JUVENILE SCALLOP DISCARD RATES AND BED DYNAMICS: TESTING THE MANAGEMENT RULES FOR SCALLOPS IN BASS STRAIT.

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NON TECHNICAL SUMMARY

2003/017	**Juvenile scallop discard rates and bed dynamics: testing the management rules for scallops in Bass Strait.**

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Objectives:

1. Determine, using VMS, the relative fishing intensity and extent of scallop dredging in both the Bass Strait Central scallop fishery and the Tasmanian scallop fishery, in areas opened to fishing in 2003 and 2004.
2. Determine the relative impact of fishing on different size classes of scallops on those beds open to fishing, especially the rate of survival of undersized scallops.
3. Determine whether a relationship exists between juvenile settlement success in different areas and the relative fishing intensity, as defined by VMS data, experienced by those different areas.
4. Determine the major bycatch species taken with commercial scallop dredging gear on the main scallop beds fished in Bass Strait (including Tasmanian, Central Bass Strait and, if possible, Victorian scallop beds).
5. Initial study of the effects of scallop dredging on benthic fauna by comparing closed areas and areas open to fishing in a before and after sampling design.
6. Generate management options aimed at optimizing the use of area based management strategies for scallop fisheries.

Benefits and Adoption:

- Following the collapse and closure of the Bass Strait scallop fishery in 1999/2000 the different spatial management systems introduced in Tasmanian and Commonwealth waters required the development of sets of decision rules to aid the management of the scallop stocks. The research involved in this project, particularly with regard to scallop growth, has directly assisted with the development of the decision rules used to manage the scallop fishery in Tasmania and, to a lesser extent, the Commonwealth fishery. This includes a confirmation of the need to return to 90 mm shell length as the minimum legal size, which occurred in Tasmania (2003) and in the Commonwealth (2004).
- Our research continues to lead to an evolution of the use of the 20% undersized discard rate as one of the decision rules when deciding whether to open a particular bed or not within detailed spatial management. In the context of detailed spatial management, the 20% discard rate can now be used as a limit reference point. In addition, this has led to a discussion with regard to the need for enforcing a minimum legal size once a particular scallop bed has been opened to fishing. This management strategy, which should improve Industry's economic efficiency, is now being considered, at least where spatial management is operating at a fine geographical scale (most closed, little open).
- Work on the bycatch of scallop dredging and the determination of area fished using the Vessel Monitoring System data has been used to define the potential impact of scallop dredging on the benthic environment in the strategic assessments made in the Commonwealth and Tasmania to address the Department of Environment and Heritage's requirements for obtaining a permit to export native wildlife. Our research led to an improved understanding of how focused scallop dredging is in relatively small areas implying that the negative impacts are localized and hence of limited concern in terms of impact on non-target species and communities.
- Our research has encouraged the initiation and on-going development of Industry-Mediated surveys for providing the advice on scallop sizes, abundance and location, which is necessary to implement small-scale spatial management as in Tasmania. This has led to a further FRDC funded project (2005/027) aimed at developing a workable and credible system giving Industry itself much more responsibility for the sustainable management of the resources they harvest.
- Our research has provided the management advice to guide the scallop fishery since 2000, and especially following the reopening in 2003. More importantly, it has defined the information needs for the continued management of the scallop stocks into the future.

Non-Technical Summary:

The fishery for commercial scallops (*Pecten fumatus*) in southern Australia has historically exhibited cycles of boom and bust in its catches. These pathological cycles were the result of sequentially discovering large scallop beds and systematically fishing them down. As the value of the fishery increased, the numbers of vessels involved also increased. By the late 1980s there were no more major aggregations of scallops to find and the fishery collapsed yet again. By this time the Industry had built up such an excess of fishing capacity that even when there was a successful recruitment event, by the time the scallops reached legal size (at that time only 80 mm shell length) the available biomass could easily be caught before the stocks could properly recover. In effect, the booms in the cycle had been severely reduced. After the latest collapse of the Bass Strait and Tasmanian scallop fisheries in the late 1990s, a very different management regime was instigated in an attempt to make the fishery sustainable and occur each year.

Both the Tasmanian managers (DPIW) and the Commonwealth managers (AFMA) implemented forms of spatial management in which, unlike previously, the whole fishery would not be opened for exploitation, but rather some spawning biomass would be protected by a closure in an effort to provide a source that could replenish fished areas with juvenile scallops. In the Commonwealth managed fishery, knowledge of two beds of scallops within either the eastern or western zones of the fishery was required before fishing could occur. If two beds were discovered, then one bed of known minimum biomass was to be closed to fishing (broodstock), while all remaining areas of the fishery would be opened to commercial operations. For simplification, this management strategy will be referred to as a 'most open, little closed' strategy within the report. In contrast, within the Tasmanian fishery, only areas of scallop stocks known to meet a set of management decision rules would be considered for opening to commercial fishing. Only relatively small areas meeting these requirements would be opened, with all other areas of the fishery to remain closed (protecting broodstock). This strategy will be referred to as "most closed, little open" in this report.

This project aimed to explore which of these alternative spatial management strategies would provide the best outcomes for the fishery. In addition, it aimed to determine what information and decision rules would be needed to assist and coordinate the contrasting strategies. Furthermore, public perceptions about scallop dredging appear to be that it involves scraping the sea bed clean over most of the coastline and as such is an unacceptable means of fishing. To determine the validity of this view a study was made of exactly how extensive dredging activities are along the coast, and what other benthic organisms (bycatch) are impacted when dredging of a scallop bed occurs.

Ageing of scallops is difficult and most likely inaccurate; however, modal size classes of scallops can be identified and followed through time to give estimates of the presence of different age classes, and by projecting backwards, of recruitment events. The collapse of the scallop stocks in 1999/2000 led to a scientific stratified survey in 2000 that demonstrated that all commercial stocks of scallops had gone from the surveyed Commonwealth-managed waters, which covered the most productive regions of the fishery as determined by historical fisher catch return data. The only exception was a small bed of approximately 400 tonnes shell weight. In addition, most legal sized scallops were also absent from the east coast of Flinders Island in the Tasmanian fishery. Given that fishers were not willing to (or did not) explore other areas of the fishery, it was assumed that both a similar collapse had occurred through the entire

spatial extent of the Commonwealth and Tasmanian fisheries. It was this collapse that eliminated older scallops, which allowed identification of model groups in newly discovered beds of newly recruited scallops to be followed through subsequent surveys.

By surveying in Commonwealth and Tasmanian waters it was possible to study the growth of scallops under different conditions of density and location. The legal minimum size was based upon research in the 1990s that demonstrated that scallops that were 3+ years old gave rise to 3 – 5 times as many eggs as younger scallops. In addition, it was estimated that scallops would tend to grow to 75 – 85 mm shell height (about 90 mm shell length) in that time. However, that work was conducted when the scallop beds were in a relatively depleted state. In this present study, growth was found to vary with location and density. Most scallop beds discovered on the east coast of Flinders Island in Tasmanian waters were in relatively dense beds and were slower growing than most scallops found in the relatively less dense beds of adjacent Commonwealth-managed waters. However, one exceptionally dense bed found in the Commonwealth jurisdiction during 2004 (labeled as C4X) was found to grow at similar rates to those in the dense Tasmanian beds. In addition, scallops in some areas (especially in the Commonwealth fishery) were found to grow deeper than the same size scallops from other areas, so that their flesh weights (meat plus gonad) can be relatively greater in some areas by comparison with others.

These spatial variations observed in the growth of scallops could potentially be used to advantage in the spatial management system where most of the fishery is closed, and only small areas are open. For example, if a bed of scallops are known to be 3+ or more years old but do not meet the 20% trashing (discard) requirement (i.e. more than 20% of available scallops are undersize and vulnerable to incidental fishing mortality) then, as long as the yield from them meets market requirements (approximately 70 – 80 meats per kilogram), the bed has achieved its spawning requirements and there need be no objection to harvesting the scallops. However, this potential flexibility with regard to minimum legal sizes, while still avoiding compliance issues, will only work in a management system that can open a particular scallop bed with little risk of other beds being available for fishing. In a "most open, little closed" management arrangement, however, there would be the possibility of compliance problems associated with ensuring that unknown beds of small scallops that had not met the "two spawning" criterion were not fished.

By identifying age classes in the size frequencies of scallops it was possible to determine that successful settlement was widespread in 1999, with other more localized but significant settlements occurring in 2000 and 2001. Since these events, however, there has been little sign of new recruits in any numbers within the Commonwealth or Tasmanian waters surveyed in this project.

Dense or 'good' scallop beds tended to contain a single cohort of scallops, whereas less dense or even 'marginal' scallop beds were sometimes found to contain two or more cohorts. Many of the beds that this project discovered were in areas known to have held scallop beds in the past. It has been suggested that there is a need to deplete adult scallops from a bed before successful recruitment can occur again. Results of this study, however, found that while commercial fishing of scallop beds did not remove or wipe out all scallops present (not even the undersize scallops), subsequent recruitment to those beds which were fished was not observed. As such, the mechanisms leading to successful recruitment within a given area are unknown and are most likely to be complex. If a lag is required between depletion and subsequent recruitment then further observations will be required to establish this.

The study included an examination of bycatch and an attempt to define the areas and the relative intensity of fishing using Vessel Monitoring System (VMS) data. The combination of VMS and bycatch data demonstrated that Industry vessels concentrate their fishing activities in relatively small areas of highest scallop density, avoid areas where there is significant bycatch, and do not fish in most of the area open to fishing. It was possible to characterize scallop beds as being either ‘good’ scallop beds (generally high densities of commercial scallops with few bycatch species mixed in, living in well defined beds usually only 1000’s metres by 1000’s metres) or ‘marginal’ scallop beds (which had relatively low densities of commercial scallops, sometimes were characterized by large proportions of bycatch to sort through, and were of variable and smaller size than ‘good’ beds). As such, the effects of different intensity levels of fishing (determined through the use of VMS data) on the biological assemblages living in scallop beds appeared to be detectable in Tasmanian scallop beds with diversity being lowest in the most intensely fished areas. However, the opposite was found to occur in Commonwealth-managed waters, which was unexpected. Clearly there is no simple way to describe the localized impacts of commercial fishing for scallops. Because the scallop beds targeted are characterised by low species diversity and bycatch levels, the effects of scallop dredging on benthic assemblages appear to be minimal; because few bycatch items tend to live within these areas. However, if fishing were to move into ‘marginal beds’ there is a potential for greater impacts on a larger diversity of benthic species. In contrast to this statement, Smith and Rago (2004) suggest that the reproductive output of high density scallop beds, relative to low density scallop beds, make conservation of high density beds a potential management strategy, which will increase recruitment into other parts of fishery. However, given that scallops in high density beds appear to grow more slowly than those in low density beds, and thus reach reproductive maturity later, a strategy of conserving a mix of bed types, as is possible in the “most closed, little open” strategy, may provide a more balanced trade-off.

One objective of detailed spatial management would be to locate and characterize the ‘good’ scallop beds and fish them in rotation. This would focus fishing in the most profitable areas, at the same time reducing the impact of dredging on other benthic communities. The fact that scallop beds were found to reoccur in the same places they had occurred previously, despite their complete absence in earlier surveys is an indication that dredging (sufficient to cause collapses of the fishery during the 1980s and 1990s) was not sufficient to damage the benthic habitat to an unrecoverable state. This suggests that commercial fishing for scallops tends to be a highly localized practice that usually occurs in high energy environments that contain species used to disturbance. Because of the recurrence of scallops, the fishing appears to cause minimal long term damage to the sea bed or the communities that live there.

The implementation of detailed spatial management will obviously require that information be collected across the whole fishery, with specific requirements concerning the location and extent of scallop beds, along with the relative abundance, size distribution and condition of the scallops present. Such information will allow decisions to be made concerning the sequence in which scallop beds could best be fished under a rotational harvest, spatial management strategy. In this study, alternative approaches to providing this information have been considered, including video surveys, acoustic surveys, and Industry mediated surveys. Both the video and acoustic surveys were interesting, but could not form the basis of wide scale, informative survey methods. A trial was made in Tasmanian waters of an Industry survey using special permits. The outcome of this first survey was very promising, with the information obtained ranging from excellent to minimal. The development of a credible system of Industry mediated surveys appears to be the only economical way of obtaining the information requirements of a detailed spatial management system. This observation led to the success of a second FRDC funded project entitled "Facilitating Industry Self-Management for Spatially Managed Stocks: A Scallop Case Study" 2005/027. That project aims to devise a system whereby Industry members provide the advice that determines the management of the scallop stocks.

Given a set biomass of scallops, the "most closed, little open" approach currently employed within Tasmania managed waters has most likely maximized catches of scallops, which has enabled significant fisheries to occur since 2003. In Commonwealth-managed waters only 2003 was a productive fishing year, however, this was most likely the consequence of poor recruitment within the Commonwealth jurisdiction relative to the Tasmanian fishery. Regardless, a "most open, little closed" management strategy has many obvious disadvantages, especially when the scallop fleet still has the capacity to fish down a stock quickly. Even if there were immediate and successful recruitment back onto the scallop beds, it would take at least three years for those juvenile scallops to grow to a fishable size again. With the minimum protection afforded by a 'most open, little closed" management regime, such a strategy would most probably fail to prevent the boom and bust thought to be typical of scallop fisheries.

Although Tasmanian licensed fishers could have taken much greater catches if they had been given access to more of the stock in 2003, it would most likely have led to reduced fisheries in subsequent years (2004 – 2005). A very clear message from Industry members (both fishers and processors) was that to maintain continuity of markets, expertise and infrastructure within the scallop fishery, it is essential for a significant scallop season to occur each year. It is clear that a most closed, little open management strategy, where an array of possible scallop beds are fished in a rotational manner, provides the best opportunity for recruitment within areas, and a subsequent fishery each year. Unfortunately, the periods of high catches during the 1980s and 1990s, which ultimately led to multiple collapses of the fishery, have led to an expectation that scallop catches should be very high. The sustainable productivity of areas should be identified as part of future management strategies, and even jurisdictional arrangements, so that expectations are driven by scallop stocks available rather than economics and historical catches (the source of a number of current TACs). Although such productivity levels have still to be determined it should be obvious that if an annual production is required from southern Australian scallop fisheries, then it would be best to manage all southern Australian scallop fisheries together. From recent discussions concerning the Offshore Constitutional Settlement dealing with scallops, this would appear to be possible only when their individual management strategies become more similar, and there are fewer active scallop licenses. Ultimately, it will not matter who is responsible for the formal management of the resource as long as the management approach used is based on "most closed, little open, rotational fishing concept". In order to reduce the costs of such a management system, it is clear that it should be the Industry who undertake the necessary survey work to provide the credible information needed to generate the management advice, which, because it stems from their own members, should be acceptable to all.

KEYWORDS: Commercial Scallops; *Pectin fumatus*; spatial management; management decision rules; Industry surveys.

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BACKGROUND

Traditionally, there have been three jurisdictions of the southeast Australian commercial scallop, *Pectin fumatus*, fishery. The spatial distributions of these three fisheries are illustrated in Figure 1. All three fisheries have a history of boom and bust; for example, the Central Zone fishery was worth between $13 and $14 million beach value in 1994 and 1995, but dropped to one worth about $1.5 million in 1998 (Scott *et al*., 1999). As a result of this decline in scallop stocks, the Commonwealth fishery was closed in 1999, with subsequent management decisions to be based, at least in part, on the result of a formal AFMA funded survey of the scallop beds. The random-stratified survey found only one relatively small scallop bed in an area east of Flinders Island and north of Babel Island (Semmens *et al*., 2000; Semmens, 2000). A survey conducted at the same time as the Commonwealth survey within Tasmanian waters, funded by DPIWE, found what was believed to be an extension of the single remaining Commonwealth bed. In both Commonwealth and Tasmanian waters the decision was made to keep this bed of scallops closed. In the Commonwealth the decision was also made to open the rest of the Bass Strait Central Zone. Following limited exploratory fishing in Commonwealth waters by Industry during 2000, the single bed found during the scientific survey remained the only known bed of scallops in the Central Bass Strait Zone.

In an attempt to move away from this traditional boom and bust nature of scallop fishing, both the Commonwealth managed Bass Strait and Tasmanian managed scallop fisheries elected to move towards a new system of area-based management, which they hoped would provide a more sustainable resource supporting an on-going annual fishery. Such management is based around opening only particular scallop beds in different years, total catch limits, and management decision rules. A greater understanding of scallop bed dynamics (minimum size, minimum distance between beds, size structure of scallops in beds, etc) would provide a strong basis for the introduction of the new management plan.

One of the most important management rules currently used is known as the 20% juvenile trashing (or discard) rate. The rule is that if the proportion of scallops in the catch from a bed under the legal minimum length of 80 mm shell length (maximum diameter) is greater than 20% then the bed should not be fished (Zacharin, 1994). The legal minimum length was changed to 90 mm across the maximum length in Tasmania for the 2003 season and for the 2004 season in the Commonwealth. The assumption is that once a scallop bed is opened to fishing then, due to the nature of dredging, the bulk of scallops not taken or retained in fishing operations will be damaged or destroyed (hence “trashing rate”). The changing management regimes in both the Central Bass Strait Zone and in Tasmanian waters provides an opportunity to test the assumption that most undersized scallops are destroyed if fished, which is central to whether there is a fishery or not. The use of this decision rule has altered as a result of this FRDC project. Prior to the re-opening and implementation of spatial management, the trashing (discard) rate rule gave guidelines to Industry members about whether to remain fishing in a scallop bed. Now the 20% trashing rate rule is used as one of the criteria for opening and / or closing scallop beds. This now requires some form of survey before the opening (or closing) but increased information needs are one of the costs of spatial management approaches.

