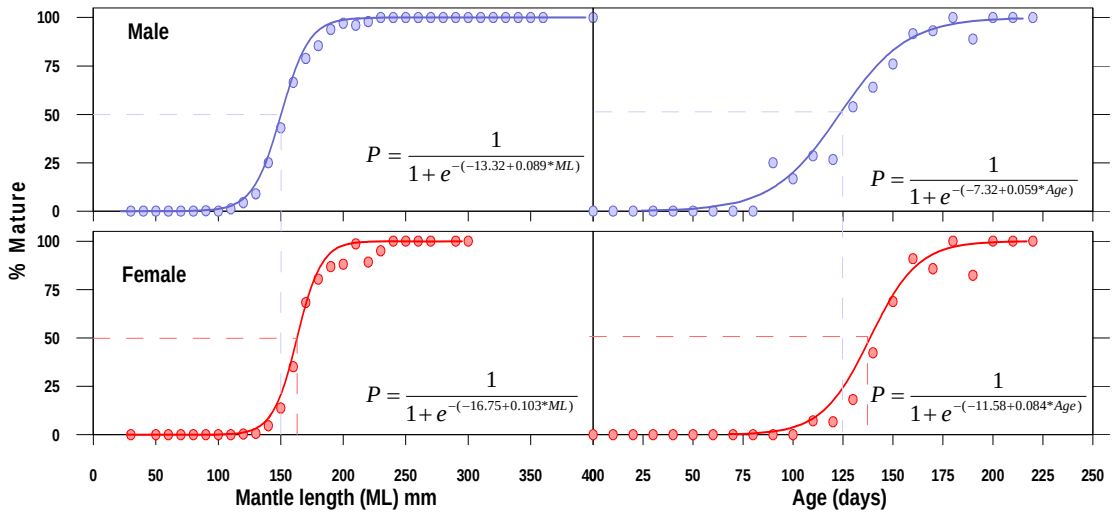

Figure 5.5. Logistic relationships between the number of reproductively mature individuals expressed as a proportion of the population, against mantle length (mm) and age (days) for both males and female calamary from Gulf St. Vincent.

5.5. Maturity stages

Fishery-independent sampling revealed that most males (90.2%) were fully mature, with few approaching maturity (7.1%), immature (2.0%) and spent (0.8%). The highest proportion of immature males was caught in late summer and autumn (Fig. 5.6). This was also characterised by a decline in male GSI where average weight of testes contributed to a relatively low proportion (~2.5%) of the body weight (Fig. 5.6). Most females (66.2%) contained ovulated eggs and were in spawning condition and a further 29.2% were in an advanced stage of maturity. Few were immature (3.5%), or spent (1.2%). Females displayed considerable variability in the proportions of individuals at each maturity stage between months (Fig. 5.6). The greatest proportion of immature females were caught in mid autumn with average GSI falling below 2% Females were in peak spawning condition in late spring/early summer with GSI's exceeding 13%.

The sex ratio of calamary caught from inshore waters varied over the sampling period. Males tended to dominate when females were in spawning condition (Fig. 5.6), most likely a result of reduced female catchability. Sex ratios were relatively even during autumn. The sex ratio of

trawl-caught calamary (see Chapter Four), which is presumably non-selective, revealed a 1:1 male to female ratio.

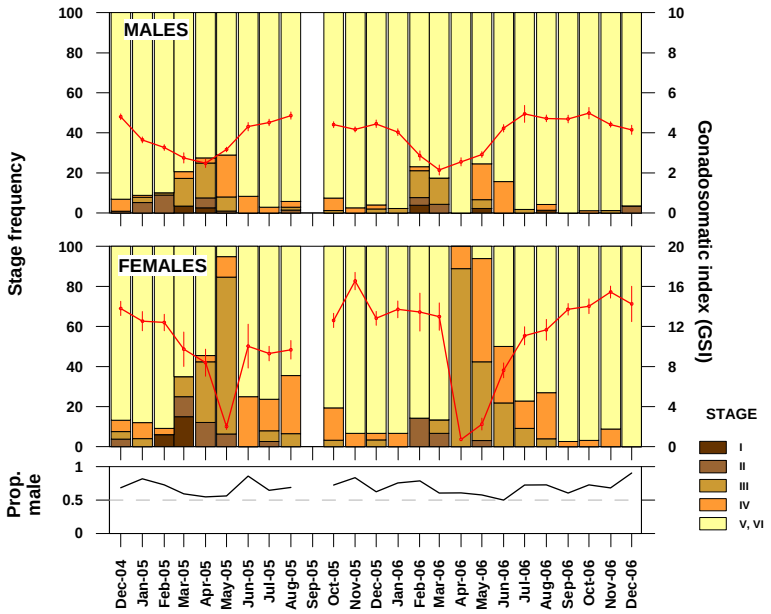

Figure 5.6. Percentage distribution of maturity stages and mean gonadosomatic index (± se) for male and female calamary within Gulf St. Vincent from December 2004 until December 2006. Sex ratio expressed as proportion male also presented. Legend indicates maturation stages.

5.6. Distribution and abundance of eggs

Sizes of egg masses varied considerably, ranging from solitary egg strands attached to the ends of seagrass blades to large masses containing up to 1,912 strands. Most egg masses contained < 300 egg strands (Fig. 5.7).

Calamary spawned throughout the year, however the seasonal pattern of spawning activity was not consistent across locations (season*location interaction; $F_{21, 7679} = 19.140$; $p < 0.001$). The highest average egg densities were found during spring and summer at Myponga, with shallow seagrass areas consistently supporting >1,000 egg strands per 100 m² (Fig. 5.8.). Such high egg densities at Myponga during the warmer months are consistent with historical data (Triantafillos 2001). By late autumn, only hatched (Stage IV) egg masses were evident, suggesting that spawning had finished at this location (Fig. 5.9). Lower level spawning activity (<500 strands per 100 m²) was observed at Marino throughout the summer months. Average egg density in this region peaked at 1,604 strands per 100 m² in April 2005, recording similar levels to that previously seen at Myponga (Fig. 5.8). This, however, was not maintained, as there was little evidence of spawning in subsequent winter months (Fig. 5.8). Port Vincent also exhibited low level spawning activity during the summer months but unlike Marino, this extended throughout autumn and peaked in mid-winter 2005 at 1,210 strands per 100 m² and again in October 2005 at

982 strands per 100 m² (Fig. 5.8). Spawning intensity was greatest during spring and summer at Edithburgh, however egg densities rarely exceeded 250 strands per 100 m² (Fig. 5.8).

The large error variances associated with the estimates of mean egg density are indicative of the extreme spatial patchiness of calamary spawning (Fig. 5.8). Discrete spawning aggregations were frequently observed in close proximity to each other. On other occasions, individuals in obvious spawning condition (i.e. females with swollen oviducts and sperm in their spermathecae) were caught, yet no eggs were found in the immediate vicinity. This observation suggests that calamary spawning is behaviourally complex and the cues required to initiate egg deposition are unknown. In many cases, spawning beds had eggs in various stages of development, indicating that the area had been used repeatedly (Fig 5.9).

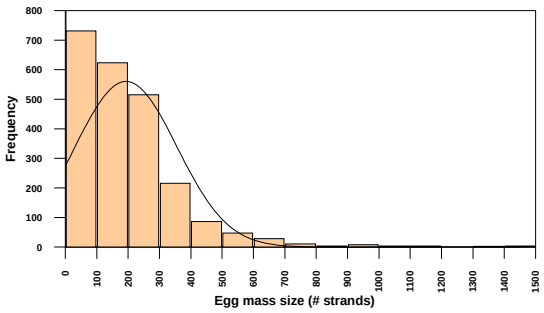

Figure 5.7. Size frequency distribution of egg masses in Gulf St. Vincent (as determined by the number of individual strands) measured from December 2004 until December 2006.

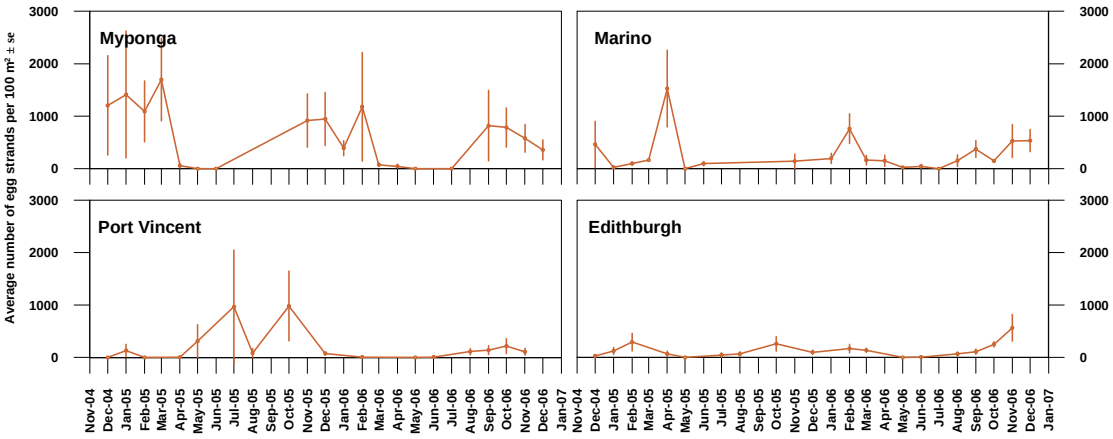

Figure 5.8. The average density (± standard error) of calamary egg strands per 100 m² at each of the four locations in Gulf St. Vincent from December 2004 until December 2006.

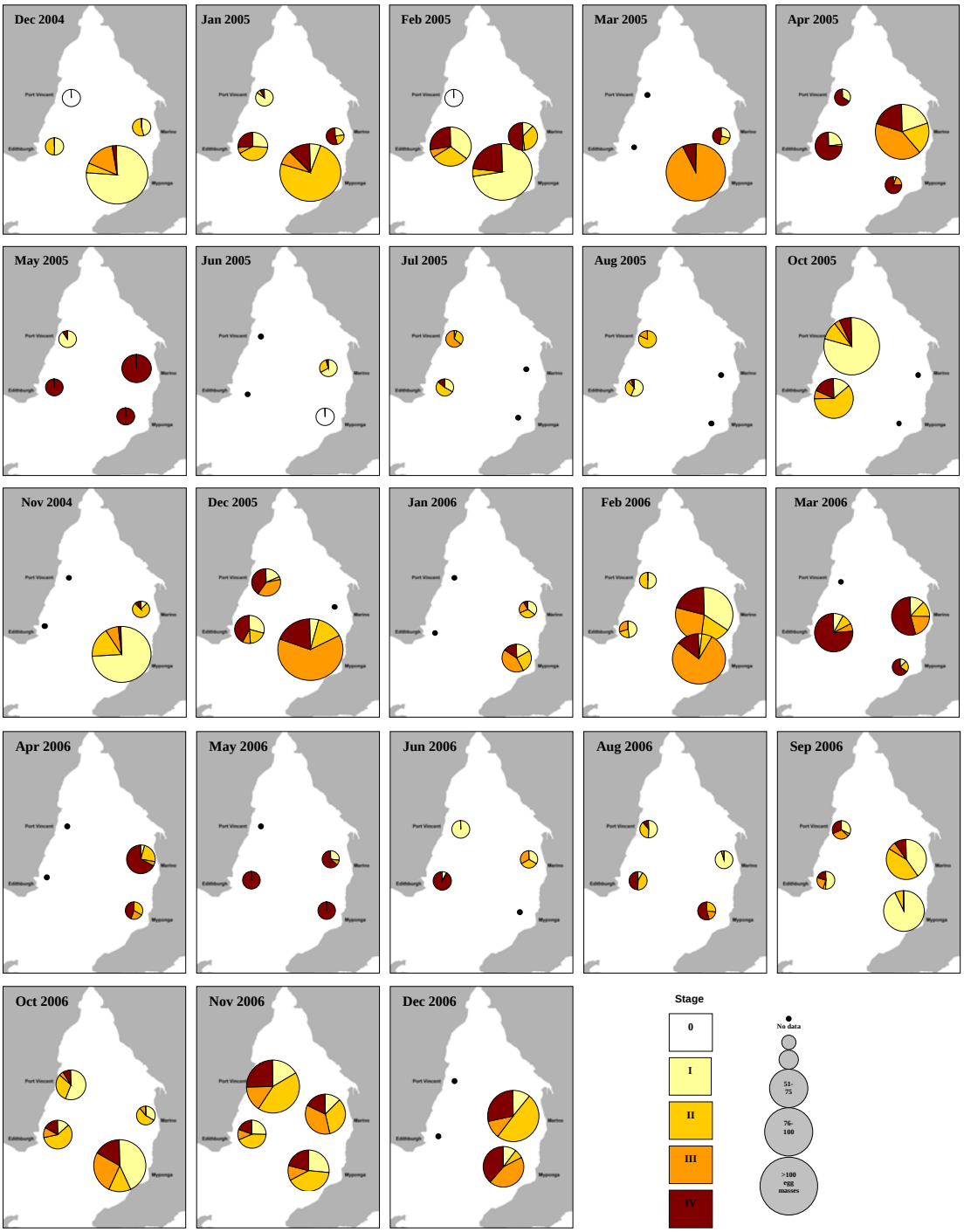

Figure 5.9. Distribution and abundance of calamary egg masses and their various stages of development from December 2004 until December 2006 in Gulf St. Vincent.

6. CALAMARY PRE-RECRUIT INDICES

Trends in spatial and temporal commercial catch, effort and estimates of catch per unit effort (CPUE) data are currently the only indicators of stock biomass for the South Australian calamary fishery. Time delays associated with compiling and analysing catch and effort data combined with the squid's short lifespan means that there may be no warning of impending recruitment failure. Consequently, there is a need for reliable pre-recruit indices that would allow managers to track the status of the fishery and to respond quickly to negative indicators. Several approaches are currently being developed for use in other squid fisheries. The use of environmental proxies, such as sea surface temperature and wind strength, has demonstrated predictive potential (Pierce and Boyle 2003; Miyahara et al. 2004). However, the results from these stock-recruitment studies are still preliminary but may potentially be used to manage a number of well-understood and high-value squid fisheries (eg. *Loligo vulgaris reynaudii* Sauer and Smale 1993; *Todarodes pacificus* Sakurai et al. 2000; *Loligo opalescens* Zeidberg et al. 2006).

Egg and pre-recruit surveys, including both paralarval and sub-adult sampling, are the most promising and have yielded significant correlations with subsequent stock size (Augustyn et al. 1992). Measures of egg production have been limited to inshore calamary species as they typically deposit their eggs in shallow, accessible, coastal environments. Structured dive and acoustic surveys have been used to quantify egg production on known productive spawning grounds for chokka squid (*L. v. reynaudii*) in South Africa (Sauer et al. 1993) and southern calamary in Tasmania (Moltschaniwskyj et al. 2003). So far, only weak, negative relationships between egg production and the following year's commercial catch and CPUE have been identified and the significance of these relationships remain inconclusive (Ziegler et al. 2006).

Trawl surveys, both fisheries dependent and independent, have been used as predictors of squid abundance in other fisheries, as well as providing information on spatial distribution patterns, species composition, environmental processes and information on the life cycle (Dawe and Hurley 1981; Okutani and Watanabe 1983; Lange and Sissenwine 1983; Pierce et al. 1998; Brodziak and Hendrickson 1998; Lordon et al. 2001). To date, the strengths of these predictions have been variable and attributed to problems associated with standardising trawl surveys, flexibility in the timing of life cycle events, unrefined commercial CPUE data (Pierce et al. 1998) and squid catchability (Brodziak and Henderickson 1999). Many of these problems, however, do not apply to South Australia, which is unique for a number of reasons. Firstly, the majority of calamary that are incidentally caught by prawn trawlers are either juveniles or sub-adults, which provides regular access to an important pre-recruit, life-history stage that has proven difficult to reliably sample in other squid fisheries. Secondly, trawl gear and fishing methods are

standardised across the prawn trawling fleet alleviating biases associated with diverse sampling methodologies. Finally, several commercial fishing vessels can be used in a structured survey to simultaneously sample across a broad geographic area under the same moonlight conditions.