In the Commonwealth Central Bass Strait Zone, once a scallop season is open, it remains open until the end of the season. In Tasmanian waters, the location of the fishery can be closed once catch rates or scallop condition drops below acceptable levels. This closure prevents fishers from “scratching about on the beds” and reduces incidental mortality. This difference in management approach enables us to test for differences in bed recovery rate under different treatments.

Following the effective collapse of the fishery in 1999/2000 (it appears likely that the stocks had collapsed between the 1998 and 1999 season but information to that effect only became available early in 2000, hence the ambivalence about the exact date), the scallop beds within the Tasmanian fishery have recovered to an extent that scallops can now be found over a wide area. Many of the scallops present in the beds found during the surveys reached sizes greater than 80 mm in 2003 but the spatial management regime was such that not all areas were opened to fishing. This area-based management strategy provided an opportunity for investigating the effects of fishing on those scallop beds that are opened. All scallop vessels must now have a Vessel Monitoring System (VMS) installed and this data had the potential to provide a more exact estimate of the fishing intensity experienced by the different beds. Given this characterization of the spatial distribution of fishing intensity, this project aimed to determine the relative impacts of the different levels of fishing pressure on the scallop and bycatch populations using appropriately designed surveys. The effects on both the target species and any bycatch species are of interest because the impacts of dredging are assumed to be severe on all species encountered by the gear. It was hoped that the use of underwater video and acoustic methods to compare heavily fished with lightly fished areas would provide a rapid means of both obtaining the required information and of communicating any differences to interested stakeholders. The work on the bycatch and by-product species has already had immediate input when addressing some of the conditions that Environment Australia (now DEH) has placed upon the Wildlife Trade Operation approval for the Bass Strait and Tasmanian scallop fisheries.

Some of the questions to be answered by this work would include: What proportion of legal sized animals remain after fishing? What proportion of juvenile animals is destroyed by fishing (as a function of fishing intensity)? Is bed recovery rate influenced by previous intensity of fishing and distance from un-fished beds? Is any level of dredging catastrophic to bycatch species and the benthic communities they derive from or is the impact a function of fishing intensity? What is the actual geographical area over which the fishery is executed relative to the rest of Bass Strait?

NEED

The scallop fisheries in the Central Bass Strait and Tasmanian waters are both moving to area-based management schemes in which only part of the available fishing grounds will be opened to fishing each year. Under the current strategies, the proportion of available beds opened in Tasmania is likely to be smaller than that opened in the Central Bass Strait. The Victorian fishery, at the time of writing, is considering different regimes of spatial management but usually have a trial period of fishing at the start of the season and make decisions within each season about continuing the opening. Such a trial period of fishing has the objective of being a commercial operation and should not be confused with Industry surveys that have very different objectives. The effectiveness of area-based management and how it is best implemented will be determined by how the open scallop beds respond to differences in relative fishing intensity (as defined and determined by VMS data) and how quickly they can recover (in particular recruitment of scallops back into the area) from the losses due to fishing. It is anticipated that the un-fished bed(s) will aid in the reseeding of the fished beds. In the process of attempting to assess the effectiveness of area-based management for Bass Strait / east Tasmanian scallops, the project will assess the effectiveness and importance of another major management rule/guide, the juvenile trashing (discard) rate. If all or most juvenile scallops on a scallop bed are destroyed when fishing occurs then the bed may take longer to recover than if the very smallest scallops survive the fishing. An understanding of the relative vulnerability of different sized scallops to the effects of fishing will enable the current guess of 20% being undersized leading to a management response of no fishing, to be modified into a workable and justifiable limit reference point in the management of scallops. Finally, the impact of scallop dredging on benthic communities is assumed to be profound and destructive. This project will permit an examination of the relationship between the benthic communities found in areas that experience different levels of fishing intensity and thereby determine whether the impacts on bycatch are the same at all levels of dredging intensity. In summary, the three major needs of a sustainable fishery for scallops in southern Australian waters are 1) to determine whether area-based management will succeed in permitting a sustainable scallop fishery to operate, 2) to formalize and refine the management rule relating to the assumed destruction of juvenile scallops when a bed is fished, and 3) to examine the actual extent of fishing and its impact on benthic communities.

OBJECTIVES

1. Determine, using VMS, the relative fishing intensity and extent of scallop dredging in both the Bass Strait Central scallop fishery and the Tasmanian scallop fishery, in areas opened to fishing in 2003 and 2004.
2. Determine the relative impact of fishing on different size classes of scallops on those beds open to fishing, especially the rate of survival of undersized scallops.
3. Determine whether a relationship exists between juvenile settlement success in different areas and the relative fishing intensity, as defined by VMS data, experienced by those different areas.
4. Determine the major bycatch species taken with commercial scallop dredging gear on the main scallop beds fished in Bass Strait (including Tasmanian, Central Bass Strait and, if possible, Victorian scallop beds).

5. Initial study of the effects of scallop dredging on benthic fauna by comparing closed areas and areas open to fishing in a before and after sampling design.
6. Generate management options aimed at optimizing the use of area based management strategies for scallop fisheries.

STRUCTURE OF THE REPORT

This report is structured into 12 Chapters.

Chapter 1 gives general information about commercial scallops (*Pecten fumatus*), provides a brief history of commercial scallop fisheries in southeast Australia, and discusses the need for spatial management of scallop stocks.

Chapter 2 describes the use of Vessel Monitoring System data in the study of scallops and other benthic organisms found in the Commonwealth and Tasmanian scallop fisheries.

Chapters 3 to 5 focus on the benthic fauna taken in dredges. Chapter 3 details the main benthic species dredged within the survey regions; Chapter 4 attempts to define the main benthic species found not only in different areas but also the influence of different scallop abundances on other benthic species; and Chapter 5 discusses the impact of commercial dredge fishing on benthic communities.

Chapters 6 – 8 describe the stock dynamics of scallops by considering recruitment, scallop growth, and bed dynamics. Chapter 6 provides an overview of the results of all surveys conducted since 2000; Chapter 7 discusses the relative growth of scallops from different locations; and Chapter 8 discusses growth rates, density dependent growth, and the impact of fishing of scallops.

Chapters 9 – 11 examine the use of other methodologies in the sampling of scallops. Chapter 9 looks at the use of underwater video; Chapter 10 details the potential use of acoustic sounder technology; and Chapter 11 discusses the option of using Industry to collect data and aid in the self-management of their own fishery.

Chapter 12 is the concluding chapter and discusses the main results of this research with respect to the spatial management of scallop stocks, including a discussion of the best future options for management.

1. COMMERCIAL SCALLOPS (*PECTEN FUMATUS*) AND SPATIAL MANAGEMENT.

1.1 Introduction

The commercial scallop fishery (*Pecten fumatus*) has historically been the most important scallop fishery within the southeast of Australia. Traditionally, this species has been caught by dredging, with the product being landed in the shell, split manually at processing plants, and sold ‘roe on’ to both local and export markets. At present, there are three components of the fishery for commercial scallops, made up of the Tasmanian Fishery, the Commonwealth Central Bass Strait Fishery and the Victorian Fishery (this latter fishery was not sampled during this project) (Figure 1.1). Each of these fisheries is run by a different management organization; the Tasmanian government, the Commonwealth government, and the Victorian government respectively. The main aims of this chapter were to:

1) Provide background knowledge of the biology and ecology of *Pecten fumatus*;
2) Describe the ‘boom and bust’ history of Commonwealth and Tasmanian fisheries;
3) Introduce the concept of spatial management of scallop stocks; and
4) Introduce the overall objectives of the Fisheries Research and Development Corporation project 2003/017, “Juvenile scallop discard rates and bed dynamics; testing the management rules for scallops in Bass Strait”.

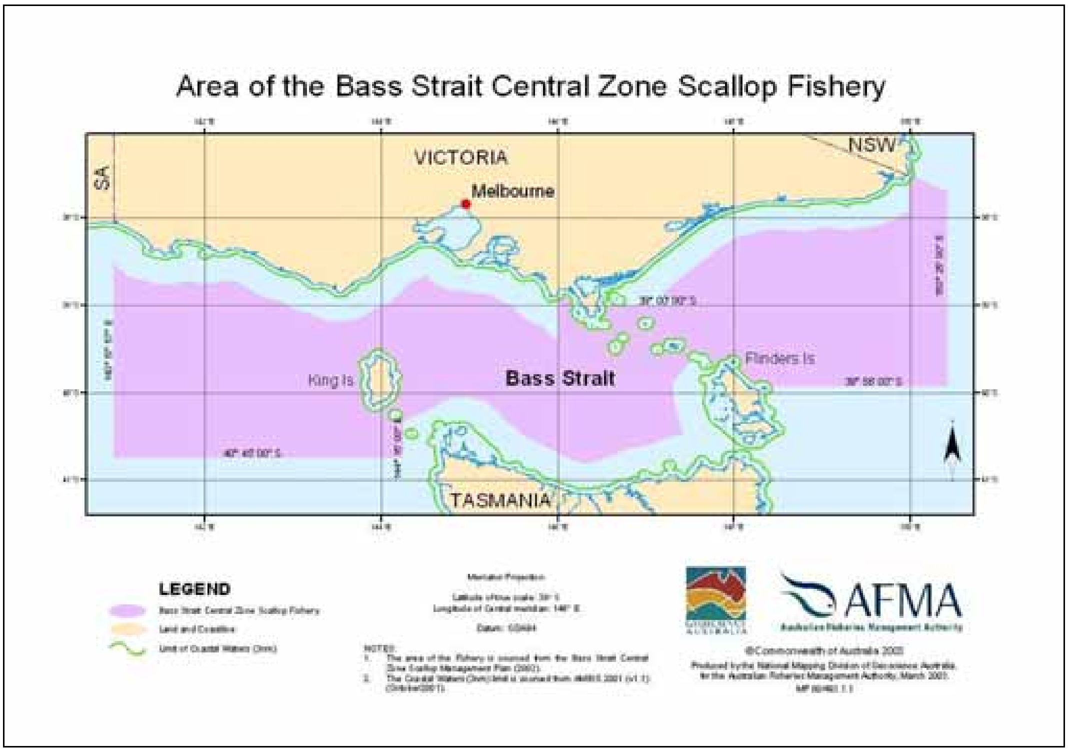

Figure 1.1: The spatial distribution of the three scallop fisheries of southeast Australia. The darker section in Bass Strait is the Central Commonwealth fishery, while the Victorian and Tasmanian jurisdictions are the lighter sections near each state. The diagram is taken from the AFMA website (www.afma.gov.au).

1.2 Biology and Ecology of *Pecten fumatus*

1.2.1 Distribution

The commercial scallop, *Pecten fumatus*, occurs in coastal waters from the southeastern Queensland coast (Hervey Bay), around Tasmania in the south, and westward beyond the border between South Australia and Western Australia (Young *et al*., 1990, Young *et al*., 1999). The taxonomy of P. fumatus has historically been confused, being referred to as *P. modestus, P. alba and P. meridionalis* in various parts of its distribution (Woodburn 1990). There is little doubt that the Victorian, Bass Strait and Tasmanian forms of Pecten are a single species (Woodburn 1990) and possibly a single stock. The species can occur within sheltered inshore areas (*i.e.* Port Phillip Bay, D'Entrecasteaux Channel) and exposed, offshore regions (*e.g.* Commonwealth Central Bass Strait beds, Banks Strait). The species can be found in depths ranging from 5 to 90 meters, on substrates ranging from mud to coarse sand.

Commercial scallops can usually be found at least partially buried within the sediment, with only the flat, right valve visible. Individual scallops can also be found to occupy small depressions in the substrate, and may be totally covered with sediment. Commercial scallops frequently aggregate into beds, the orientation of which is influenced by the strength and direction of tidal current flows. The species is capable of swimming, and individuals have been observed to rise up to 1.7m off the bottom and cover horizontal distances of up to 4 m (Young *et al*., 1989). The ocelli around the mantle are light sensitive and scallops can react to the approach of divers and dredges (Young *et al*., 1989).

1.2.2 Reproduction and Recruitment

Pecten fumatus is a functional hermaphrodite, with individuals generally becoming mature in their second year of life (Young and Martin 1989). Spawning activity has been shown to vary between locations, however, peak spawning activity generally occurs from August to October in southern Tasmania. There is some evidence that smaller, partial spawnings that are followed by gonadal redevelopment may occur in this species (Young *et al.*, 1999). Under laboratory conditions, gonad development and spawning can be induced at any time of the year by controlling food supply and water temperature (Young *et al.*, 1989), suggesting that the timing of spawning within wild populations is controlled by environmental influences.

Early laboratory studies of the larval development of *P. fumatus* showed that fertilized eggs become trochophores after 2 days and secrete the prodissochonch shell to become straight hinged veligers after 3 days at temperatures between 13 and 15^{O}C (Young *et al.*, 1989). Umbones and larval shell are secreted when larvae are about 220µm and metamorphosis occurs around 31 days after fertilization (Young *et al.*, 1989). Laboratory studies indicate that the time taken to reach metamorphosis is shorter at higher temperatures (Young *et al.*, 1989).

Commercial scallop settlement has been shown to be highly variable both temporally and spatially. Studies looking at the settlement of scallops at different locations near King Island and Banks Strait, Tasmania, found temporal differences in settlement from one location to another, within the same location (Young *et al*., 1988), and from one year to the next (Fuentes, 1994). Although settlement may occur over an extended period of time, which appears consistent with the duration of spawning, there is some evidence to suggest that major settlement peaks result from gametes shed over a more limited time (Young *et al*., 1999). In general, major settlement periods occur between

September and December in southern Tasmania (Fuentes, 1994) and between November and December in eastern Bass Strait (Young *et al*., 1989; Young *et al*., 1990).

Trends in scallop settlement times and abundances have previously been determined using spat collectors, as *P. fumatus* spat have been shown to settle readily on these collectors (Young *et al*., 1989). Observations made over a four year period in Port Phillip Bay, Victoria, suggested a consistent positive relationship between the abundance of *P. fumatus* spat in collectors and subsequent year class strength of juveniles (Young *et al*., 1989). However, studies conducted in Bass Strait indicated that the number of juveniles settling on the bottom showed no association with the numbers of spat that had settled on nearby collectors, or the catch-per-unit effort of adult scallops within the same region (Young *et al.*, 1990). This result suggests that, as well as controls on the production and survival of larvae to metamorphosis, there are additional controls on the settlement and survival of recently settled juveniles on the sea bed, such as adverse small-scale hydrodynamic processes, the absence of suitable settlement substrata, and predation on settled juveniles (Young *et al*., 1990). It has also been suggested that the widespread failure of scallop beds to show significant recruitment immediately following commercial exploitation suggests that fishing results in some change to the settlement environment (Young *et al.*, 1990).

1.2.3 Post-Settlement Growth

In their first year of growth, commercial scallops have been shown to reach a shell height of around 60 mm (approximately 70 mm shell length) (Dix, 1981, Sause *et al.*, 1987), however, scallop growth is highly variable (Fairbridge, 1954, Young *et al*., 1989). For example, two-year old scallops from Port Phillip Bay, Victoria, attained shell heights of between 71 and 87 mm (81 to 97 shell length) (Sause *et al.*, 1987), while in Jervis Bay (New South Wales) scallops reach 70 mm in height (80 mm shell length) after two years and 77 mm height (86 mm shell length) by the end of the third year (see Young et al., 1989). Furthermore, aging studies using growth rings within the shell have indicated that scallops with a shell height of 78 mm (88 mm shell length) varied in age from 2.5 to 6 years, depending upon the region from which they were collected (Fairbridge, 1954). Such variation in growth has been attributed to food availability and density-dependent restraints on growth (Young *et al*., 1989). Where scallops were aged using external rings in the shell, the variation may also reflect an inability to accurately age scallop shells, with the suggestion that the rings are spawning related stress marks and not related to age (Richard McLoughlin pers. coms.).

Although *P. fumatus* have been shown to live for up to 14 years (Fairbridge, 1953), most individuals living in wild populations probably live for between 5 and 9 years, reaching sizes between 90 mm and 140 mm. The largest scallop recorded during the course of this research was 155 mm maximum shell diameter and was caught in southern Tasmania (Karl Krause pers. coms.).

1.3 History of the Bass Strait Scallop Fisheries: Boom and Bust

The following brief description of the history of the Tasmanian and Commonwealth scallop fisheries has been summarized from Zacharin (1988), Zacharin (1994), AFMA (2002), and DPIWE (2005). For a full description of the history of the rules and regulations implemented within each fishery throughout history, how effective they were at maintaining stocks, and their application to spatial management techniques see Chapter 12.

1.3.1 Pre 1980

Prior to 1970, the commercial scallop (*Pecten fumatus*) fisheries in southeast Australia focused effort on inshore regions, in particular the D'Entrecasteaux Channel and east coast regions of Tasmania; and within Port Philip Bay and near Lakes Entrance in Victoria. By the late 1970's, most inshore regions had been completely exploited, but with the discovery of major new grounds off the Furneaux group of islands and Banks Strait, most Victorian and Tasmanian boats moved to these offshore scallop beds (Figure 1.1 and Figure 1.2).