This chapter aims to assess the feasibility of using environmental proxies of wind strength, direction and sea surface temperature, estimates of calamary egg production, and fishery-independent by-product CPUE data from the South Australian prawn sector as a means of forecasting recruitment strength for the calamary fishery.

6.1. Environmental proxies

Historic records of daily wind speed (km/h) and direction were obtained from the Bureau of Meteorology. These data were collected from weather stations on the eastern and western sides of both gulfs (i.e. Adelaide and Edithburgh in Gulf St. Vincent and Warooka and Port Lincoln in Spencer Gulf) from 1st January 1984 until 31st December 2006, and were chosen on the basis of their proximity to the four most productive calamary fishing regions (SCGSV, NWGSV, SESG and SWSG). Monthly averages were calculated and vector plots incorporating monthly targeted jig CPUE were constructed for each of the four regions. Monthly wind stress indices were calculated for each region isolating the southerly, south westerly and south easterly wind components using the following equations:

$$\text{Southerly wind component} = \text{wind speed} \times \cos(\text{wind direction} * ((2\pi)/360^{o}))$$

$$\text{South westerly wind component} = \text{wind speed} \times \cos(\text{wind direction} - 45^{o} * ((2\pi)/360^{o}))$$

$$\text{South easterly wind component} = \text{wind speed} \times \cos(\text{wind direction} - 315^{o} * ((2\pi)/360^{o}))$$

Estimates of sea surface temperature (SST) for Gulf St. Vincent and Spencer Gulf were obtained from a series of satellite images from the Physical Oceanography Distributed Active Archive Centre (http://podaac.jpl.nasa.gov). Monthly averages were calculated from a 1° x 1° grid in the central part of each gulf from 1st January 1984 until 31st December 2006. It was assumed that SST in these regions was representative of each gulf.

Retrospective cross correlation functions were used to explore whether fluctuations in commercial calamary catch rates significantly correlated with local wind conditions and sea surface temperature.

A 23-year analysis of average monthly wind strength and direction identified seasonal systemic wind conditions for SCGSV where strong local winds prevailed from the south and southeast in

summer and prevailed less consistently from the south west in late winter (Fig. 6.1). In winters where the winds prevailed from the south west they were generally strong, often reaching speeds >18 km/hr. Historically, targeted calamary catch rates in SCGSV were positively correlated with strong winds regardless of their direction (Fig. 6.1; Table 6.1). Catch rates, however, were found to increase one month after a period of strong southerly winds (Table 6.1), peaking in late spring / early summer (Fig. 6.1).

Local wind patterns in NWGSV were more variable than those in SCGSV and tended to prevail from a more westerly direction during winter (Fig. 6.1). Calamary catch rates were consistently higher during the winter months, generally peaking approximately three months after a period of offshore winds (Table 6.1). Catch rates were negatively correlated with strong southerly and south easterly winds (Table 6.1).

A more consistent seasonal weather pattern was evident for SESG, characterised by south westerly winds during winter, shifting south easterly during summer (Fig. 6.2). Calamary catch rates were also seasonal, typically increasing after a period of offshore winds and declining once the onshore, south westerly winds, set in (Table 6.2). Catch rates were highest during the winter months in SWSG also coinciding with periods of offshore winds.

The seasonal oscillation of sea surface temperature was similar for both Gulfs, each displaying a winter minima of 13.3 ºC and a summer maxima of ~ 21.5 ºC (Fig. 6.3). Retrospective cross correlation functions identified weak, significant, relationships between calamary catch rates in each gulf and SST six to ten months prior (Table 6.3).

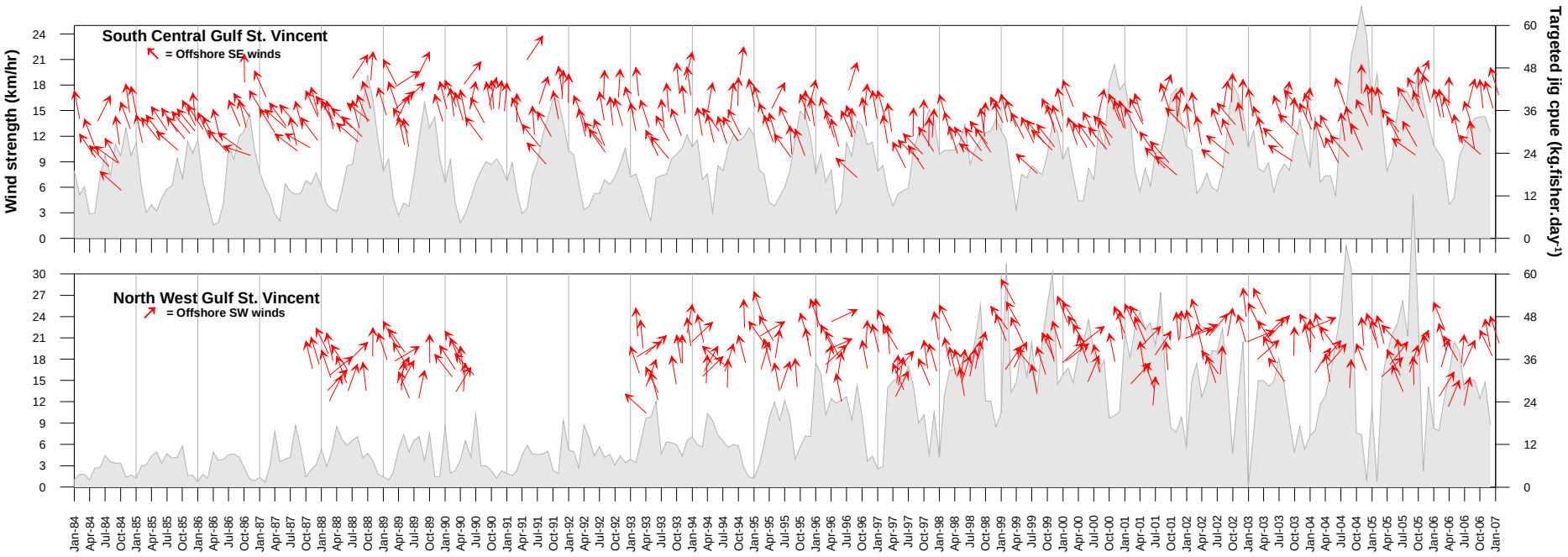

Figure 6.1. Historical record of monthly commercial targeted jig cpue and associated local wind conditions (wind strength and direction) from January 1984 until December 2006 for South Central Gulf St. Vincent and North West Gulf St. Vincent.

Table 6.1. Correlation matrices of commercial targeted jig cpue with directional wind stress over a three month period for South Central Gulf St. Vincent and North West Gulf St. Vincent. * denote significant (α = 0.01) correlations. Value highlighted in green indicates the strongest positive correlation and those in red the strongest negative correlation.