1.3.2 The Boom: 1980 - 1986

The shift in fishing effort to the newly discovered offshore scallop stocks near Flinders Island resulted in a rapid increase in the annual scallop catches during the early 1980's, with the catch being just over 4000 tonnes meat weight, in 1982, an increase from 500 tonnes meat weight in 1978 (Figure 1.2). New operators continued to enter the fishery to harvest the increasingly valuable resource, especially in the Banks Strait and Flinders Island regions. By 1983, fishing effort was out of control, having tripled in the previous two years, catches were declining, and few restrictions applied to the fishery. In particular, the scallop fleet was fishing 12 months of the year, many operators were upgrading to larger boats, and Tasmania had no license restrictions on entry to the fishery. The fishery had been depleted to a state of collapse (Zacharin, 1988).

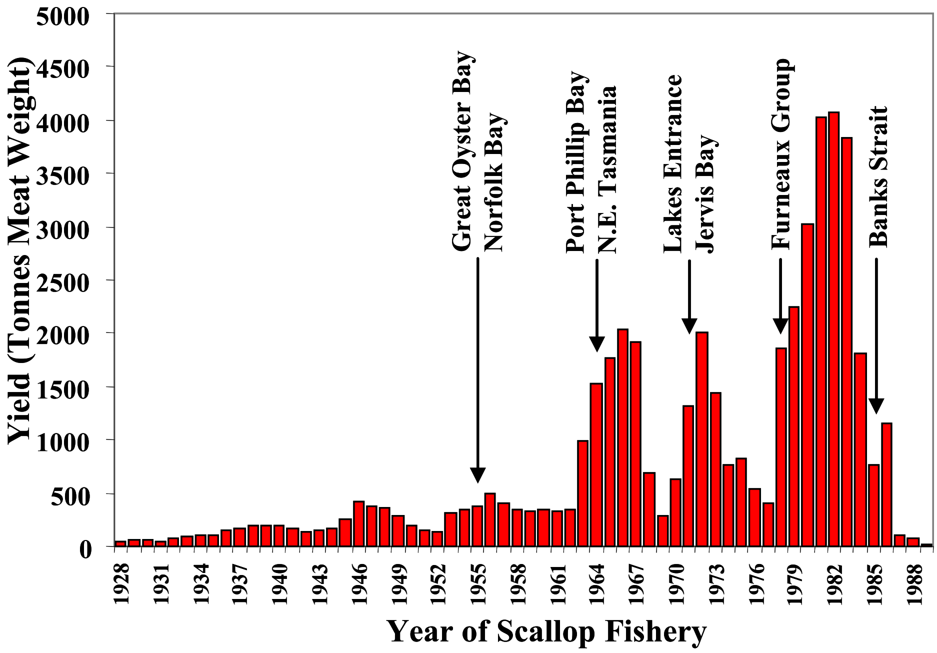

Figure 1.2: Commercial catches, as total meat weights, of *P. fumatus* from southeastern Australia from 1928 to 1989. The years when new beds were first exploited are indicated. (data and diagram after Young *et al.*, 1990).

Rationalization of scallop resource management between Victoria, Tasmania and the Commonwealth was recognized as being of paramount importance in protecting the remaining resource from over-exploitation and in November 1983 the Bass Strait Interim Management Regime was introduced. Under the Interim Regime, 97 Victorian and 134 Tasmanian based vessels were given access to the whole Bass Strait fishery (i.e. their respective State waters and Commonwealth proclaimed waters). In 1984, the Bass Strait Scallop Task Force (BSSTF) was established by the Commonwealth Government to provide advice on long term management arrangements for the Bass

Strait scallop fishery. By 1985, this taskforce concluded that 'due to irreconcilable management differences' the most rational solution to the fishery was to introduce a management regime which achieved a high degree of separation between the Tasmanian based and Victorian based components of the Bass Strait scallop fleet (BSSTF Final Report). The fishery was thus divided into the three currently recognized jurisdictions. This separation was finalized with the implementation of the Offshore Constitutional Settlement (OCS) in June 1986.

As part of the OCS agreement, the Tasmanian scallop fishery had restrictions placed on the number of participating boats (187). Furthermore, each vessel possessed a fixed unit per trip quota in an attempt to rationalize and limit the harvest rate. This trip quota was, however, implemented for economic, not conservation purposes and bore no relationship to available biomass. Despite the implementation of these and several other management regulations, both the Tasmanian and Commonwealth-managed fisheries collapsed during the late 1980's (Figure 1.2).

1.3.3 Post 1990

In an attempt to regenerate depleted scallop stocks, several new management strategies and regulations were implemented within both the Tasmanian and Commonwealth fisheries. By 1991 the Bass Strait Scallop Consultative Committee (BSSCC) was formed to develop a management plan for the Bass Strait scallop fisheries. Fishermen and managers recognized that future harvesting strategies needed to be based on up-to-date biological knowledge of the species (in regard to reproductive maturity and growth rates), fleet dynamics and the need for economic efficiency. The resultant management strategy combined input and output controls to restrict the number of fishers; to prohibit the taking of small scallops; to control scallop landings, and to provide a level of profitability to the fleet.

The two main strategies of the Central Bass Strait management plan were the '20% trashing rate' requirement and the 'two major spawnings' criterion. These rules were implemented following the analysis of data collected by the CSIRO during the mid-1980's (Young *et al.* 1989). The 20% trashing rate was designed as a yield optimization strategy, through limiting the capture of, and minimizing incidental mortality to, small scallops. The 'two major spawning' criterion was a parallel management requirement, designed to allow scallops two major spawnings prior to their being fished, without regard to size. Two major spawnings from adults was considered essential if sufficient reproduction output to the fishery was to occur. Seasonal closures were also adopted, which shut the scallop season during the summer months. This minimized the impact of scallop dredging during the highest spatfall (settlement) period, and stopped the landing of scallops in poor condition. Despite these changes, the Commonwealth and Tasmanian scallop fisheries had again collapsed by 1999/2000 (Figure 1.3). From 1999 (Commonwealth) and 2000 (Tasmania) to 2002, both the Central Bass Strait scallop zone and the Tasmanian scallop zone remained closed to commercial scallop fishing due to low abundance of commercial sized scallops. Although the Commonwealth-managed fishery was open during 2001 and 2002, no fishing occurred (Figure 1.3).

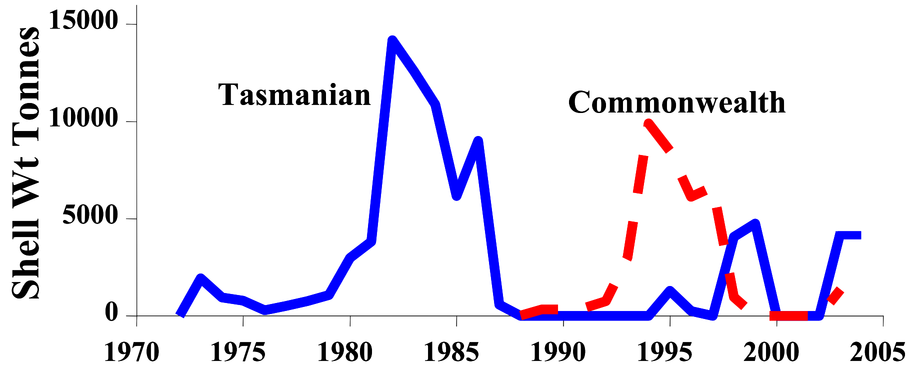

Figure 1.3: Commercial scallop catch (shell wt) within the Tasmanian (solid line) and Commonwealth (dotted line) scallop fisheries using available data.

1.4. Why the 'Busts'?

During the 1970's and early 1980's, declines in the annual catches of scallops resulted from the over-exploitation of known stocks. These 'busts' were quickly followed by high annual scallop catches ('booms') as new unfished scallop stocks were discovered (Figure 1.2, 1.3). It is clear that this phase of fishing was in no way sustainable but rather was systematically and serially depleting each new area of scallop beds as they were found. By the late 1980's this cycle of 'boom and bust' culminated in the exploitation of all identifiable scallop beds within each fishery and their ultimate collapse. Changes to the management regulations appropriate to each of the fisheries (see section 1.3) may have coincided with natural recovery of scallop stocks (recruitment success) during the 1990's, which allowed some commercial fishing operations during this period. However, both the Tasmanian and Commonwealth fisheries again collapsed in the late 1990's. This had been predicted by Young *et al.* (1989, p.15) who stated: "The last major bed in Bass Strait was fished out during the 1986 season, leaving the industry with few prospects for the remainder of the decade and a legacy of excess fishing capacity that will ensure the rapid depletion of any new beds that may be found in the future."

The high levels of continued exploitation of scallop beds during the 1990's possibly depleted adult scallops stocks (spawning biomass) to levels where the population did not have the reproductive capacity to replenish itself in the short term, a condition known as recruitment overfishing. Furthermore, the high physical impact of scallop dredging over suitable habitat may have resulted in the catastrophic incidental mortality of any recruits and the subsequent elimination of new year classes (cohorts) to the fishery. The continued impact of fishing over several years would therefore have the potential to lead to the collapse of the fishery.

Recruitment failure, combined with the removal of the adult spawning biomass through commercial fishing operations and natural mortality, would also result in the collapse of the fishery. Recruitment failure would occur if scallop beds failed to spawn or scallop larvae failed to settle. Anecdotal evidence, however, suggests that commercial scallops, to some extent, do settle successfully each year. For example, oyster and mussel farmers located on the east coast of Tasmania have reported the attachment of juvenile commercial scallops on mussel lines and oyster racks as an annual occurrence; and owners of marine farming leases within the D'Entrecasteaux Channel, who have been granted permits to collect scallop spat in spat collectors, have reported spat catches annually (Phil Lamb, pers. Coms.). It is unknown whether these observed levels of settlement are sufficient to maintain commercial populations of scallops, or if physical (dredging) and environmental parameters post-settlement and resultant high mortality rates lead to unsuccessful recruitment to the fishery.

Even if successful recruitment to the beds occurs immediately following a stock collapse the time lag involved in allowing those juvenile scallops time to grow to a legal size can be three or four years or more. This became apparent in the late 1980s collapse when in order to obtain some small catches the legal minimum size was reduced: "In 1987, with the prospect of poor catches, and with widespread violation of the existing size limit, the minimum size for *P. fumatus* was reduced to 80 mm at the maximum diameter" (Young et al., 1989, p.32). To avoid the boom and bust nature of the past Tasmanian and Commonwealth fisheries, it seems logical to suggest that some degree of protection to both the spawning biomass and suitable habitat for settlement would greatly increase the potential for continuity of scallop stocks between years (i.e. eliminate the busts). This concept forms the basis of spatial management regimes.

1.5. The Introduction of Spatial Management Strategies

In 2003, it was determined that the scallop stocks within both the Commonwealth (see Haddon and Semmens 2003) and Tasmanian managed areas were showing signs of recovery and a commercial scallop season was opened within both jurisdictions. However, a new system of management, spatial management, was implemented in an attempt to move away from the boom and bust nature of the commercial scallop fishery. The main idea behind spatial management was to protect areas of scallops by closing them to fishing, such that they would provide a spawning biomass to replenish fished areas, and provide undisturbed habitat for the settlement of juveniles. This was termed "paddock" fishing by Tasmanian licensed fishers. If successful, spatial management of scallop stocks would greatly improve the chances of maintaining annual continuity in the fisheries (i.e. eliminate or greatly reduce the 'busts').

Different strategies of spatial management were adopted by the Tasmanian and Commonwealth management organisations, while the Victorian fishery maintained its approach of exploratory scallop fishing each season. The following sections briefly discuss the key approaches of the three management authorities to the scallop stocks falling within their management areas, as summarised in: *A review of the offshore constitutional settlement arrangements for Bass Strait scallops. Options paper. 9 July 2004* (Anon, 2004).

1.5.1 Victorian Fishery

The means available for managing the Victorian scallop fishery are set out in the *Fisheries Act 1995* and the *Fisheries Regulations 1998*. As of 2004, the Victorian government had deferred writing a formal Management Plan for their scallop fishery. If it becomes apparent that the existing jurisdictional arrangements for the Bass Strait scallop fishery are not to change, then it will be necessary for Victoria to write a Management Plan for the fishery, consistent with the provisions of the *Fisheries Act 1995*.

For a number of years Victorian fisheries managers had adopted the practice of opening the fishery in May (for 2004 the season opened in April), with a relatively low TAC set for a three-month period. Once a season is declared open, catch rates and size and condition of scallops are monitored and this information determines how the fishery is managed for the rest of the season. If catch rates are good and the quality of scallops taken is satisfactory, consideration can be given to increasing the annual TAC. Conversely if catch rates are poor and the condition of scallops indicate that they are not suitable for harvesting, the fishery will be reviewed and closures of the entire fishery considered. No decision rules have been documented as to what level of catch rates constitute “good” or “poor”. In recent years there have been reports of the processing sector acting to effectively close the fishery when the scallops became too small or out of condition for the markets.

1.5.2 Central Bass Strait (Commonwealth) fishery

AFMA’s objectives for the Central Bass Strait Scallop Zone are listed in the *Fisheries Administration Act 1991* and the *Fisheries Management Act 1991*, which determine and limit all AFMA’s operations.

AFMA’s management goals in the Central Zone fishery are to protect the (adult) spawning biomass through a system of closed areas; to protect the settlement of juvenile scallops through closed seasons; and to distribute the catch between operators through a combination of TAC and individual transferable quota (ITQ) entitlements. AFMA’s general approach has been to protect the minimum spawning or mature biomass for effective recruitment (through closed area/s) and allow operators access to all other areas of the fishery, giving them maximum flexibility within the TAC and fishing season.

1.5.3 Tasmanian fishery

Sustainable management of Tasmania’s marine resources is the responsibility of the Department of Primary Industries, Water and Environment (now DPIW) under the *Living Marine Resources Management Act 1995*. The objectives of the Resource Management and Planning System of Tasmania are described in Schedule 1 of the *Living Marine Resources Management Act 1995*.

Tasmania’s specific objectives in the scallop Management Plan include:

- to allow stocks to rebuild to acceptable levels by protecting new scallop beds from fishing until scallops in those beds have the opportunity to complete two major spawnings;
- to take scallops at a size likely to result in the best use of the yield from the fishery;
- to provide measures to minimise the accidental harvesting of undersized scallops;
- to minimise incidental fishing mortality as a result of fishing operations; and
- to ensure the scallop fishing fleet and scallop processors continue to provide employment and an economic return to the coastal communities of Tasmania.

Strategies used to try and achieve these objectives include an area-based, rotational harvesting strategy, which generally restricts fishing activity to one discrete open area at a time, while the rest of the fishery is closed to fishing; a minimum size limit; restriction on the total catch for the fishery; and the possibility of restrictions to promote orderly harvesting and to minimise the risks of overloading the processing sector and subsequent poor return both to fishers and the wider community. Within the Tasmanian fishery, there is scope for fishers to provide information to managers on the condition of scallops once the season has started. Such advice can subsequently lead to spatial and temporal closures.

1.5.4 Other Legislation

The scallop fisheries aim to export at least some of the yield from the fishery as a way of maximizing the economic return from the fishing activity. In order to export Australian wildlife (including product from fisheries) it is necessary to obtain a Wildlife

Trade Order exemption or to complete a strategic assessment of the export fishery under the conditions of the Environment Protection and Biodiversity Conservation Act administered by the Department of Environment and Heritage.

1.5.5 Current Management Strategies

The box below provides a comparison and summary of the alternative management strategies adopted in each of the three jurisdictions holding sway over the commercial scallops in the southeast corner of Australia.

Victorian Fishery	All beds open every year, with an implied TAC. There is scope for temporal closures depending on condition and size of scallops.
Commonwealth fishery	Need for at least two scallop beds of certain biomass. Majority of the fishery is opened and one bed (relatively small spatial area) of known scallops is closed to protect adult biomass.
Tasmanian fishery	Most scallop beds closed, with small area(s) open, with a flexible maximum catch allocation per quota unit within the fishery, and size and trashing rate limits.

1.6 Testing the Management Rules for Scallops (FRDC 2003/017)

The implementation of the different spatial management strategies in the Commonwealth and Tasmanian scallop fisheries provided a unique opportunity to study scallops and the relative success of the different sets of spatial management rules applied to each fishery (see section 1.5.5). In 2003, the Tasmanian Aquaculture and Fisheries Institute successfully submitted an application for a project titled, "Juvenile scallop discard rates and bed dynamics: testing the management rules for scallops in Bass Strait (FRDC 2003/017) to the Fisheries Research and Development Corporation (FRDC). The main objectives of this project were:

1) Determine, using VMS, the relative fishing intensity and extent of scallop dredging in both the Bass Strait Central scallop fishery and the Tasmanian scallop fishery, in areas opened to fishing in 2003 and 2004.
2) Determine the relative impact of fishing on different size classes of scallops on those beds open to fishing, especially the rate of survival of undersized scallops.
3) Determine whether a relationship exists between juvenile settlement success in different areas and the relative fishing intensity, as defined by VMS data, experienced by those different areas.
4) Determine the major bycatch species taken with commercial scallop dredging gear on the main scallop beds fished in Bass Strait (including Tasmanian, Central Bass Strait and, if possible, Victorian scallop beds).
5) Conduct an initial study of the effects of scallop dredging on benthic fauna by comparing closed areas and areas open to fishing in a before and after sampling design.
6) Generate management options aimed at optimizing the use of area based management strategies for scallop fisheries.

2. USE OF VMS DATA TO DETERMINE THE EXTENT AND INTENSITY OF SCALLOP FISHING.

2.1 Introduction

The first objective of this study was to 'determine, using VMS, the relative fishing intensity and extent of scallop dredging in both the Commonwealth Central Bass Strait scallop fishery and the Tasmanian scallop fishery, in areas open to fishing in 2003 and 2004'.

The AFMA web page illustrates that Vessel Monitoring Systems (VMS) consist of three components

- the tracking unit on the vessel - Automatic Location Communicator (ALC);
- the transmission medium – *e.g.* Inmarsat and secure internet connection; and
- the base station

Within the Commonwealth Central Bass Strait and Tasmanian Scallop fisheries, ALC's with a built in Global Positioning System (GPS), are fitted to each vessel and regularly transmit information on vessel position and speed, via an Inmarsat communications satellite, to a land earth station (LES), and then by a secure internet connection to a computer base station at the Australian Fisheries Management Authority in Canberra and the Department of Primary Industry, Water and Environment in Hobart respectively. The information sent from individual vessels includes date, time of day and latitude / longitude.

Although the primary role of VMS is for monitoring fisher compliance with spatial and seasonal fishery management regulations, the high-resolution position data has potential applications in fisheries research, in particular, for identifying specific areas being fished. While a few examples of using GPS (Rijnsdorp *et al.* 1998) and VMS (Deng *et al.*, 2005) technology for research exist, no standard methodologies for using VMS data for such purposes are available. Consequently, a set of procedures for using VMS data to define regions and level of fishing activity within the Tasmanian and Commonwealth fisheries were developed as part of this project.

The main aims of this chapter were to:

1) describe the methods used to analyse the scallop fishery VMS data to identify areas of different fishing intensity,
2) use these methods to determine the geographical extent and relative intensity of fishing in both the Commonwealth and Tasmanian scallop fisheries, and
3) make a general comparison of fishing operations in the two jurisdictions.

2.2 Use of VMS in Survey Design and Analysis

VMS data for the 2003 and 2004 Commonwealth Central Bass Strait and Tasmanian scallop fisheries were obtained, with the agreement of the scallop fishing industry, through special security and confidentiality agreements between the researchers and AFMA and TAS-DPIWE. The data, once transferred, was stored on a secure database at the MRL / TAFI. The actual data acquired consisted of the following fields:

- Name of vessel
- Vessel code
- Date
- Time of day
- Latitude
- Longitude
- Measured speed
- Calculated speed

2.2.1 Data 'Screening'

VMS position data was available for all actively licensed scallop boats fishing the 2003 and 2004 Commonwealth and Tasmanian scallop seasons. Coordinates (latitude and longitude) were then plotted on to a map using the software package ArcView GIS 3.2a for Windows. In order to use VMS data to characterize fishing operations it was obviously necessary to develop criteria for deciding whether a VMS 'poll' occurred during fishing operations or at other times. VMS 'polls' falling outside of the open fishing areas were assumed to be vessels travelling either to or from the fishing grounds (this included periods when vessels were tied up in port), or conducting other fishery operations. In addition, VMS 'polls' that were in the open areas but recorded from vessels moving at speeds greater than 8 knots (measured or calculated speed) were also classified as taken from travelling boats (i.e. not fishing). Neither of the travelling categories was used when estimating area fished or fishing intensity. Confidentiality and security agreements prevent information concerning polling frequencies being described in this report; nevertheless, in general they were sufficient for the purposes of delineating the distribution of fishing pressure.

At the completion of this data screening and plotting process, several relatively small, discrete areas of fishing activity were identified within each fishing jurisdiction (see Figure 2.1a).

2.2.2 Defining Fishing Extent and Intensity of Fishing

A grid creator extension in ArcView 3.2a was used to place 500m x 500m grids over each discrete fishing area (Figure 2.1b). This grid size was chosen because an individual five minute scientific dredge tow generally covers between 400 - 450m, and would subsequently fall within an individual grid cell, allowing for individual cells to be examined in fisheries independent surveys (see Chapter 5). A 'point count' script was used to perform a count of the total number of VMS polls falling within each individual 500m x 500m cell. These counts were then classified into four defined categories of inferred fishing intensity: no fishing, low, moderate and heavy / high fishing intensity areas (Figure 2.1c). The different fishing intensity categories implied that the cells contained different relative numbers of VMS 'polls'. Because of the confidentiality and security agreements between TAFI and AFMA / DPIWE, no explicit quantification of the number of 'polls' making up each category can be given, however, Table 2.1 gives an indication of the relative abundance of VMS 'polls' within each category, relative to the 'polls' in low fishing intensity. Estimates of total area open to fishing, compared to areas actually fished at different intensities were determined using area calculators in ArcView 3.2a for Windows.

Table 2.1. Relative abundance of VMS 'polls' in the different intensity categories. No indication of absolute intensities can be given for confidentiality reasons. When selecting survey areas the upper bounds of the categories were used.

Intensity Category	Relative Lower Bound	Max. Relative Upper Bound
Heavy	> 2.5	<5.0
Moderate	>1.0	< 2.5
Low	>0.5	<1.0
No Fishing	<0.5	

The fishing intensity categories used were the same between years and between Tasmanian and Commonwealth waters. The main assumption of this methodology was that areas containing higher VMS poll counts correspond to areas of increased fishing intensity, which are assumed to correspond to areas containing higher abundances of scallops / more productive scallop grounds. When selecting areas to survey areas meeting the upper bounds of each intensity category were chosen in order to maximise the chances of selecting the appropriate category type (see later chapters),.

2.2.3 Defining Fishing Extent and Intensity of Fishing

Within the Tasmanian scallop fishery, management rules require individual boats to record catch data for each fishing trip conducted. This data is recorded at a spatial scale of fishing locality block, each of which is $^{1}/_{8}{}^{th}$ degree, with data recorded for each day fished. Data fields recorded include date, block locality ID and hours spent fishing within that block. Within this section it was assumed that the number of hours spent fishing per locality block could be used as an indicator for fishing intensity. It was therefore expected that locality blocks with a higher number of hours fished would overlap those areas identified using VMS data as having low, moderate and heavy fishing intensity. The spatial scale differences in the two techniques meant that overlap was expected but with an unknown degree of correlation. A comparison was made and discrepancies discussed.

2.3 Results

2.3.1 Commonwealth-managed Fishery – Extent and Intensity of Fishing

Only a relatively small area of the Commonwealth-managed fishery was closed to commercial fishing during the 2003 scallop season (Figure 2.3), with all remaining areas being open. Despite this large open area only three very small discrete areas, which covered approximately 2,300 hectares, were identified within strata 1, 2 and 3 as being fished at detectable levels of fishing (Figure 2.4a). Of the total area fished, 125 hectares, or approximately 5%, was fished at the heavy intensity (Figure 2.4a).

The closed area for the 2004 Commonwealth scallop fishery remained very small relative to the available open area (Figures 2.3 and 2.4), with VMS data identifying two very small areas within strata 2 and 5b, which covered an area of approximately 375 hectares combined, as being fished (Figure 2.4b). Furthermore, when using the same scale as that used for the 2003 dataset, no areas were identified as being fished at heavy intensity during 2004 (Figure 2.4b).

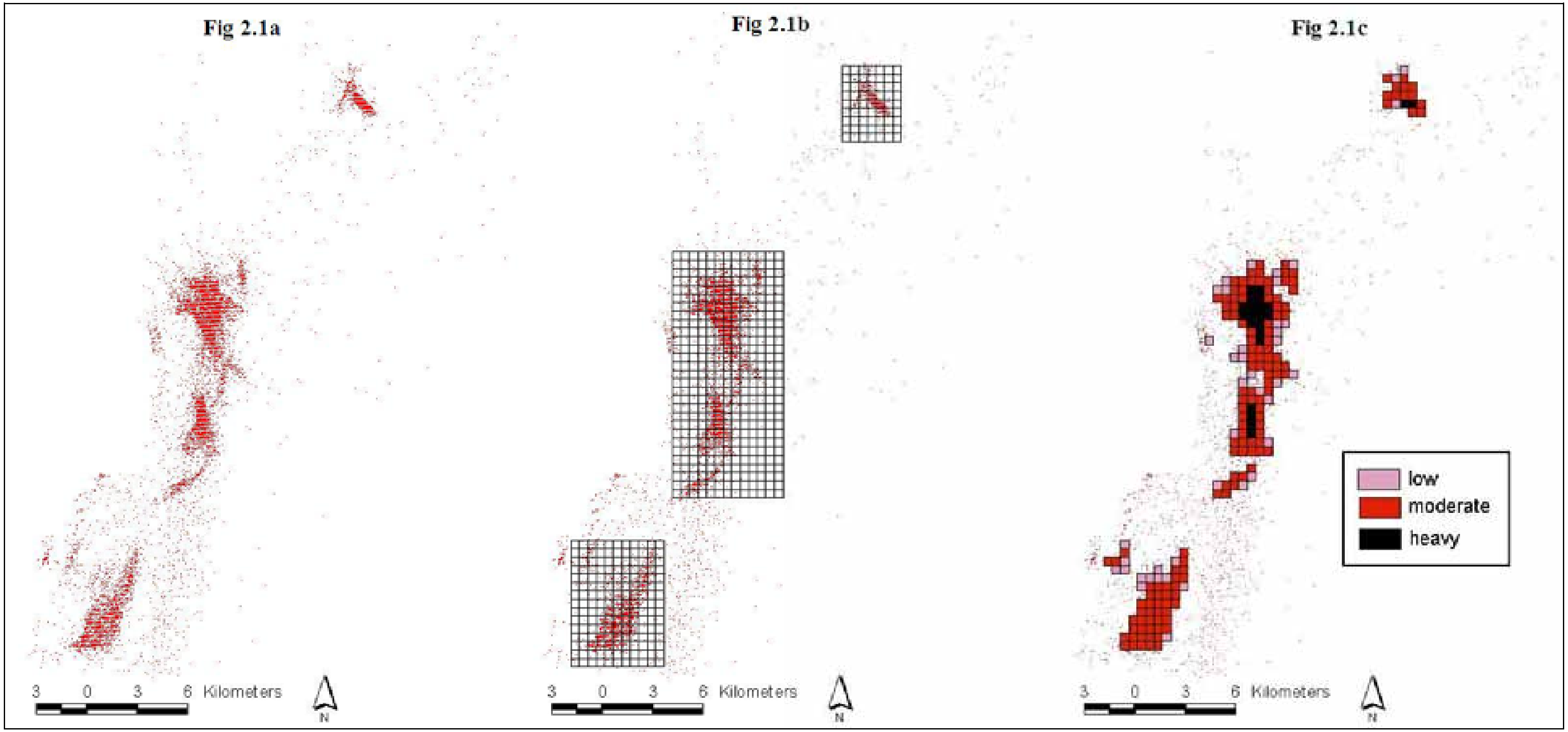

Figure 2.1. Indicative maps drawn in the GIS program ArcView 3.2a for Windows representing 2.2a) raw latitudes and longitudes identifying discrete fishing areas; 2.2b) 500m x 500m grid overlay; and 2.2c) categorisation of fishing intensity areas, where heavy intensity areas had at least 2.5 times the number of hits vs low intensity areas. Areas outside those identified were considered 'no-fishing' areas.

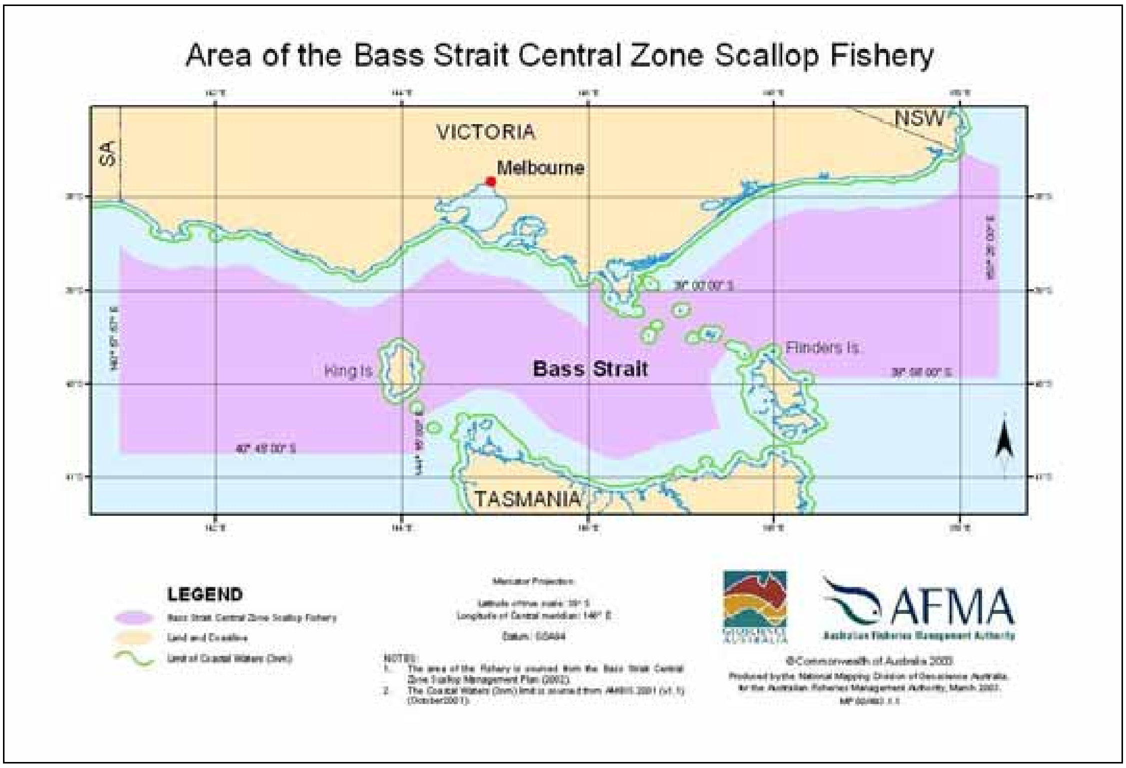

Figure 2.2. The total area falling within the Commonwealth Central Bass Strait scallop fishery, illustrated in Pink / darker region within Bass Strait. Diagram obtained from the AFMA web site.

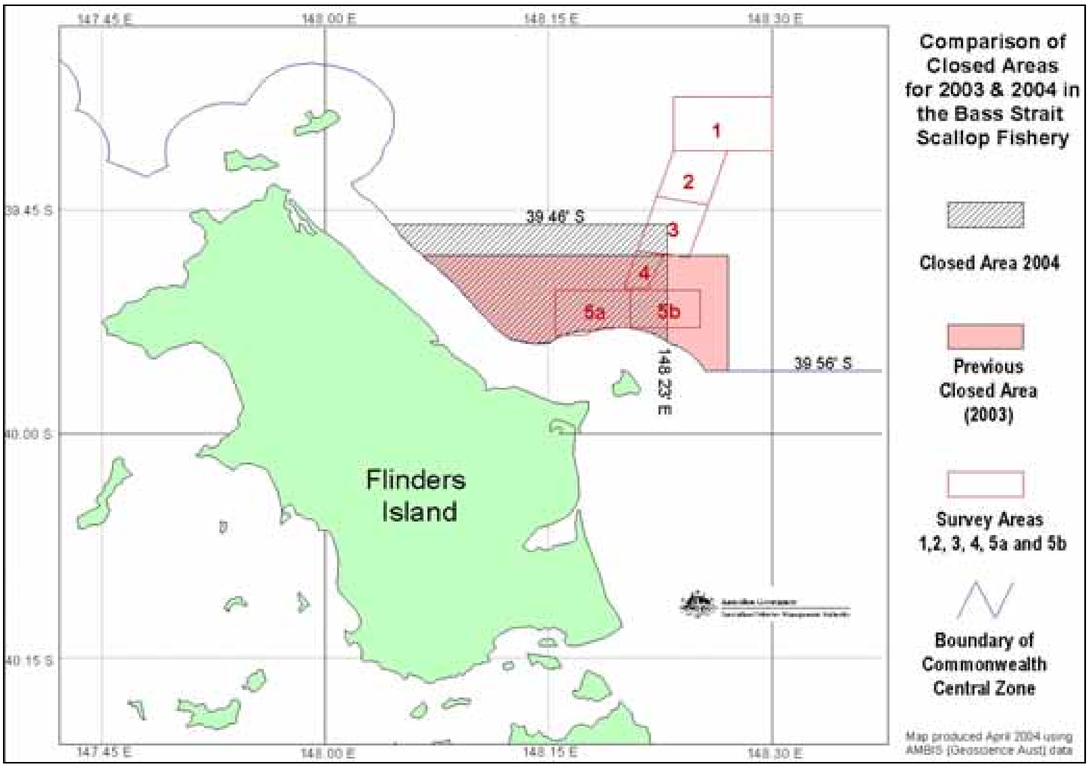

Figure 2.3: Map illustrating the areas closed during the 2003 (pink area) and 2004 (diagonal lines) Commonwealth-managed scallop seasons. All other areas shown were open to fishing. The numbered boxes were the Commonwealth strata used in the formal surveys. (Courtesy of AFMA).