SCGSV				
Time Lag	*0 month*	*1 month*	*2 months*	*3 months*
Southerly	*0.448**	***0.511****	*0.379**	*0.169**
South Westerly	*0.405**	*0.408**	*0.256**	*0.029*
South Easterly	*0.040*	*0.147**	*0.197**	*0.247**

NWGSV				
Time Lag	*0 month*	*1 month*	*2 months*	*3 months*
Southerly	***-0.322****	*-0.275**	*-0.180**	*-0.018*
South Westerly	*0.118*	*0.124*	*0.134*	***0.206****
South Easterly	*-0.284**	*-0.256**	*-0.201**	*-0.139*

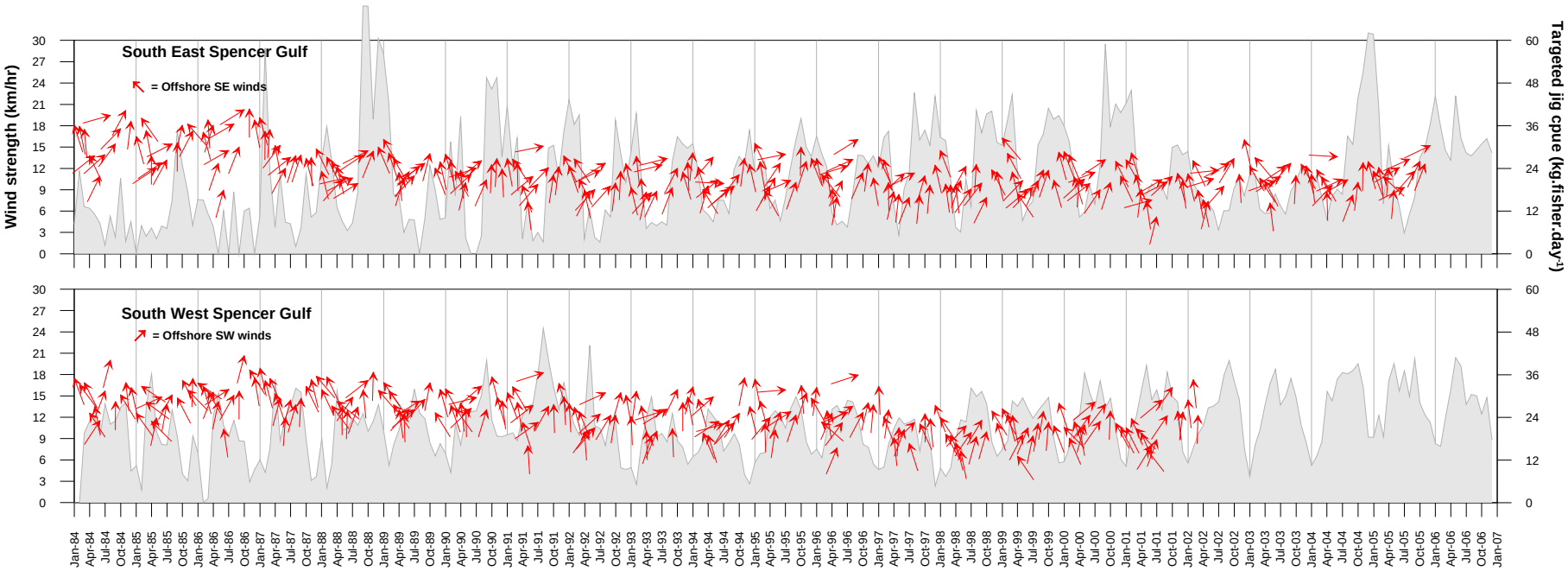

Figure 6.2. Historical record of monthly commercial targeted jig cpue and associated local wind conditions (wind strength and direction) from January 1984 until December 2006 for South East Spencer Gulf and South West Spencer Gulf.

Table 6.2. Correlation matrices of commercial targeted jig cpue with directional wind stress over a three month period for South East Spencer Gulf and South West Spencer Gulf * denotes significant (α = 0.01) correlations. Values highlighted in green indicate the strongest positive correlation and those in red the strongest negative correlation.

SESG				
Time Lag	*0 month*	*1 month*	*2 months*	*3 months*
Southerly	*0.153**	*0.209**	*0.105*	*0.015*
South Westerly	*-0.230**	*-0.363**	***-0.466****	*-0.446**
South Easterly	*0.291**	***0.428****	*0.400**	*0.276**

SWSG				
Time Lag	*0 month*	*1 month*	*2 months*	*3 months*
Southerly	*-0.342**	*-0.216**	*-0.114*	*0.001*
South Westerly	*0.282**	***0.359****	*0.311**	*0.198**
South Easterly	***-0.474****	*-0.432**	*-0.316**	*-0.143*

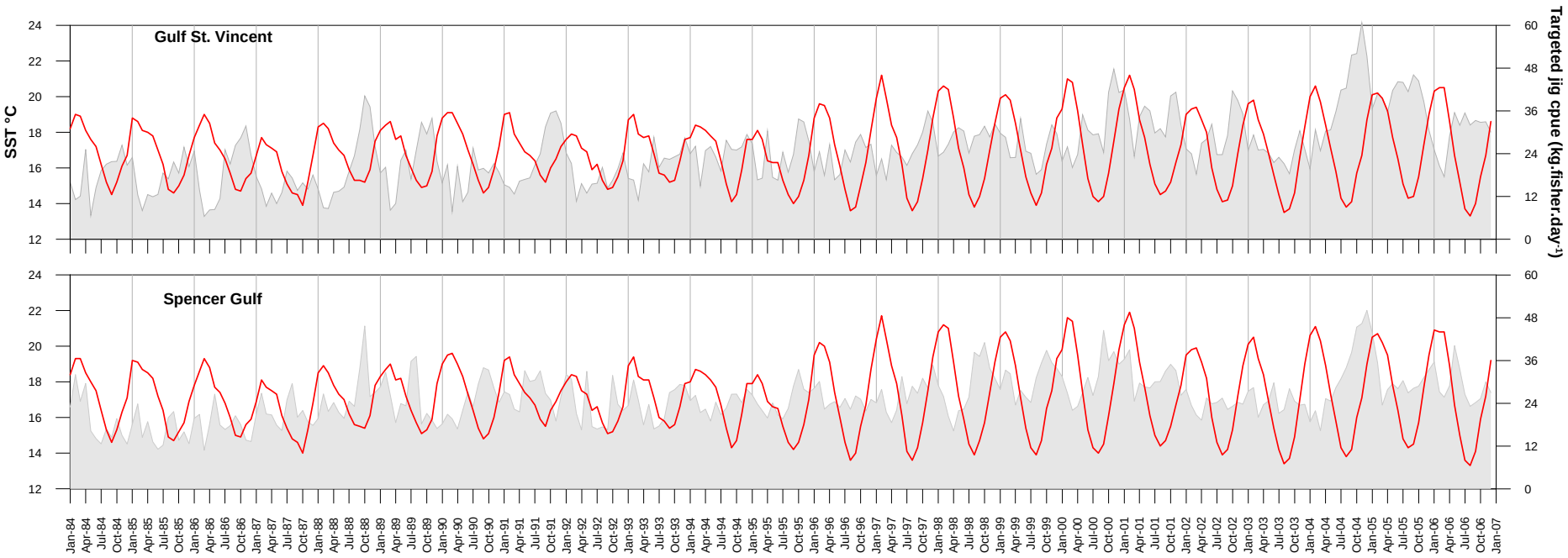

Figure 6.3. Historical record of monthly commercial targeted jig cpue and average sea surface temperature from January 1984 until December 2006 for the entire Gulf St. Vincent and Spencer Gulf.

Table 6.3. Correlation matrices of commercial targeted jig cpue with sea surface temperature over a 12 month period for Gulf St. Vincent and Spencer Gulf * denotes significant ($\alpha = 0.01$) correlations. Values highlighted in green indicate the strongest positive correlation.

Lag	0	1	2	3	4	5	6	7	8	9	10	11	12
GSV	*-0.145*	*-0.226**	*-0.219**	*-0.129*	*0.015*	*0.173**	*0.291**	*0.358**	***0.367****	*0.296**	*0.153**	*-0.016*	*-0.176*
SG	*-0.019*	*-0.134**	*-0.196**	*-0.190*	*-0.123*	*-0.001*	*0.152**	*0.276**	***0.320****	*0.284**	*0.195**	*0.071*	*-0.068*

6.2. Egg surveys

Total (Gulf St. Vincent) and regional (Myponga, Marino, Edithburgh and Port Vincent) average monthly egg density per 100 m² was calculated from data obtained from regular SCUBA surveys (see section 5.1). Estimates of monthly egg production were then separately compared to commercial targeted jig CPUE for Gulf St. Vincent six months later. This six month lag period was based on the assumption that the average age of calamary caught on the spawning grounds was approximately five months (see section 5..3) and the developing embryos take approximately one month to hatch (see Steer et al, 2003a), giving a total of six months from egg fertilisation to recruiting adult.