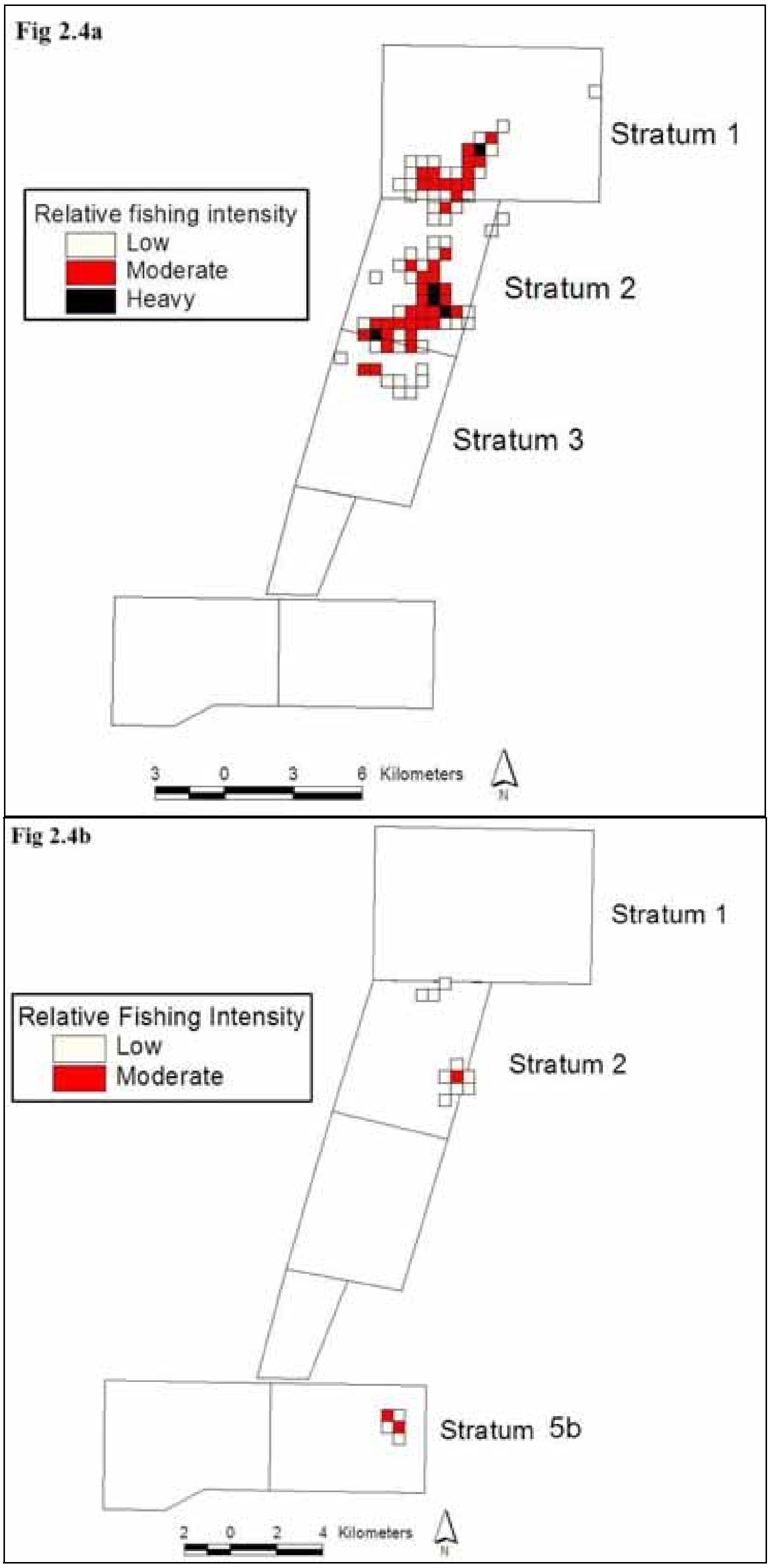

Figure 2.4. Extent of fishing, and areas of different fishing intensity for the 2003 Commonwealth fishery (2.4a) and 2004 Commonwealth fishery (2.4b). These two maps of fishing intensity use the same intensity scale as used in Figure 2.6 (Tasmanian-managed fishery).

2.3.2 Tasmanian-managed Fishery – Extent and Intensity of Fishing

Two relatively small, discrete areas were open to commercial fishing during the 2003 Tasmanian scallop season, while all remaining areas were closed to fishing. From mid-June to mid-July 2003 approximately 39,000 hectares to the east of Cape Barren Island was open to fishing (Figure 2.5). VMS data detected that approximately 1,800 hectares, or 4.6%, of the total open area, was fished, with 525 hectares (30%) being fished at heavy intensities (Figure 2.6a). The scallops in this area were reported as being in poor condition and this led to the early closure of this area near Cape Barren Island. For the reminder of the 2003 season (mid-July to mid-December), an area of approximately 89,000 hectares was opened to commercial scallop fishing east of Eddystone Point (Figure 2.5). Within this total open area, approximately 4,725 hectares, or 5%, was fished; and 1,450 hectares, or 30%, of this fished area was fished at heavy intensities (Figure 2.6b).

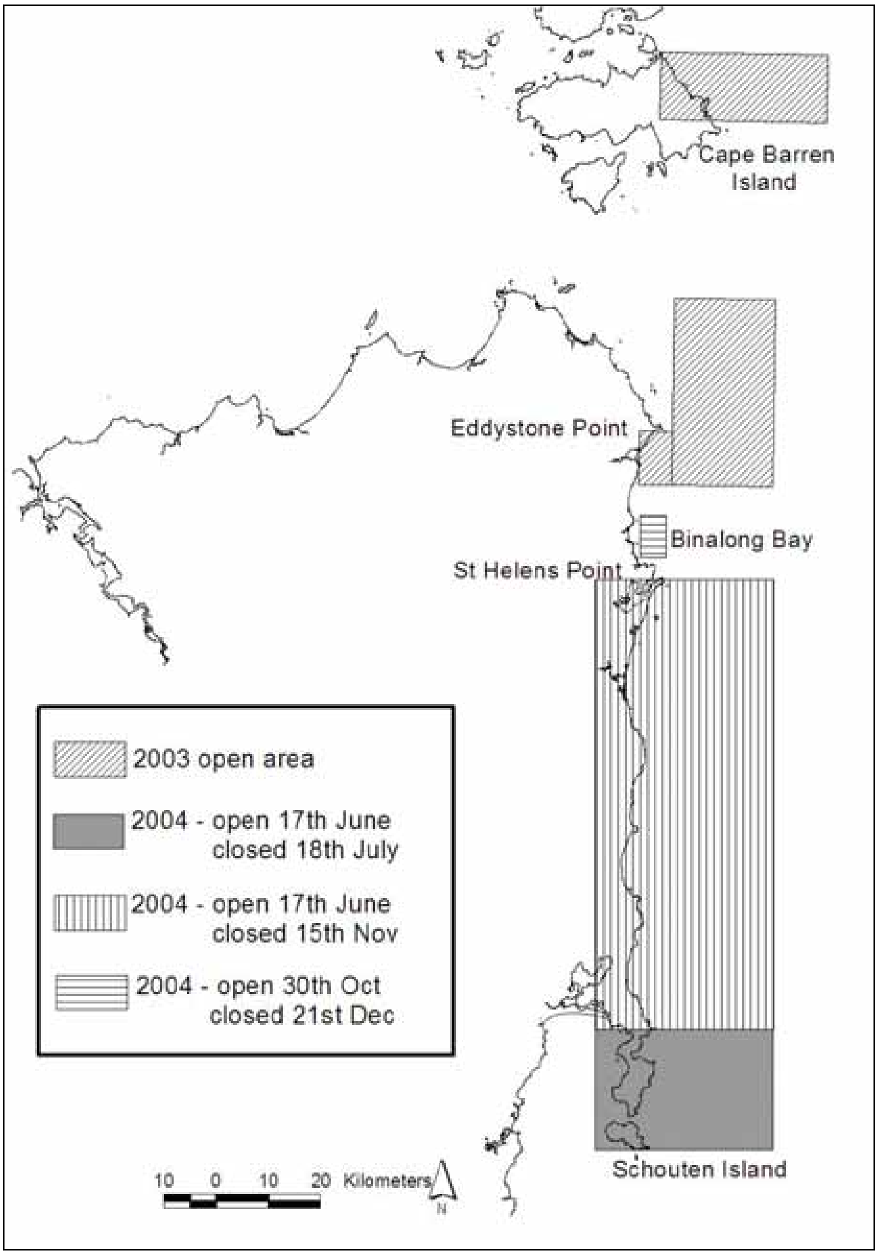

Figure 2.5. Open areas of the Tasmanian scallop fishery during 2003 and 2004.

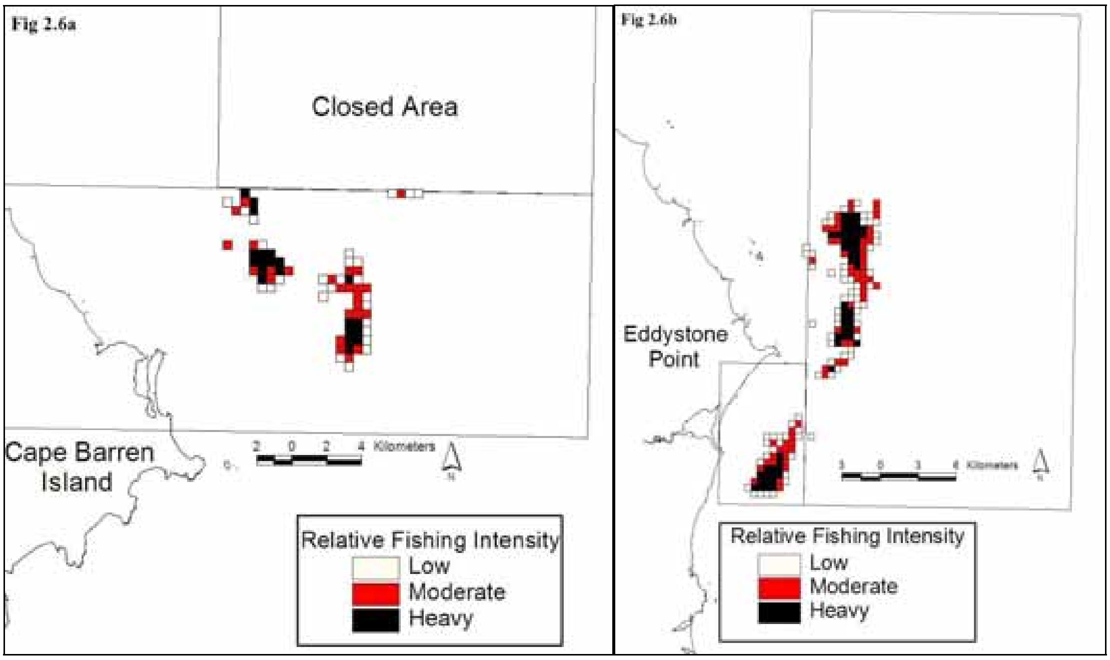

Figure 2.6: Extent of fishing during the 2003 Tasmanian scallop season in the area off Flinders Island (Fig 2.6a) and Eddystone Point (Fig 2.6b).

The 2004 Tasmanian scallop season also had a series of temporal and spatial openings and closures (Figure 2.7), with the main open area occurring between St Helens Point and Cape Tourville from June 17th to November 15th 2004 (Figure 2.7). Although this open area covers approximately 94 km of coastline, which represents a very large potential fishing area, only small, discrete areas were fished at detectable levels (Figure 2.7). A small discrete area to the north of St. Helens Point (Binalong Bay) was opened for the last four weeks of the 2004 scallop season (Figure 2.7). The approximate area fished, the area fished at heavy intensity and % of total area fished at heavy intensity for each discrete area fished during 2004 was identified using VMS (Table 2.2). It needs to be noted that other, much smaller areas were fished by fewer than 5 boats. Data from these operations cannot be shown due to confidentiality issues.

Table 2.2: Characteristics of the five scallop beds fished in 2004. Id relates to location indicator on Figure 2.7. hec relates to hectares.

Bed location	Id	Area Fished (hec)	Area heavily fished (hec)	% fished at heavy intensity
St. Helens Island	1	1325	375	28.3
Nth Long Point	2	3650	1300	35.6
Sth Long Point	3	1400	650	46.4
Bicheno	4	1250	325	26
Binalong Bay	5	2300	925	40.2
TOTAL		**9925**	**3575**	**36**

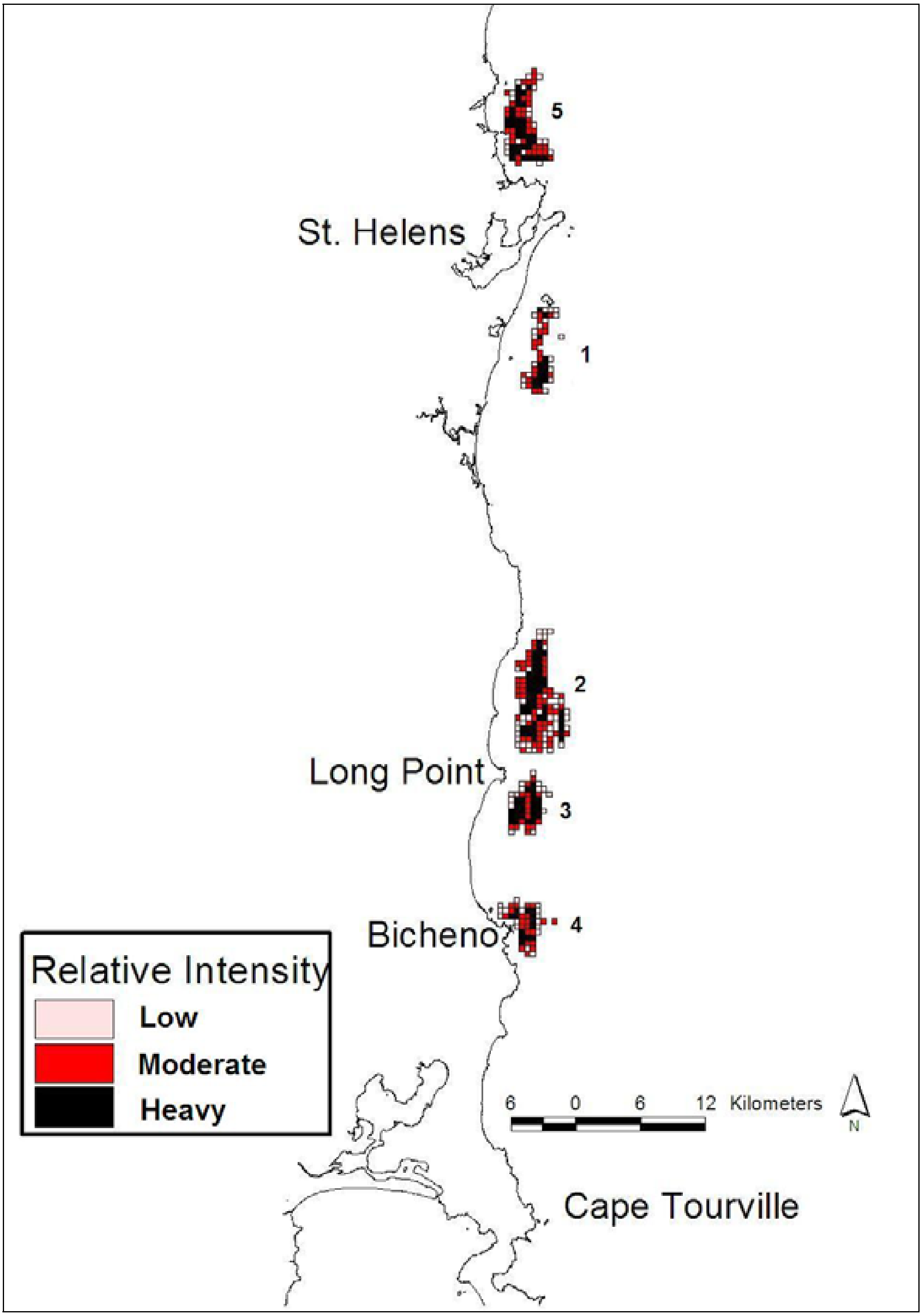

Figure 2.7: Extent of fishing during the 2004 Tasmanian scallop season in the area from Binalong Bay just north of St. Helens Point south to Cape Tourville.

2.3.3 Comparison of Tasmanian with Commonwealth Scallop Beds

Scallop beds in the surveyed regions of the Commonwealth-managed area were generally smaller in size, and had a much lower proportion of heavy fishing intensity areas compared to the Tasmanian-managed scallop beds (compare figures 2.4, 2.6, 2.7). This result could imply that scallop beds in the Commonwealth-managed areas contain lower scallop densities relative to the Tasmanian scallop beds. It may also reflect a different benthic habitat and/or perhaps a different sediment type and/or differences in earlier settlement and recruitment patterns of scallops.

2.3.4 Accuracy of VMS methodology

When the statistical fishing locality blocks were overlayed on the VMS fishing intensity maps, it was generally found that blocks with a greater number of hours fished did overlap areas defined using VMS data as having heavy, moderate and low intensities of fishing (Figure 2.8a and 2.8b and Table 2.3). This observation was generally supported by a scatter plot of the number of hours fished within individual locality blocks, and a ranking of the number of VMS polls occurring within that locality block (Figure 2.9). However, there were several instances where VMS data identified minimal or no fishing, but fisher catch return data showed relatively high hours fished in the overlapping locality block.

In some instances, these anomalies are the result of fished areas not being identified using VMS data because of the ‘five or fewer boats’ confidentiality rules’ that apply to data access. Thus, when small numbers of boats were fishing, fisher catch returns still indicate relatively high levels of fishing (e.g. fishing block 4H4I in Figure 2. 8a and Table 2.3). In these circumstances the observed differences are transparent. Other anomalies, however, cannot be explained in this way as the VMS data indicates very minimal fishing activity within some areas while fisher catch returns have identified a high number of hours fished (e.g. fishing locality block 5H1D in Figure 2.8a and Table 2.3). In these instances it is believed that fishers have allocated the hours fished to the incorrect locality block, possibly as a result of the close proximity of fishing activities to two locality blocks while there is no provision for recording more than one locality block in a single day’s records.

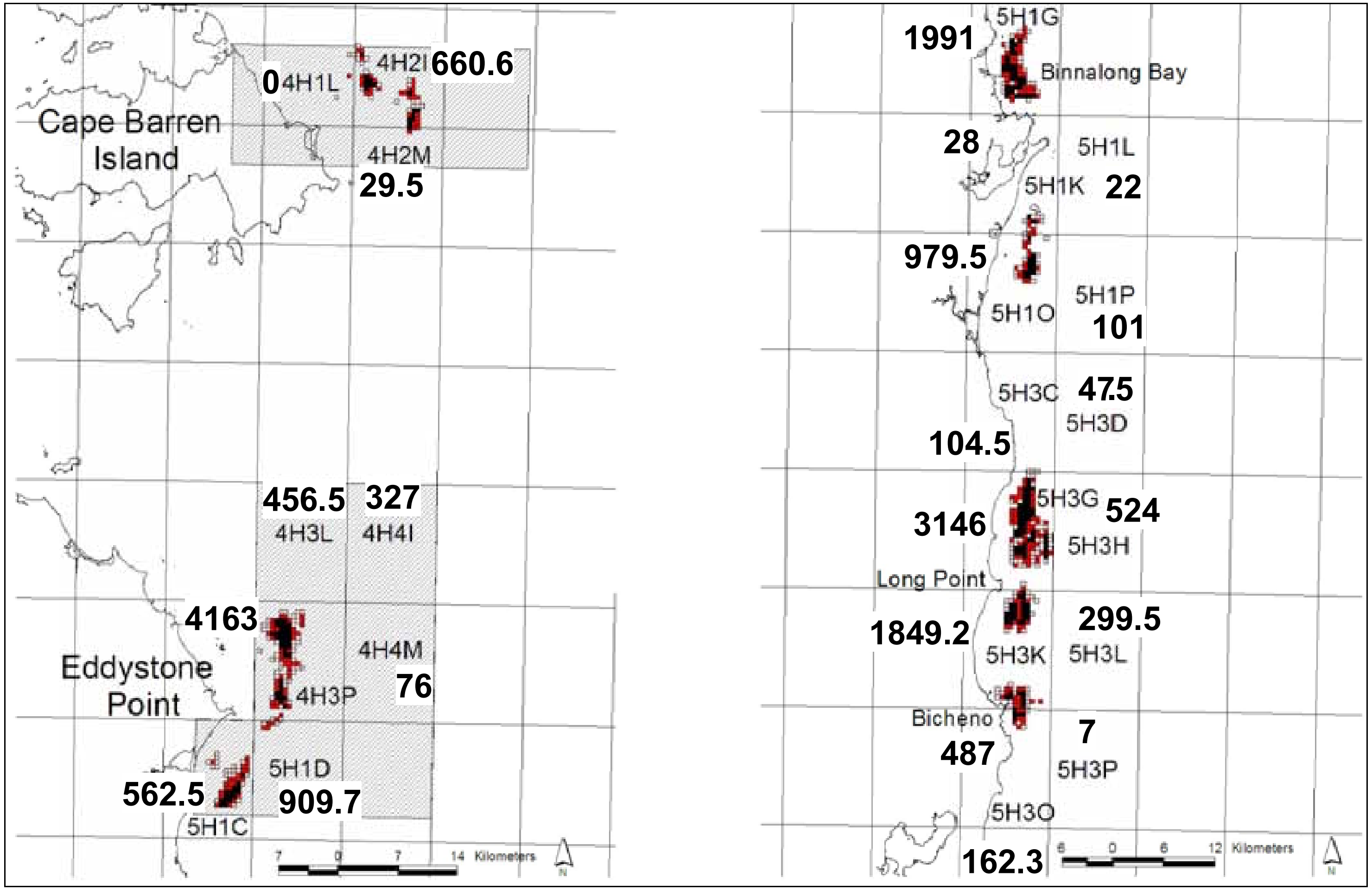

Figure 2.8. Identifying the hours fished (effort) in each fishing statistical reporting block for comparison with the effort distribution implied by the VMS data.

Table 2.3: The reported effort in each 15' x 15' statistical reporting area open to commercial dredging in 2003 and 2004.

Year	Block ID	Hours Fished	VMS Intensity
2003	4H1L	0	Low
2003	4H2I	660.6	High
2003	4H2M	29.5	Low
2003	4H3L	456.5	No Fishing
2003	4H4I	327	No Fishing
2003	4H3P	4163	High
2003	4H4M	76	No Fishing
2003	5H1C	562.5	High
2003	5H1D	909.7	Moderate
2004	5H1G	1991	High
2004	5H1K	28	Moderate
2004	5H1L	22	No Fishing
2004	5H1O	979.5	High
2004	5H1P	101	No Fishing
2004	5H3C	104.5	Low
2004	5H3D	47.5	No Fishing
2004	5H3G	3146	High
2004	5H3H	524	No Fishing
2004	5H3K	1849.2	High
2004	5H3L	299.5	No Fishing
2004	5H3O	487	High
2004	5H3P	7	No Fishing
2004	6H1C	162.3	No Fishing

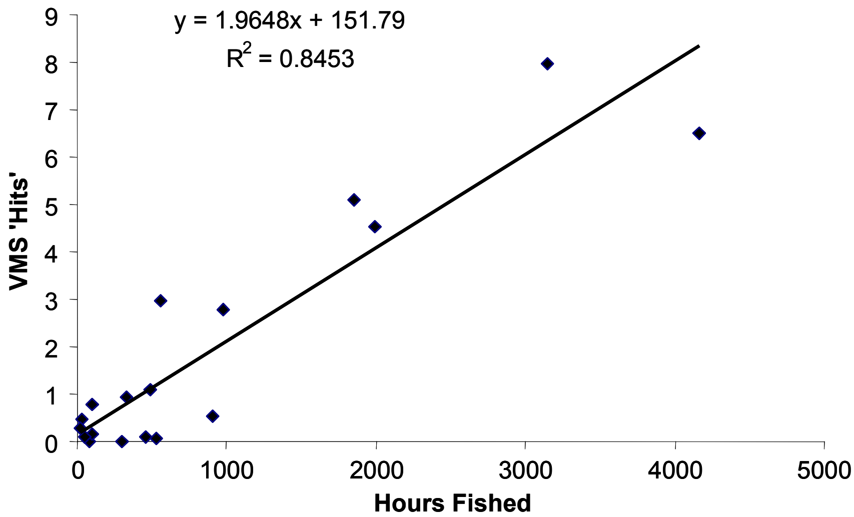

Figure 2.9: Scatter plot of the number of hours fished within different statistical reporting blocks and the rank of the number of VMS polls within corresponding reporting blocks. The higher the VMS ranking the greater the number of polls within that locality block. Data is for a representative number of fishing blocks from the 2003 and 2004 Tasmanian fishing seasons. The fitted line is only indicative because VMS hits are ranks rather than absolute values.

2.4 Potential Improvements of VMS Methodology

Data presented elsewhere in this report suggests that scallop beds can range from dense discrete areas containing predominately commercial scallops, which can occur over scales of 1000's of meters; to a patchy array of benthic assemblages, which may vary over scales of 10's to 100's meters (Chapter 4). Consequently, although the 500m x 500m cells used to define fishing intensity is a very fine scale spatial resolution compared to scales used in logbooks, as required by fisheries management agencies (as shown in section 2.3.4), it may actually be inadequate in the most highly patchy benthic environments found in some areas. Several approaches can be employed to improve the spatial resolution of inferred fishing intensity areas using VMS data.

The simplest approach would be to reduce the grid size from 500m x 500m. Because Vessel Monitoring System's are based on GPS technology, the accuracy of VMS is only limited by the accuracy of GPS, which allows a range of grid sizes less than 500m x 500m to be used. To illustrate the benefits of using finer scale grid sizes when defining fishing intensity areas, Figure 2.10 compares the spatial distribution of fishing intensity within the same area using 500m x 500m and 250m x 250m grid sizes. This comparison clearly illustrates the improved spatial precision gained by using the 250m x 250m grids, with some areas defined at higher intensities using 500m's dropping or gaining one category when 250m grids are used. However, such benefits were only observed within some fished areas.

Another approach that could be used to improve the spatial resolution of detectable fishing intensity areas would be to specify a very rapid poll rate (in the order of only seconds) for individual boats, groups of boats or the entire fleet and monitor individual boats, or groups of boats, to determine specific dredge tows, which would represent areas of increased fishing intensity. Because of privacy and confidentiality concerns this would require the cooperation of the compliance agency and the fishers. However, such a high poll rate would provide extremely high spatial resolution and would permit a detailed characterization of the fleet dynamics and how different fishers conducted their fishing operations. The cost of such a high polling rate across the fleet may place a time limit on such an operation but it would not necessarily have to operate at that level for a complete season to characterize a fishery.

The more detailed spatial fishing-effort data that would be collected using the methods described above may have advantages for future spatial and temporal management strategies within areas opened to fishing. They may allow broad estimates of catchability of scallops by dredging gear, and more detailed catch-per-unit-effort estimates and catches from given areas, which may, inturn, allow more detailed biomass estimates to be calculated for particular scallop beds.

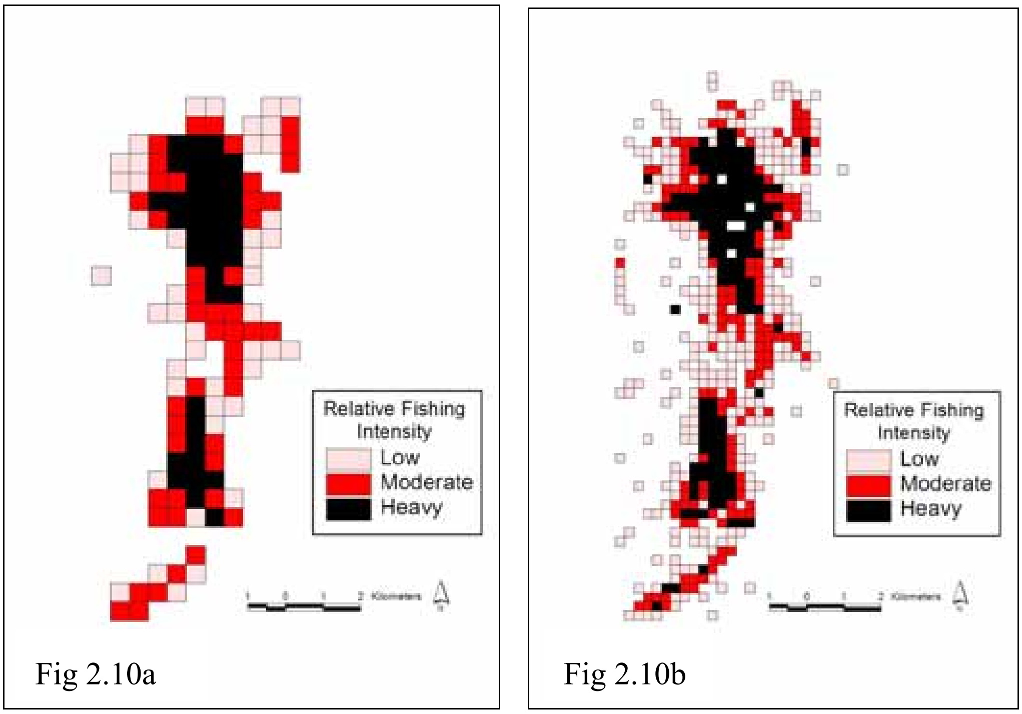

Figure 2.10. Comparison of the spatial distribution of fishing intensity areas using 500m x 500m grids (Fig 2.10a) and 250m x 250m grids (2.10b). The scale of fishing intensity in each panel are of the same intensity, which implies that the frequency of polls in the 250m x 250m grid are a quarter of those in the 500m x 500m grids.

2.5 General Discussion

The results of this study indicate that VMS data from scallop fishing can easily be manipulated to determine fine scale (100's meters) estimates of the extent and intensity of fishing, with much higher precision than that given by fisher catch return data. Although other studies have also used GPS technology to study the activities of commercial fishing fleets and associated impacts of fishing on benthic assemblages, datasets have generally been restricted to sub-samples of the entire fleet (e.g. Rijnsdorp et al. 1998, Dichmont *et al.*, 2001). Consequently, the questions that could be answered by such studies could not characterize the movements / impacts over the entire fishery and fleet. Such a limitation is not an issue for the results of this present study because it is a license requirement of all vessels participating in the Commonwealth and Tasmanian scallop fisheries to have a VMS fitted and, with the fisher's permission, all VMS data taken from fishing operations were made available. Consequently, the results presented in this study are indicative of each fishery's spatial dynamics. The use of VMS data appears to have identified issues with reporting resolution in fisher catch return data. Such errors may be overcome by examining the coarse logbook data in conjunction with the finer scale VMS data and may provide a useful tool for the future management of the South East commercial scallop fishery.

The maps illustrating the extent and intensity of fishing within the Commonwealth and Tasmanian managed scallop fisheries have revealed much about the dynamics of both scallop beds and fishing behaviour. The most striking observation is that scallop beds / areas of higher scallop abundances occur in relatively small discrete patches within the open areas. Furthermore, within the Tasmanian-managed fishery not only were larger areas fished, but also a higher proportion of these fished areas were identified as being impacted at heavy intensities, relative to the Commonwealth-managed fishery. These observations do not reflect the success or failure of each management regime, but instead reflect habitat differences, settlement patterns, and / or environmental differences and the increased successful settlement within areas to the East of Tasmania within more recent years. Nonetheless, the above mentioned observations do suggest criteria for defining ‘good’ scallop beds (see Chapter 4), and may have important applications with respect to both fisheries management and the impact of dredge fishing both on scallop populations and other benthic species / assemblages.

It appears that the general public perception of scallop fishing is that dredging occurs indiscriminately along the whole coast, within the open areas, scraping and destroying everything off the bottom. However, the VMS data presented here clearly demonstrates that scallop fishers search to identify what may be called “good’ scallop beds (areas of increased scallop abundance) and focus their fishing effort within these regions. Such an approach is rational as it would maximise catch per unit effort. In reality, fishers avoid areas with high abundances of other species (e.g. sponge, oyster, doughboy scallops) as the sorting of these discard species takes time, and therefore reduces economic efficiency. Although this trend in scallop fishing is an artefact of fisher behaviour based on economic return, the fact that almost all dredging occurs in small discrete areas dominated by scallops has both environmental and managerial benefits. The environmental advantages are that bycatch is kept to a minimum and any effects of dredging on the sea bed are concentrated in relatively small areas. As there is evidence that scallop beds develop in the same particular areas of sea bed even following a scallop stock collapse, then it may be concluded that dredging does not always lead to unrecoverable damage to the benthic habitat. Smith and Rago (2004), do suggest, however, that high density scallop areas, such as those being fished within the Tasmanian-managed areas, are far more valuable as recruitment sources, and therefore should be protected from fishing, and that lower density beds of less value as recruitment sources should be fished.

If the discrete areas containing predominately scallops (as seen in the ‘good’ scallop beds observed in the Tasmanian fishery in 2003 and 2004) can be identified, then more closely defined areas could be opened to commercial fishing rather than extensive areas of the benthos. Such an approach would benefit fishers, as they would be ‘put on the spot’ of most efficient fishing, while at the same time, other benthic assemblages dominated by species other than scallops would be protected from potentially negative impact of even exploratory dredge fishing. However, mechanisms for locating discrete areas of scallops (exploration) need to be determined. These issues will be dealt with in more detail later in this report.

2.6 General Conclusions

VMS is a useful research tool allowing fine scale knowledge on the extent and intensity of fishing.

Commercial scallop fishing within the Commonwealth and Tasmanian scallop fishery is limited to small, discrete patches within areas open to the fishery.

Tasmanian east coast scallop beds had a higher proportion of fished areas impacted at high intensities (approximately 30 – 40% of total area fished) compared to areas of more sparse scallops north-east of Flinders Island, in the Commonwealth-managed area, where less than 5% of total area is fished. Such 'good' scallop beds lead to higher catch rates and greater economic efficiency than lower density, more patchily distributed scallop beds.

3. DREDGED BENTHIC ASSEMBLAGES.

3.1 Introduction

The scallop stocks in Bass Strait and around Tasmania experienced a collapse around 1999/2000. The Tasmanian Aquaculture and Fisheries Institute (TAFI) has conducted scientific dredge surveys within both recent and historically fished areas of both the Commonwealth and Tasmanian scallop fisheries to detect and monitor the recovery from this collapse since 2000. While the primary objective of such surveys has been to determine the extent and size structure of any commercial scallop beds discovered it was also possible to collect and identify incidental bycatch. These surveys were conducted with commercial scallop dredges, usually with a mesh liner, to increase the chances of detecting very small scallops. They therefore provided an opportunity to study the benthic structure of soft-bottomed habitats over a very large scale. The collation of such information not only provides detail of the benthic community structure in specific regions, but also increases our knowledge of the distribution and abundance of both commercially targeted and ecologically significant species within a region. Such information is essential for effective fisheries management and the protection of unique and fragile habitats and communities, particularly for spatially managed stocks such as the Commonwealth and Tasmanian-managed scallop fisheries.