There were no clear relationships between average egg density and subsequent commercial targeted jig CPUE six months later (Fig. 6.4). Average egg density explained little of the variation in subsequent commercial catch rates for all regions. Port Vincent egg density provided the strongest negative relationship explaining 32% of the variation in commercial CPUE (Fig. 6.4).

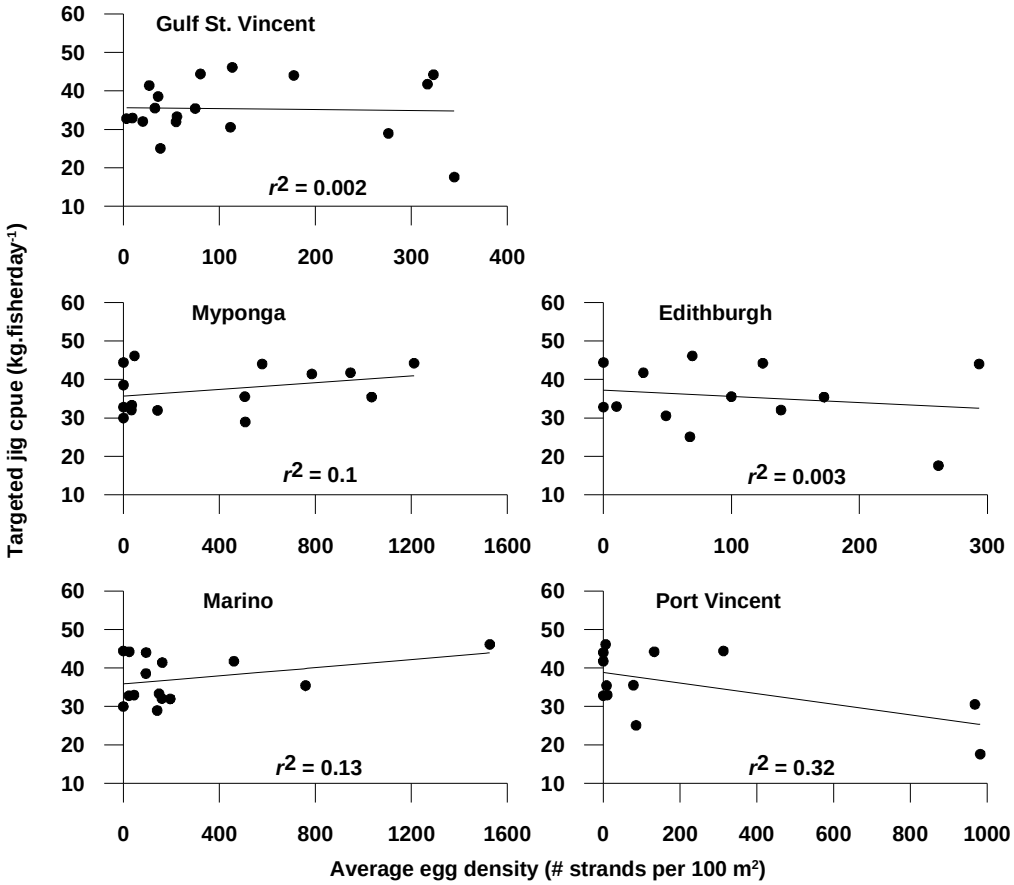

Figure 6.4. Relationships between average egg densities, calculated as the number of egg strands per 100 m² for the entire Gulf St. Vincent, Myponga, Marino, Edithburgh and Port Vincent and commercial targeted jig cpue six months later. Coefficients of determination (r^2), describing the proportion of the variation explained is presented for each graph.

6.3. Trawl 'pre-recruit' surveys

The age structure of calamary sub-adults collected from structured, fishery-independent trawl surveys (see section 4.2) was determined through statolith analysis. This structure was compared to the age structure of the adult calamary caught on the inshore spawning grounds (see section 5.3). The difference in mean age between these two populations was assumed to represent the time taken for the offshore sub-adults to recruit onto the inshore spawning grounds and enter the marine scalefish fishery. The mean catch rates of the sub-adults caught during the trawl surveys were subsequently compared with mean commercial targeted jig CPUE data incorporating the appropriate time lag, to determine whether offshore catch rates could be used as an independent indicator of stock status.

It was evident from the size and age comparisons that the offshore prawn trawl and the inshore commercial sectors harvested different components of the calamary population. All offshore animals were significantly smaller (Mann-Whitney U: $Z = -66.2$, $p < 0.001$) and younger ($Z = -15.1$, $p < 0.001$) than the inshore animals (Fig. 6.5). A comparison of the age structure of the inshore and offshore animals which share common, back calculated hatch dates, indicated that there was a 55.3 day (~ 2 months) difference between the modal ages of the two population components (Fig. 6.5). Comparison of the mean catch-rates of the sub-adults in the offshore prawn fishery with mean CPUE data collected from the inshore commercial fishery, incorporating the a two-month lag, revealed a significant positive relationship ($F_{1, 7} = 19.8$, $p = 0.004$, $r^2 = 0.77$) (Fig. 6.6).

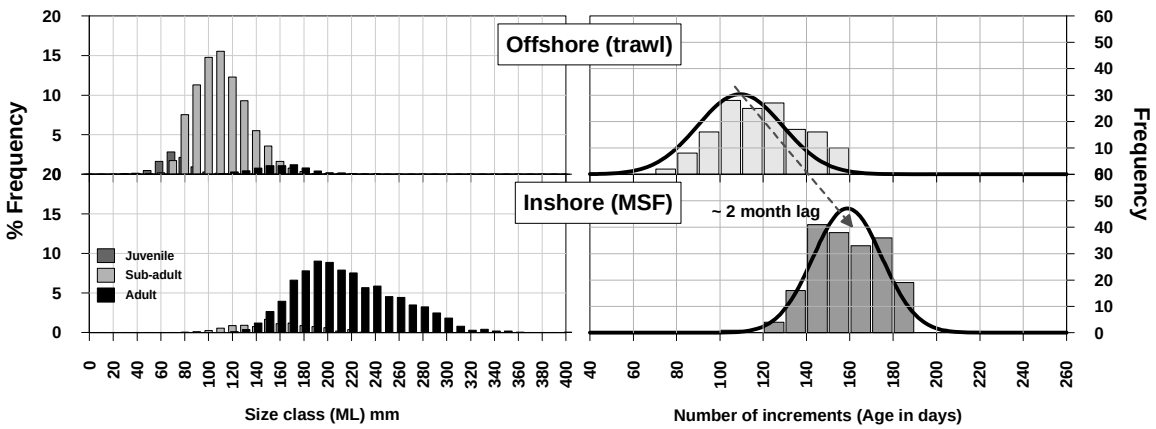

Figure 6.5. A comparison of the size and age structure of calamary caught by the offshore trawl surveys and inshore fishery-independent jig surveys. Note the 2-month difference in the age composition between offshore and inshore calamary.

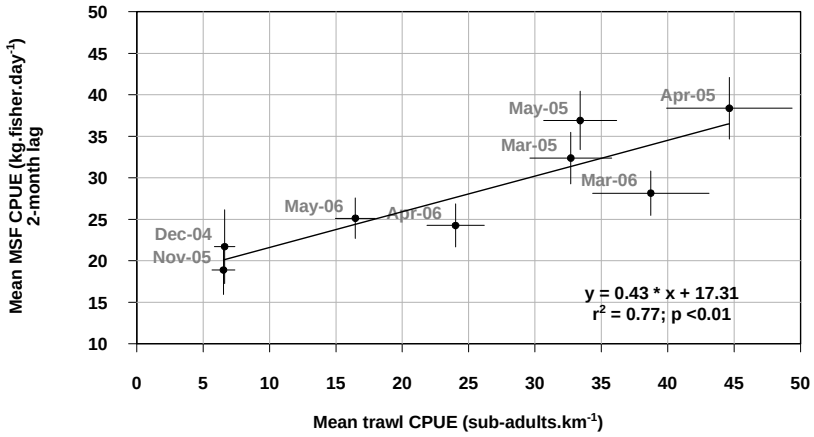

Figure 6.6. Relationship between the catch rates of the sub-adult calamary from the fishery-independent, trawl surveys and subsequent calamary catch rates in the inshore commercial marine scalefish fishery two months later for Gulf St. Vincent. Trawl month and standard errors are presented.