Scallop beds tend to re-occur in particular areas through time but in the process of surveying the areas for signs of recovering scallop beds, information about the community structure over a wide range of habitats was also obtained. During these surveys, bycatch specimens were identified to the lowest practicable taxon. The numbers of each taxa were recorded for the vast majority of sample tows from 2001 onwards. The resulting database therefore contains extensive information about the dredged benthic assemblages found in soft sediment habitats within areas of the Commonwealth and Tasmanian scallop fisheries. While this present project only had a two year time-span it was decided to use data from the full time-series of observations available to maximize the value of the report. While the dredge and video observations in Commonwealth waters have been reported in the survey reports to the Australian Fisheries Management Authority (AFMA; Semmens *et al.*, 2000; Haddon & Semmens, 2001, 2002, 2003; Haddon *et al.*, 2004 & 2005) along with some discussion, a summary of all observations with a detailed discussion has yet to be produced.

The main aim of this chapter was to provide detailed species lists for spatially separate regions surveyed within Tasmanian and Commonwealth-managed waters since 2001. 2000 data are not included, as abundance information for the bycatch species are not available for this year’s data set. This aim directly relates to Objective 4 of the current project, FRDC project 2003/017 – “Determine the major bycatch species taken with commercial scallop dredging gear on the main scallop beds fished in Bass Strait (including Tasmanian, Central Bass Strait and, if possible, Victorian scallop beds)”. Basic descriptive statistics and abundance maps of the main species caught were also presented. Later chapters consider other analyses of the available bycatch data and provide detailed discussions.

3.2 Methods and Materials

Data presented in this chapter was collected during scientific dredge surveys conducted in the Commonwealth and Tasmanian scallop fisheries from June 2001 to March 2004.

Later surveys did not always give the same priority to data collection on bycatch as they were more focussed on elucidating particular details of the scallop bed dynamics. All surveys were conducted on board the chartered fishing vessel *Dell Richey II* at the times and locations shown in Table 3.1 and Figure 3.1.

Surveys conducted in Commonwealth waters were initially of a random stratified sampling design; however, in later surveys, sample stations, while haphazard were selected with regard to their proximity to traditional or known scallop beds, occasionally repeating previously visited stations, and as such are not strictly random. For more complete descriptions of the sampling design see Haddon and Semmens (2001, 2002, and 2003) and Haddon *et al*. (2004, 2005).

Within the Tasmanian fishery, sample tows were initially conducted within traditionally known scallop grounds (East Flinders, West Flinders and Banks Strait), while in later surveys, sample tows were conducted within known scallop beds. Within the Eddystone Point location, sample tows were conducted in areas that were fished during the 2003 commercial scallop season, as identified using Vessel Monitoring System (VMS) data (see Chapter 2). Although the specific objectives of the surveys used in this chapter varied between survey regions and between years, the surveyed areas coincided with historical and current scallop beds, as identified by fisher catch returns and anecdotal information from scallop fishers. As a consequence, the species identified are indicative of the species located within and near habitats occupied by scallops. It will become clear, however, that habitats that were obviously not linked to scallop beds were also sampled.

Table 3.1: Timing and location of scientific dredge surveys conducted from 2001 to 2005 within the Commonwealth and Tasmanian scallop fishery areas.

Year	Month	Survey Location (see Figure 3.1)
2001	June	Commonwealth Fishery
2002	March	Commonwealth Fishery
		East Flinders – Tasmanian Fishery
2002	May	West Flinders – Tasmanian Fishery
		Banks Strait – Tasmanian Fishery
2003	March	Commonwealth Fishery
		East Flinders – Tasmanian Fishery
2003	November	Commonwealth Fishery
		Eddystone Point – Tasmanian Fishery
		East Flinders – Tasmanian Fishery
2004	March	Commonwealth Fishery
		Eddystone Point – Tasmanian Fishery
		East Flinders – Tasmanian Fishery
2004	November	Commonwealth Fishery
		Eddystone Point – Tasmanian Fishery
		East Flinders – Tasmanian Fishery
2005	March	Commonwealth Fishery
		Banks Strait – Tasmanian Fishery
		East Flinders – Tasmanian Fishery

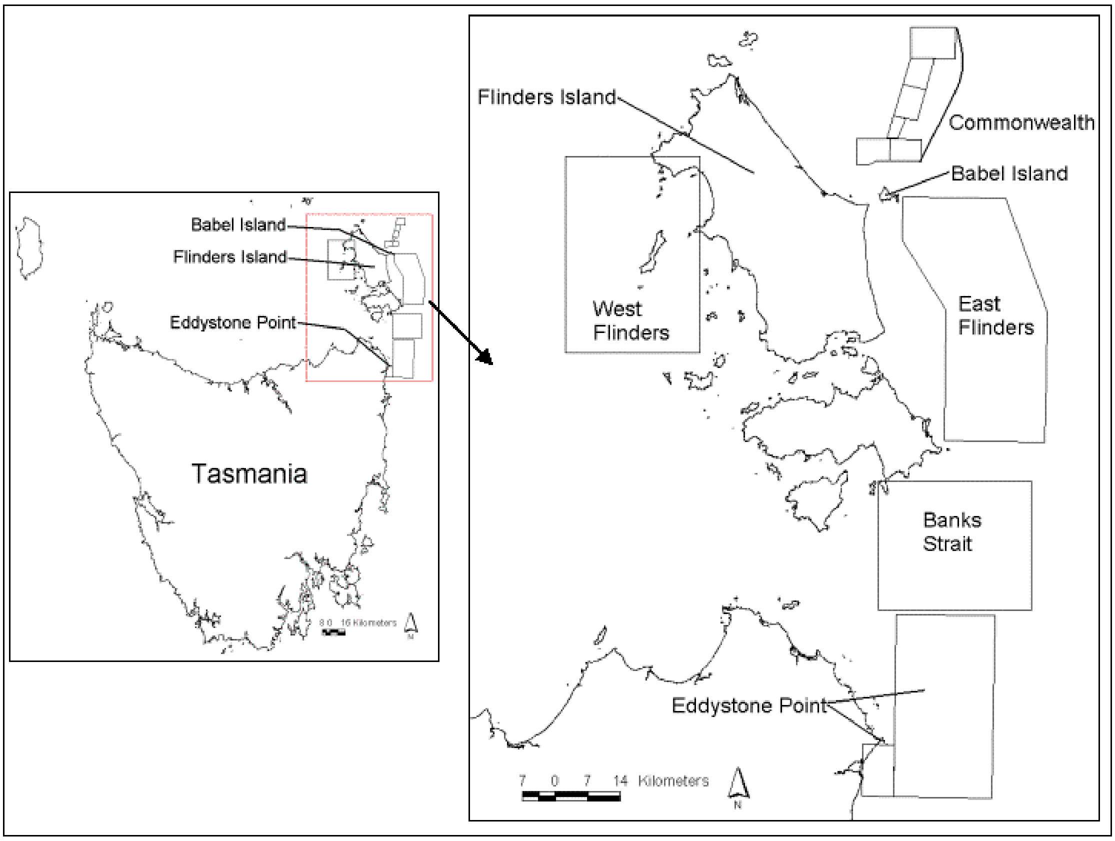

Figure 3.1. General locations of each survey area identified in Table 3.1.

A standard commercial 'toothed dredge', with a width of 4.26 m and mesh dimensions of 46 x 70 mm, was used in all surveys. From March 2002, a 23 x 35 mm wire mesh liner was fitted to the dredge to aid in the retention of small (juvenile) scallops and other small taxa. All tows were approximately 5 minutes duration and covered a distance of between 350 and 450 meters, in depths ranging from 33 to 49 meters at West Flinders and Banks Strait; 20 to 40 meters at East Flinders and Commonwealth waters; and 50 to 64 meters at Eddystone Point.

Upon completion of each sample, the dredge contents were sorted and all individuals identified to the lowest practicable taxon. Sponges were grouped and not identified beyond phylum, due to the difficulty in identifying them to species. Where numbers of individual taxa were low, all individuals were counted. Where numbers were large, numbers in the total catch were determined by enumerating those present in a volumetric sub-sample of the catch randomly selected from the total and then scaled up to 100%.

The number of live screwshell and dead screwshell occupied by hermit crabs was determined using the results of Reid (2003), who showed that screwshell samples collected from the Bass Strait region typically included 85% occupied by hermit crabs, 10% by live screwshell organisms, with 5 % being empty (dead) shells.

The abundance of sponges and other easily damaged soft bodied organisms were extrapolated from the body parts available. A standardised mass of sponge was used to determine the overall numbers of sponge caught. Other unidentified species, such as lace corals and bryozoans, were not included in the basic statistics because of difficulties in determining the abundances (most being damaged in the dredging process). Their presence, when observed, was recorded.

The abundance of each taxon was standardised to the relative number caught per $1000m^2$ to standardise for variations in the tow distance of individual samples.

A complete species list showing the average number of each taxon caught per $1000m^2$ dredge tow within the survey areas of West Flinders, East Flinders, Banks Strait, Eddystone Point and NE of Flinders Island (within the Commonwealth Managed fishery) (± SE) was completed using all available data from 2001 to 2004. For each survey area a range of basic comparative statistics was used to summarise both the entire data set, and data for separate animal groups. The animal groups used were Phylum Mollusca (Molluscs), Subphylum Crustacea (Crustaceans), Phylum Echinodermata (sea stars and urchins), Class Osteichthyes (Bony fishes), Class Chondrichthyes (Cartilaginous fishes), Class Cephalopoda (octopus, cuttlefish and squid) and 'Others'. 'Others' refers to those species typically found within a soft sediment sponge habitat (*e.g.* Ascidians, hydroids, sea pens, porifera, etc.), and incorporated the species: *Sarcoptilus grandis*, *Primnoella australasiae*, *Pyura stolonifera*, *Pyura* sp., an unidentified Gorgonian Fan species and Sponges.

To identify the distribution of the major taxa, the abundance of the main species caught within each $1000m^2$ tow was plotted using the GIS program ArcView 3.2a for Windows. The relative abundances were visually compared to determine general trends in distributions.

3.3 Results / Discussion

3.3.1 Species List

A species list identifying the average number of each species caught per $1000m^2$ sample (± SE) within each of the 5 areas surveyed is presented in Table 3.2. Where possible, individual species names were used, however, some species remained unidentified, or were grouped into broader categories.

Table 3.2: Average number of individual dredged bycatch species per 1000m^2 sample ± Standard Error (SE) within each of the 5 sample areas surveyed from 2001 to March 2004 (Figure 3.1). Where values are stated as 0 ± 0 the average number caught was < 0.001 per 1000m^2 sample shot. Where cells are blank, no specimens of that species were caught. Species names which are underlined represent the most abundant species caught. **NOTE:** Abundances of the Prosobranch volute species *Amoria undulata* also include individuals of the similar wavy volute species *Ericusa sowerbyi*, because the two species were not separated in early surveys. Three main species of hermit crab were found to occupy empty *Maoricolpus roseus* shells, *Paguristes tuberculatus* (95% of total), juvenile *Strigopagurus strigimanus* and juvenile *Paguristes squamosus* (Reid 2003). As *Paguristes tuberculatus* dominated, this name was used to collectively describe all three species. Two Diogenid hermit crabs, *Trizopagurus strigimanus* and an unidentified species, were found to occupy large empty Prosobranch shells, but because these were not separated as two species in the earlier surveys, they are collectively referred to as *Trizopagurus strigimanus*. Within Class Osteichthyes (bony fish) *Platycephalus* sp. refers to both *Platycephalus bassensis*, and *P. richardsoni*. Several species of *Pyura* were found in relatively low abundances within all strata. Furthermore, many species of large and small sponge were sampled but not identified as individual species. Other individuals caught during sampling included several species of bryozoans, lace corals, hard corals, amphipods, isopods and annelids, however, due to damage and time constraints during surveys, these species were not identified and abundances not recorded.

	West Flinders 147° 73' 40° 19'	East Flinders 148° 47' 40° 06'	Banks Strait 148° 37' 40° 71'	Eddystone Point 148° 41' 40° 94'	NE Flinders 148° 40' 39° 76'
No. Shots Conducted	17	46	17	58	190
Opisthobranchia					
Unidentified Sea Hare					0.4 ± 0.23
Prosobranchia					
Pleuroploca australasia	0.77 ± 0.21	10.03 ± 1.64	7.5 ± 2.16	1.66 ± 0.31	7.11 ± 0.65
Amoria undulata	0.37 ± 0.13	1.45 ± 0.26	0.65 ± 0.17	0.26 ± 0.07	0.8 ± 0.1
Cymbiola magnifica	0.03 ± 0.03				
Charonia Lampus		0.12 ± 0.05	0.1 ± 0.05	0.12 ± 0.05	0.34 ± 0.09
Cymatium parthenopeum				0.01 ± 0.01	0.02 ± 0.01
Cabestana spengleri		0.05 ± 0.02	0.03 ± 0.03	0.01 ± 0.01	0.07 ± 0.04
Fusinus novaehollandiae		1.98 ± 0.66	0.22 ± 0.1	1.72 ± 0.33	2.81 ± 1.57
Cypraea comptoni			0.1 ± 0.07	0.02 ± 0.02	0.05 ± 0.02
Cyprea hesitata		0.01 ± 0.01		0.05 ± 0.02	
Clanculus undatus			0.03 ± 0.03	0.19 ± 0.1	0.17 ± 0.07
Conus anemone			0.03 ± 0.03		0.01 ± 0.01
Semicassis pyrum	0.02 ± 0.02	0.04 ± 0.02	0.07 ± 0.07	0.02 ± 0.01	0.03 ± 0.01
Penion maximus		0.13 ± 0.05		0.63 ± 0.15	0.59 ± 0.49
<u>*Maoricolpus roseus*</u>		<u>29.32 ± 17.77</u>	<u>787.21 ± 230.95</u>	<u>909.07 ± 211.43</u>	<u>144.8 ± 37.64</u>
Bivalvia					
<u>*Pecten fumatus*</u>	<u>35.52 ± 12.85</u>	<u>850.88 ± 107.9</u>	<u>12.04 ± 4.16</u>	<u>315.6 ± 52.74</u>	<u>120.44 ± 11.65</u>
<u>*Mimachlamys asperrimus*</u>	<u>142.58 ± 23.14</u>	<u>152.11 ± 46.9</u>	<u>34.46 ± 19.03</u>	<u>11.73 ± 4.64</u>	<u>291.11 ± 82.17</u>
Bassina disjecta		0.06 ± 0.04			0.04 ± 0.02
Katelysia scalarina		0.01 ± 0.01			0.07 ± 0.05
Dosinia caerulea					0.03 ± 0.02
Tawera lagopus	0.06 ± 0.04	0.26 ± 0.16	0.15 ± 0.15	0.09 ± 0.05	0.27 ± 0.11
Tawera gallinula		0.16 ± 0.16			0.29 ± 0.19
Eucrassatella kingicola	0.2 ± 0.16	10.47 ± 2.55	17.51 ± 9.03	3.76 ± 0.66	11.07 ± 2.08
Glycymeris striatularis	25.36 ± 16.67	49.67 ± 12.62	96.53 ± 50.13	12.56 ± 3.12	42.93 ± 7.72
Glycymeris grayana		0.51 ± 0.19	0.09 ± 0.09	0.03 ± 0.03	21.13 ± 7.89
Ostrea angasi		38.32 ± 17.17	35.06 ± 16.14	38.13 ± 13.7	170.22 ± 33.44
Atrina tasmanica	0.18 ± 0.08	0.09 ± 0.05		0.11 ± 0.08	0.05 ± 0.02
Solen vaginoides		0.05 ± 0.05			
Modiolus sp.	0.19 ± 0.14	0.01 ± 0.01	0.03 ± 0.03	0.16 ± 0.1	0.02 ± 0.01
Neotrigonia margaritacea	6.1 ± 6.07				
Amygdalum beddomei		0.18 ± 0.09		0.48 ± 0.15	1.05 ± 0.25
Mesopeplum tasmanicum		0.06 ± 0.05			0 ± 0
Spondylus tenellus				0.13 ± 0.05	