6.4. Synthesis

The calamary population in Gulf St. Vincent is spatially segregated. Juveniles and sub-adults predominantly occur offshore, whereas the inshore areas are dominated by spawning adults. There is, therefore, a clear division between the nursery and spawning grounds within the Gulf. The age structures of both population components suggested that offshore sub-adults take approximately two months to mature and migrate to the inshore spawning grounds, where they are targeted by commercial and recreational fishers. The average age of calamary caught on the inshore spawning grounds was estimated to be five months.

The present study suggests that inshore calamary abundance in South Australia can be estimated two months in advance. Previous studies have developed recruitment indices for a number of squid species. Dawe and Hurley (1981) demonstrated that catch rates of the short-finned squid *Illex illecebrosus* on the Grand Bank, Newfoundland in late June were directly associated with levels of inshore abundance in the following five months (July to November). Similarly, Pierce et al. (1998) found a relationship between February survey abundance and commercial CPUE approximately six months later for *Loligo forbesi* in the North Sea. Sampling pre-recruits at an earlier life-history stage is one way of predicting catches over a longer time frame. Structured paralarval surveys carried out in the *Todarodes pacificus* fishery in Japan and the *Loligo opalescens* fishery off the Californian coast have displayed predictive potential up to a year in advance (Okutani and Watanabe 1983; Zeidberg 2006). However, for South Australia's calamary fishery and the majority of other squid fisheries, obtaining reliable, quantitative data from paralarvae is logistically challenging, as they are inconspicuous.

This study attempted to extend the predictive time-frame by using egg density as an additional proxy to estimate subsequent recruitment strength. Back-calculated hatch dates from age analysis suggested that calamary take approximately five months to migrate onto the spawning grounds from hatching. Previous research has additionally estimated that the average developmental period for calamary embryos is approximately one month (Steer et al. 2003b), so the average generational turn-over is approximately six months. A comparison of average egg density (# calamary egg strands per 100m^2) for Gulf St. Vincent, and for four regions within it, with subsequent commercial targeted jig CPUE six months later, yielded inconclusive results. There were no clear indications that estimates of egg density could be used to forecast stock status. This is likely a function of the difficulties associated with obtaining an accurate measure of egg production within an area. The formation of discrete spawning aggregations is extremely patchy and dynamic and the proximate cues that initiate spawning are unknown. This, coupled with the expansive availability of spawning habitat within the Gulf makes it extremely challenging to accurately quantify egg production cost-effectively. A similar situation has been encountered in the Tasmanian calamary fishery, however, that fishery is also further complicated by various management arrangements and interruptions (Ziegler et al. 2006).

The reliability of recruitment indices is often questioned, particularly when they apply to squid fisheries (Caddy, 1983; Pierce and Guerra 1994). This is due to plasticity in growth and sensitivity to environmental fluctuations that lead to differences in the timing of recruitment into the fishery. Retrospective investigation of wind strength and direction with calamary catch rates within the Gulfs indicated that catches were generally low when winds were strong and onshore, which are likely to create turbid conditions in shallow, inshore, waters. Turbidity has been demonstrated to strongly influence spawning in the South African chokka squid, *Loligo vulgaris reynaudii*, which shares a similar life history to southern calamary (Roberts and Sauer 1994). It was generally found that periods of high turbidity forced the spawning population to move to clear waters, as their spawning behaviour was heavily reliant on vision (Jantzen and Havenhand 2003b). Although, commercial catch rates appeared to be correlated with local wind conditions further investigation is required to investigate the feasibility to use long range weather forecasts to predict stock status. Sea surface temperature has offered greater predictive potential, particularly for annual species that exhibit a defined spawning season (Robin and Denis 1999; Waluda et al. 2001). Calamary catch rates, in both Spencer Gulf and Gulf St. Vincent, were found to positively correlate with sea surface temperature six to ten months prior. Warm conditions during embryonic development are suggested to improve early growth and survival leading to greater recruitment success. Although these correlations of catch rates with SST were statistically significant they were relatively weak and it is possible that they were compromised by conditions affecting the later life-cycle and ultimately recruitment strength.

Back-calculated hatch dates and regular egg surveys indicate that the South Australian calamary fishery is supplied by a continuum of micro cohorts throughout the year (chapter 5). Separating these micro cohorts was achieved through statolith age analysis, which relies heavily on the assumption that one increment represents one day of growth (Jackson 2004). Unlike the development of other pre-recruit indices, this study verifies the predictive relationship with age information, which effectively allows micro cohorts to be retrospectively identified and tracked from the nursery area to the spawning grounds. Furthermore, given the short two-month lag, there is reduced potential for recruiting stocks to be perturbed by environmental processes. This benefit, however, will only be evident if future collection and analytical methods are streamlined and a 'real time' at-sea assessment is developed. Although there is a degree of variance associated with the offshore/inshore relationship, it should be noted that it does not necessarily need to be exact to be usefully employed (Hilborn and Waters, 1992). For example, if catch rates from fishery-independent surveys fell below an agreed target threshold, managers could be informed immediately and could adopt a conservative harvest strategy to reduce the risk of overexploitation on the inshore spawning grounds. Conversely, a less conservative strategy could be employed if fishery-independent catches were exceptional.

7. PERFORMANCE INDICATORS

7.1. Total commercial catch

The 3rd highest commercial calamary catch over the 23-year reference period was in 1998 at 429.5 t, whereas the 3rd lowest catch was in 1985 at 193.1 t (Fig. 7.1). The greatest interannual change occurred in 2004, where the total catch of 464.61 t was 47.7% greater than the previous year's catch of 314.52 t. The greatest increasing three-year trend was observed from 2002 to 2004 where total commercial catch increased at a rate of 47.1 t per year (Fig. 7.1). The greatest decreasing trend occurred over the last three years, where catches decreased at a rate of 82.9 t per year thus breaching this limit reference point in 2006 (Table 7.1).

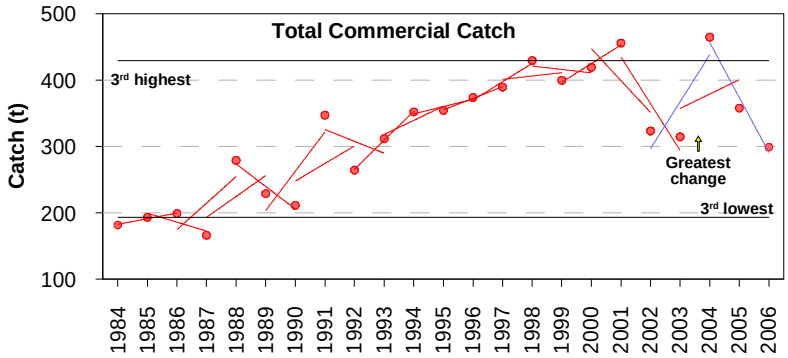

Figure 7.1. Total commercial calamary catch over the 23-year reference period, indicating the 3rd highest and 3rd lowest values, the greatest change and three-year trends. Blue lines represent the greatest increasing and decreasing three-year trends within the reference period.

Table 7.1. Summary of the results of the comparisons of the limit reference points indicated in the Marine Scalefish Fishery Management Committee Agenda paper # 99 for total commercial catch.

Performance Indicator	Limit Reference Point	Breached?	Details
A. Total commercial catch	3rd lowest/3rd highest	No	
	Greatest interannual change (±)	No	
	Greatest 3-year trend (±)	**Yes**	**↓ 82.9 t.yr^{-1}**

7.2. Targeted effort

7.2.1. Targeted jig effort

The 3rd highest targeted jig effort value was recorded in 1997 at 9,761 fisher days (Fig. 7.2). The greatest interannual change occurred in 2005, where targeted jig effort decreased by 24.5% from 9,496 to 7,169 fisher days. The greatest increasing three-year trend occurred from 1991 to 1993, where targeted effort increased at an estimated 770 fisher days per year (Fig. 7.2). The three-year trend, encompassing 2003 to 2005, displayed the greatest rate of decrease where targeted effort dropped an estimated 919 fisher days per year. None of the limit reference points, relating to targeted jig effort, were breached in 2006 (Table 7.2).

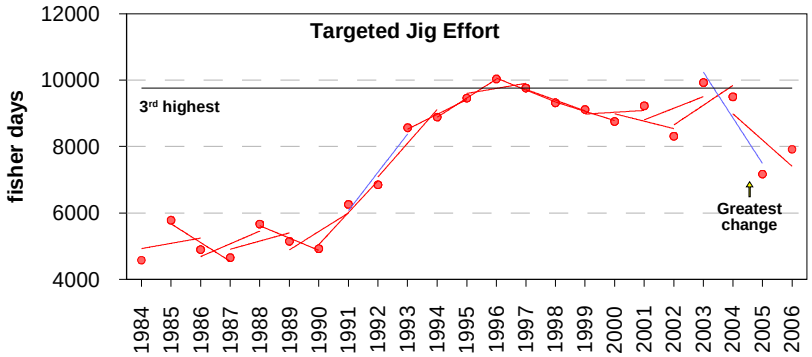

Figure 7.2. Targeted squid jig effort over the 23-year reference period, indicating the 3rd highest value, the greatest change and three-year trends. Blue lines represent the greatest increasing and decreasing three-year trends within the reference period.

Table 7.2. Summary of the results of the comparisons of the limit reference points indicated in the Marine Scalefish Fishery Management Committee Agenda paper # 99 for targeted squid jig effort.

Performance Indicator	Limit Reference Point	Breached?	Details
B1. Targeted jig effort	3rd highest	No	
	Greatest interannual change (±)	No	
	Greatest 3-year trend (±)	No	

7.2.2. *Targeted haul net effort*

The 3rd highest targeted haul net effort value was recorded in 1991 at 1,110 fisher days (Fig. 7.3). The greatest change occurred in 1993, where targeted haul net effort increased by 215.4% from 397 to 1,252 fisher days. The greatest decreasing three-year trend occurred from 1993 to 1995 at a rate of 227 fisher days per year, whereas the greatest increasing three-year trend occurred from 2002 to 2004 at a rate of 266 fisher days per year (Fig. 7.3). None of the limit reference points, relating to targeted haul net effort, were breeched in 2006 (Table 7.3).

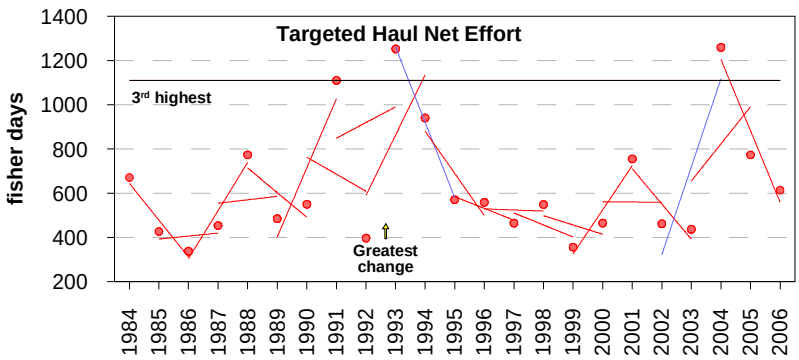

Figure 7.3. Targeted haul net effort over the 23-year reference period, indicating the 3rd highest value, the greatest change and three-year trends. Blue lines represent the greatest increasing and decreasing three-year trends within the reference period.

Table 7.3. Summary of the results of the comparisons of the limit reference points indicated in the Marine Scalefish Fishery Management Committee Agenda paper # 99 for targeted haul net effort.

Performance Indicator	Limit Reference Point	Breached?	Details
B2. Targeted haul net effort	3rd highest	No	
	Greatest interannual change (±)	No	
	Greatest 3-year trend (±)	No	

7.3. Targeted CPUE

7.3.1. Targeted jig CPUE

The 3rd highest targeted jig CPUE value was recorded in 2001 at 31.3 kg.fisher.day^{-1} and the 3rd lowest in 1984 at 17.3 kg.fisher.day^{-1} (Fig. 7.4). The greatest interannual change occurred in 1988, where targeted jig CPUE increased by 53.2% from 16.2 to 24.8 kg.fisher.day^{-1} (Fig. 7.4). The greatest three-yearly rates of change have occurred within the last six years, the greatest decrease occurred from 2001 to 2003 at a rate of 2.4 kg.fisher.day^{-1} and the greatest increase from 2003 to 2005 at 3.7 kg.fisher.day^{-1} (Fig 7.4). None of the limit reference points, relating to targeted jig CPUE, were breeched in 2006 (Table 7.4).

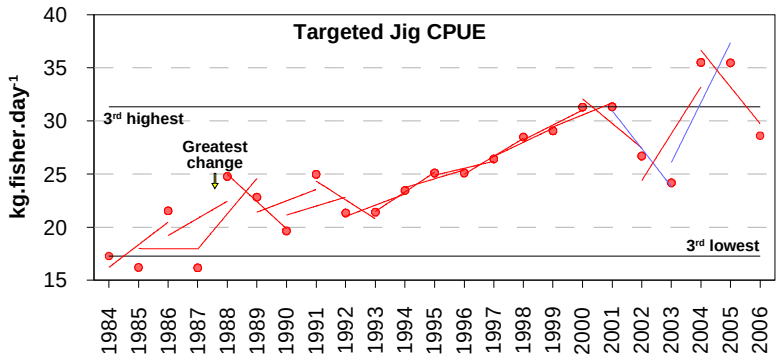

Figure 7.4. Targeted squid jig CPUE over the 23-year reference period, indicating the 3rd highest value, the greatest change and three-year trends. Blue lines represent the greatest increasing and decreasing three-year trends within the reference period.

Table 7.4. Summary of the results of the comparisons of the limit reference points indicated in the Marine Scalefish Fishery Management Committee Agenda paper # 99 for targeted squid jig CPUE.

Performance Indicator	Limit Reference Point	Breached?	Details
C1. Targeted jig CPUE	3rd lowest/3rd highest	No	
	Greatest interannual change (±)	No	
	Greatest 3-year trend (±)	No	

7.3.2. Targeted haul net CPUE

The 3rd highest targeted haul net CPUE value was recorded in 2004 at 40.4 kg.fisher.day^{-1} and the 3rd lowest in 1992 at 20.0 kg.fisher.day^{-1} (Fig. 7.5). The greatest interannual change occurred in 2004, where targeted haul net CPUE increased by 52.1% from 26.5 to 40.4 kg.fisherday^{-1} (Fig. 7.5). The greatest decrease occurred from 2001 to 2003 at a rate of 4.9 kg.fisherday^{-1} and the greatest increase from 2003 to 2005 at 6.2 kg.fisher.day^{-1} (Fig. 7.5). None of the limit reference points, relating to targeted haul net CPUE, were breeched in 2006 (Table 7.5).

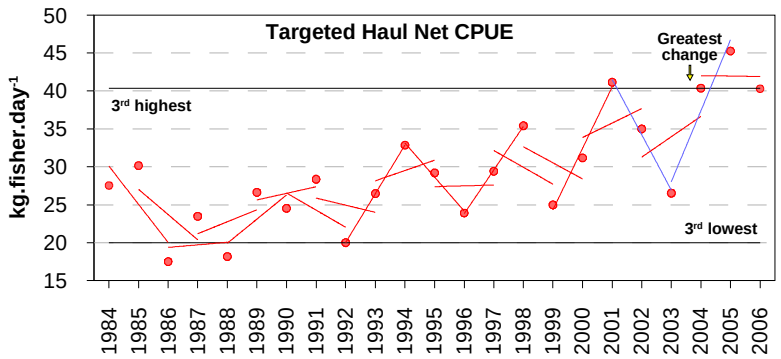

Figure 7.5. Targeted haul net CPUE over the 23-year reference period, indicating the 3rd highest value, the greatest change and three-year trends. Blue lines represent the greatest increasing and decreasing three-year trends within the reference period.

Table 7.5. Summary of the results of the comparisons of the limit reference points indicated in the Marine Scalefish Fishery Management Committee Agenda paper # 99 for targeted haul net CPUE.

Performance Indicator	Limit Reference Point	Breached?	Details
C2. Targeted haul net CPUE	3rd lowest/3rd highest	No	
	Greatest interannual change (±)	No	
	Greatest 3-year trend (±)	No	

8. GENERAL DISCUSSION

8.1. Available information

Currently the most complete and informative data to assess the status of southern calamary stocks are the regional estimates of commercial catch and effort, and the calculated estimates of CPUE. Using CPUE as an estimate of abundance for species that aggregate to spawn, such as southern calamary, is problematic. This is largely a result of the dynamic nature of the aggregations with individuals continuously moving in and out of areas, making it difficult to accurately monitor depletion rates (Carvelho and Nigmatullin 1998; Moltschaniwskyj and Pecl 2007). The depletion of stock usually occurs over a larger spatial scale than the CPUE can estimate. Calamary spawning aggregations are also predictable, which makes CPUE regionally biased. In addition, there is evidence to suggest that jigs can be selective and squid catchability highly variable (Lipinski 1994), which means that CPUE can over- or under-estimate biomass. Nevertheless, these data are valuable because they are compiled from a large, indirect, sampling network (the commercial fishers), thus providing a foundation for scientists and fisheries managers to build on.

There have been two recreational fishing surveys that estimated catches of calamary in 1994/96 and 2000/01 effort (McGlennon and Kinloch 1997; Henry and Lyle 2003), but there has not been any on-going monitoring. In the last survey it was found that recreational fishers fishers harvested a similar quantity of calamary to that of the commercial sector (Henry and Lyle 2003). The current lack of quantitative catch and effort from the recreational sector results in uncertainty around estimates of total catch. A State-based recreational survey is planned to be carried out in 2007/08 and will contribute to understanding spatial and temporal trends in recreational catch and effort.

Calamary by-catch in Gulf St. Vincent has been quantified through structured fishery-independent trawl surveys for the second consecutive year. South Australia's prawn fisheries catch small juvenile and sub-adult calamary (average individual weight ~55.0g). The estimated contribution to the State's total catch is, therefore, better represented by the number of individuals caught rather than the proportion by weight because the prawn sector is removing immature animals that are prevented from recruiting to the spawning grounds and entering the Marine Scalefish fishery (Fig. 8.1). From a combination of data collected from fishery-independent trawl surveys and commercial catch and effort data obtained from the prawn fishers, it is conservatively estimated that ~35% of the State-wide calamary catch is harvested by the commercial prawn sector (Fig. 8.1).

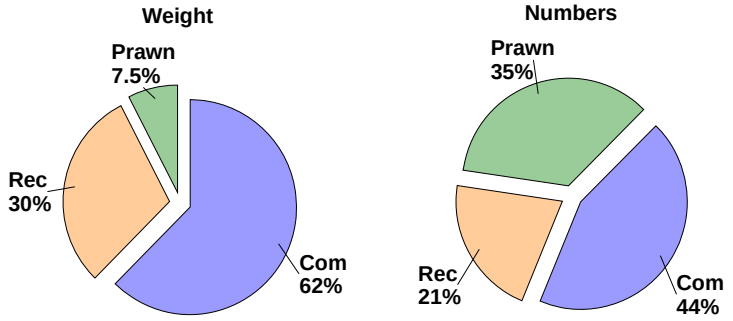

Figure 8.1. Estimated contribution to the State-wide of calamary catch by the commercial, recreational of the MSF fishery and the prawn fisheries by total weight and number of individuals caught.

8.2. Current Status

Targeted jig CPUE, calculated from fishery-dependent catch and effort data, is considered the most reliable estimate of relative abundance of southern calamary. Targeted jig CPUE in 2006 was 28.6 kg.fisher day^{-1} dropping 19.4% from the previous high catch rate in 2005. This corresponded with a moderate increase (10.4%) in targeted jig effort. A similar trend was observed for South Central Gulf St. Vincent with a 23.3% drop in CPUE and a 10.7% increase in effort. Targeted jig catch rates also declined in South East Spencer Gulf, North West Gulf St. Vincent and Kangaroo Island in association with marginal decreases in effort. Catch rates remained stable in South West and Northern Spencer Gulf and increased in the Far West Coast. Targeted jig effort increased by at least 30% in each of these three regions. Despite the downward shifts in targeted jig CPUE, catch rates remained moderately high in the major fishing regions, suggesting that calamary were relatively abundant in 2006. Declines in targeted jig CPUE in both the jig and haul net sectors were not significant enough to breach the prescribed limit reference points.

The limit reference point for catch was breached in 2006 and followed the steepest decline in catch in the history of the fishery. A similar decline was observed from 2001 to 2003, where total catch fell at a rate of 70.6 t per year. This decline however preceded record high catches and CPUE in 2004. Extreme inter-annual variability is typical of squid fisheries and it has been suggested that environmental processes affect spawning and recruitment (Boyle and Rodhouse 2005). The effects of environmental factors on sub-annual species may be extreme, and makes it difficult to establish reliable assessment and management procedures for squid (Boyle and Rodhouse 2005). Retrospective investigations of calamary catch rates with sea surface temperature, wind strength and direction revealed relatively weak, yet statistically significant

results indicating that there is a degree of environmental influence on population size (Chapter Six).

Although the lack of catch and effort data from the recreational sector limits the current assessment, an analysis of the commercial catch statistics against the prescribed limit reference points provides no genuine concern about the current status of the calamary fishery. The available data suggest that calamary are being harvested within sustainable limits. In light of this assessment, however, it should be noted that less than half (40.1%) of marine scalefish licence holders reported landing calamary, of which 35.5% specifically targeted calamary. Furthermore, the top-ten calamary fishers, who represent ~4% of marine scalefish licence holders, land 31.0% of the State's commercial catch. Such disproportional catch and extensive latent effort within this fishery is concerning, especially as calamary are highly aggregative, exhibit non-overlapping generations, are cost effective to catch and their distribution and abundance patterns are largely understood. There is, therefore, capacity for fishing effort to escalate to several times its current level.

8.3. Future research

Commercial calamary catch rates from the inshore Marine Scalefish Fishery were strongly correlated with estimates of pre-recruit abundance two months prior, as determined from the 2004/05 and 2005/06 Gulf St. Vincent by-product surveys. This suggests that the use of fishery-independent trawl data provides an encouraging and feasible means of forecasting inshore recruitment, thus offering a proxy to gauge the status of the calamary fishery in advance. It is also the most amenable and cost-effective method available thus far and has the greatest potential as an integrated fisheries management tool. The continuation of the prawn by-product surveys is required to assess the stability of the established pre-recruit index as it is currently based on two survey seasons that extend over a four-month period. The sampling regime needs to continue as it generally takes a number of years to collect sufficient information to develop a robust stock-recruitment relationship. Further extending the data set would also permit the exploration of longer-term, annual predictions. Samples from the 2006/07 season have already been collected and are currently being processed for future assessment. Carrying out similar by-product surveys in Spencer Gulf, as an integrated part of their regular fishery-independent trawl surveys, would provide greater spatial coverage and potentially permit a State-wide forecast.

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