Table 3.2 [cont.]	West Flinders	East Flinders	Banks Strait	Eddystone Point	Commonwealth
Cephalopoda					
Octopus berrima	0.09 ± 0.05	0.24 ± 0.08	0.52 ± 0.22	0.37 ± 0.08	0.46 ± 0.05
Octopus pallidus	0.08 ± 0.06	0.12 ± 0.04	0.19 ± 0.12	0.03 ± 0.02	0.17 ± 0.03
Octopus maorum					0.01 ± 0
Hapalochlaena maculosa		0.01 ± 0.01			0.01 ± 0.01
Sepia apama	0.15 ± 0.15			0.01 ± 0.01	
Notodarus gouldii		0.01 ± 0.01			
Euprymna tasmanica	0.03 ± 0.03				
Sepioteuthis australis					0 ± 0
Crustacea					
Notomithrax ursus	0.17 ± 0.12				0 ± 0
Ovalipes australiensis			0.04 ± 0.04		0.01 ± 0.01
Nectocarcinus tuberculosus	0.03 ± 0.03	0.01 ± 0.01	0.14 ± 0.11	0.02 ± 0.01	0.27 ± 0.08
Ibacus alticrenatus	0.78 ± 0.21	0.1 ± 0.06	0.05 ± 0.05	0.09 ± 0.03	0.26 ± 0.05
Leptomithrax gaimardii	0.52 ± 0.28	1.79 ± 0.58	0.52 ± 0.39	0.08 ± 0.04	9.13 ± 3.81
Trizopagurus strigimanus	0.33 ± 0.1	6.72 ± 1.78	7.87 ± 3.35	16.27 ± 1.88	14.73 ± 1.74
Unidentified Stone Crab	0.3 ± 0.16	0.03 ± 0.02		0.33 ± 0.18	0.02 ± 0.02
Pilumnus etheridgei	0.44 ± 0.2	0.8 ± 0.37	0.28 ± 0.11	0.97 ± 0.21	1.92 ± 0.3
Unidentified Pebble Crab	0.03 ± 0.03	0.01 ± 0.01			0.05 ± 0.04
Petalomea lateralis	0.08 ± 0.06	0.04 ± 0.04		0.01 ± 0.01	0.09 ± 0.05
Dromia wilsoni					0.19 ± 0.07
Paguristes tuberculatus		372.83 ± 260.01	10074.1 ± 2443.3	3636.3 ± 845.7	1283.7 ± 271.5
Stomatopod	0.03 ± 0.03				
Echinodermata					
Bollonaster pectinatus	0.15 ± 0.08	1.93 ± 0.43		0.07 ± 0.05	0.48 ± 0.13
Coscinasterias muricata		4.93 ± 0.67			0.1 ± 0.03
Plectaster decanus	1.33 ± 0.61				0 ± 0
Nectria ocellata	0.62 ± 0.18	0.04 ± 0.03			0 ± 0
Tosia magnifica	0.53 ± 0.2				
Luidia australiae	0.51 ± 0.29				
Smilasteria multipara	0.15 ± 0.15				
Fromia polyproa	0.36 ± 0.3				
Allostichaster polyplax	0.08 ± 0.06				
Paranepanthia grandis	0.47 ± 0.3				
Unifora granifera	0.11 ± 0.05				
Asterodiscides truncatus				0.02 ± 0.01	
Unidentified basket stars.	0.15 ± 0.09			0.01 ± 0.01	
Ophiomyxa australis	0.67 ± 0.24		0.07 ± 0.07	0.02 ± 0.01	0.17 ± 0.09
Ophiarachnella ramsayi	1.95 ± 0.9			0.01 ± 0.01	0.18 ± 0.06
Ophionereis schayeri					0.29 ± 0.11
Ophiothrix caespitosa					0 ± 0
Ophioplaeus bispinosis	0.34 ± 0.24				
Unidentified sea bistcuit				3.73 ± 1.37	
Amblypneustes ovum				0.11 ± 0.1	0.09 ± 0.04
Heliocidaris erythrogramma	0.04 ± 0.04	0.01 ± 0.01			0.05 ± 0.04
Holopneustes inflatus	0.54 ± 0.41				0.01 ± 0.01
Unidentified Brittle Star				1.85 ± 1.85	0.11 ± 0.08
Unidentified Pencil urchin	24.89 ± 8.7		0.05 ± 0.05		
Unidentified Heart urchin	0.14 ± 0.1	0.02 ± 0.02	0.23 ± 0.16		0.01 ± 0
Osteichthyes					
Heteroclinus perspicillatus					0 ± 0
Muraenichthys australis	0.15 ± 0.15	0.02 ± 0.02	0.44 ± 0.24	0.02 ± 0.02	0.04 ± 0.01
Zebrias scalaris					0 ± 0
Cynoglossus sp.					0.01 ± 0
Phiura kingergi			0.03 ± 0.03	0.01 ± 0.01	0.01 ± 0.01
Neosebastes sp.	0.08 ± 0.05		0.14 ± 0.08	0.13 ± 0.04	0.3 ± 0.06

Table 3.2 [cont.]	West Flinders	East Flinders	Banks Strait	Eddystone Point	Commonwealth
Petrygotriga polyommata	0.03 ± 0.03	0.23 ± 0.06		0.13 ± 0.05	0.14 ± 0.02
Diodon nicthemerus					0.04 ± 0.02
Nesogobius sp.					0 ± 0
Lepidotrigla vanessa	0.06 ± 0.04		0.1 ± 0.07	0.01 ± 0.01	0.13 ± 0.03
Meuschenia scaber					0.27 ± 0.15
Eubalichthys mosaicus	0.03 ± 0.03				0.01 ± 0.01
Thamnaconus degeni					0.07 ± 0.04
Acanthaluteres vittiger	0.03 ± 0.03		0.05 ± 0.05		0.02 ± 0.01
Meuschenia australis					0 ± 0
Acanthaluteres spilomelanurus					0 ± 0
Pseudophycis barbata	0.03 ± 0.03				0.01 ± 0.01
Pegasus lancifer		0.01 ± 0.01	0.03 ± 0.03		0.01 ± 0.01
Pseudolabrus psittaculus			0.05 ± 0.05		0.02 ± 0.01
Foetorepus calauropomus	0.03 ± 0.03	0.01 ± 0.01	0.1 ± 0.1	0.13 ± 0.04	0.18 ± 0.04
Eocallionymus papilio			0.03 ± 0.03	0.01 ± 0.01	0.02 ± 0.01
Platycephalus sp.		0.04 ± 0.02	0.1 ± 0.07		0.1 ± 0.02
Aracana aurita			0.22 ± 0.22		0.05 ± 0.03
Aracana ornata					0 ± 0
Lophonectes gallus		0.22 ± 0.07	0.25 ± 0.11	0.14 ± 0.08	0.14 ± 0.03
Hippocampus abdominalis					0.01 ± 0.01
Solegnathus spinosissimus				0.01 ± 0.01	
Unidentified pipefish				0.01 ± 0.01	
Parequula melbournensis	0.08 ± 0.08	0.01 ± 0.01			0.05 ± 0.03
Zenopsis nebulosus			0.05 ± 0.05		
Paristiopterus labiosus		0.02 ± 0.02			
Gnathophis habenata			0.09 ± 0.06		
Mullidae	0.1 ± 0.05				
Cyttus australis					0.01 ± 0.01
Hypoplectrodes maccullodi					0.01 ± 0
Gonorynchus greyi					0.01 ± 0.01
Nemadactylus macropterus					0 ± 0
Ophisurus serpens					0 ± 0
Kathetostoma laeve		0.01 ± 0.01		0.04 ± 0.02	0.04 ± 0.01
Chondrichthyes					
Narcine tasmaniensis		0.01 ± 0.01	0.03 ± 0.03		0 ± 0
Trygonorrhina guanerius					0.01 ± 0.01
Cephaloscyllium laticeps			0.05 ± 0.05		0.01 ± 0
Urolophus cruciatus		0.16 ± 0.05		0.24 ± 0.05	0.21 ± 0.04
U. paucimaculatus	0.15 ± 0.11	0.32 ± 0.1	0.09 ± 0.07	0.02 ± 0.01	0.37 ± 0.05
Trygonoptera testacea		0.1 ± 0.03		0.1 ± 0.03	0.09 ± 0.02
Raja whitleyi				0.01 ± 0.01	0.01 ± 0.01
Raja lemprieri		0.01 ± 0.01			0.03 ± 0.01
Squatina australis		0.02 ± 0.02		0.26 ± 0.07	
Cnidaria					
Sarcoptilus grandis	0.06 ± 0.04	0.03 ± 0.02			0.02 ± 0.01
Primnoella australasiae	4.86 ± 2.89			0.34 ± 0.23	1.8 ± 0.78
Porifera					
Sponges	7.05 ± 2.71	4.18 ± 1.4	10.97 ± 9.7	5.54 ± 3.67	20.45 ± 3.93
Branchiopoda					
Magellania flavescens				1 ± 0.39	0.06 ± 0.04
Ascidiacea					
Pyura stolonifera	0.21 ± 0.18	40.2 ± 19.88	0.17 ± 0.12		27.01 ± 7.29
Pyura sp.		0.26 ± 0.14	0.16 ± 0.16	3.37 ± 0.86	0.25 ± 0.08

3.3.2 Basic Descriptive Statistics

The total number of species identified from all regions surveyed was 133, with the NE Flinders sample region (see Figure 3.1) having the highest number of species represented (111). The lowest number of species was recorded at Banks Strait (50), while all other regions had slightly higher, but similar numbers of species recorded (59-62) (Table 3.3). These differences in the number of species collected from different historical scallop fishing grounds may easily be explained by the different number of sample tows conducted within each area. This explanation holds true for the NE Flinders sample area, which had the greatest sample shots conducted and the highest number of species present, while all other areas had lower sample tows and lower species recorded.

The NE Flinders (Commonwealth-managed) fishing ground does, however, contain a diverse array of habitat types and benthic assemblages compared to the other surveyed regions (unpublished video and habitat mapping data). It is well recognised that habitats containing greater structure can generally support more species. The most common explanation for this observation involves an increase in the complexity of habitats providing greater space or number of niches. As such, the relatively more diverse array of habitats within this area may support the greater number of species observed NE of Flinders Island.

The highest occurrence of individual bycatch items per shot and individual bycatch items per scallop was found at the Banks Strait sample area, while high levels were also recorded at Eddystone Point and within the Commonwealth fishery NE of Flinders Island (Table 3.3). This was due to the very high abundances of a small number of individual bycatch items within the animal groups Mollusca and Crustacea (underlined in Table 3.2). Within the group Crustacea, one species, the hermit crab occupying empty New Zealand screwshells (predominately *P. tuberculatus*) was by far the most abundant species, while within the group Mollusca, *Maoricolpus roseus* (New Zealand screwshell) was the most abundant species, however, high abundances of doughboy scallops (*Chlamys asperimus*), oysters (*Ostrea angasi*), and cockles (*Glycermeris* sp.) also contribute significantly to overall numbers of bycatch items caught (underlined in Table 3.2). The survey regions do, however, fall within historical scallop grounds, which may be considered dynamic habitats and as such, benthic assemblages and species may fluctuate over time under different conditions (disturbance and recovery). For example, it is now known that commercial scallop numbers are increasing in the Banks Strait region, so the results given here will not remain static.

West Flinders had the lowest level of bycatch items per shot, while the lowest mean level of bycatch items per scallop was seen at East Flinders. This latter result was due to the substantially higher abundances of commercial scallops caught in this area (Table 3.3). Chapter 4 deals with the concept of ‘good’ and ‘marginal’ scallop beds, and illustrates that areas of high scallop abundance within the Tasmanian fishery to the east of Flinders Island generally contain very few other benthic species, while relatively high scallop abundance areas of the NE Flinders (Commonwealth fishery area) contained relatively high abundances of a small number of bivalve species (with the exception of the very dense 4x bed). In general, the vast majority of species recorded within all sample regions occurred at low densities (Tables 3.2 and 3.3).

Table 3.3: Summary of total bycatch data and separate animal group data from each survey area. WF = West Flinders, EF = East Flinders, BS = Banks Strait, EP = Eddystone Point; and NE = NE Flinders (Commonwealth zone).

	WF	EF	BS	EP	NE
No. shots	17	46	17	58	190
Total scallops	640	43488	205	18305	20808
Scallops / tow	37.6	945.39	12.06	315.60	109.56
No. species	59	61	50	62	111
Total bycatch items	3822.4	25674.9	188309.7	269862.4	350386.6
Bycatch / shot	224.8	558.1	11077.0	4652.8	1844.1
Bycatch / scallop	6.3	0.6	919.9	14.7	16.8
	WF	**EF**	**BS**	**EP**	**NE**
Molluscs / shot	175.9	381.3	979.77	980.9	476.0
Crustaceans / shot	2.7	149.6	10083.0	3654.0	1317.7
Echinoderms / shot	33.0	7.6	0.3	5.8	1.5
Bony fish / shot	0.6	0.6	1.7	0.7	1.7
Cartilaginous fish / shot	0.1	0.6	0.2	0.6	0.7
Others / shot	12.2	18.1	11.3	9.2	45.2
Cephalopods / shot	0.4	0.4	0.7	0.4	0.6

3.3.3 Distribution of the Major Bycatch Species

Screwshells

The introduced New Zealand screwshell (*Maoricolpus roseus*) and their associated native hermit crabs (predominately *P. tuberculatus*) were the most abundant (by number) bycatch items caught within all surveyed regions, the only exception being West Flinders where no specimens were caught (Figure 3.2). However, the relative abundance of screwshells within the east Flinders region was low; very dense patches of screwshells were found within the NE Flinders and Eddystone Point regions, with large areas of no screwshells (low frequency of occurrence but high numbers); and the majority of sample locations within Banks Strait had very high abundances recorded (Figure 3.2).

Screwshells were probably introduced into Tasmania in the 1920's, since which time they have spread as far as northern New South Wales, with large numbers being found in Victorian, Bass Strait and south-eastern Tasmanian waters (Allmon *et al.* 1994). Surveys conducted by CSIRO during 1986 and 1987 located "acres of twirlies" (screwshells) within the Eastern Bass Strait region, especially within Banks Strait (Bax *et al.* 2003), while commercial scallop fishers recall catching large numbers of screwshells within the Tasmanian fishery during the 1970's and 1980's (Industry members, pers. comm.). However, it is unknown whether these early reports described live screwshells and / or empty shells occupied by native hermit crabs.

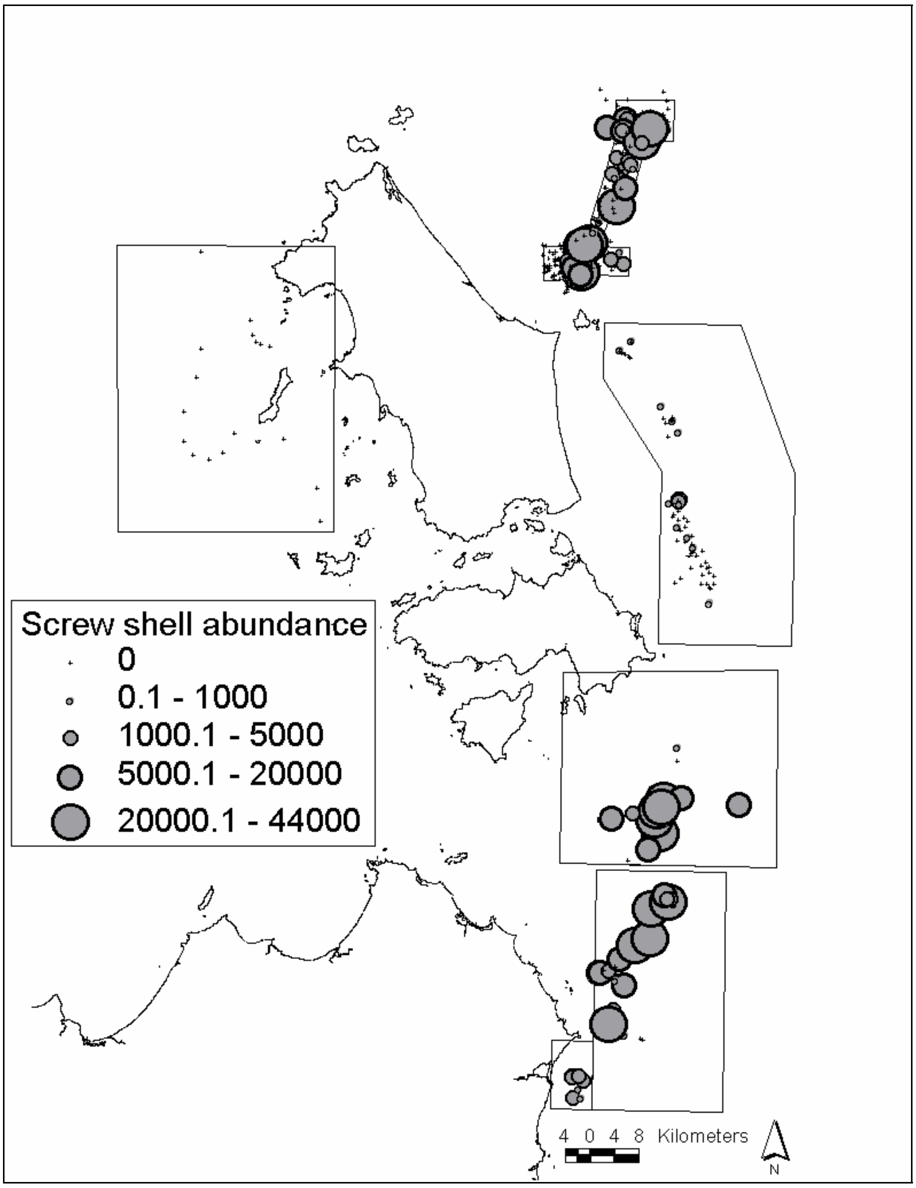

Figure 3.2. Distribution and abundance (numbers per $1000m^2$ tow) of screwshells and their associated hermit crabs (predominately *P. tuberculatus*) caught within each of the 5 surveyed regions from 2001 to March 2004.

Screwshells can dominate the benthic communities in a range of habitats, from mud and silty sand, to very coarse or firm substrates (Bax *et al.* 2003 and Allmon 1994). However, Allmon (1994) suggested that the common occurrence of *M. roseus* in areas with very coarse or firm substrates and moderate to strong currents was potentially due more to the higher suspended food supplies provided by such currents than to any substrate preference. Filter-feeding on suspended food supplies has also been suggested as one feeding strategy for some hermit crabs with laboratory observations of *P. tuberculatus* indicating that this species will remove small prey from suspension (A. Reid pers. comm.). Consequently, these two species may select similar habitat, with hermit crabs taking advantage of the abundance of empty screwshells. Determining the distribution of screwshells and their associated hermit crabs within the surveyed region, relative to water currents, is a difficult task given the lack of information about water currents within the Bass Strait region, and the complexity of the currents over small spatial scales. Research into the selection of habitat by both hermit crabs and screwshells is required and is currently the topic of several PhD researchers based at TAFI.

Doughboy Scallops

Although doughboy scallops (*Chlamys asperimus*) were among the most abundant species found in the majority of areas sampled, largest numbers were found in the northern most sampled areas, particularly in the Commonwealth fishery sample area NE of Flinders Island (Figures 3.3).

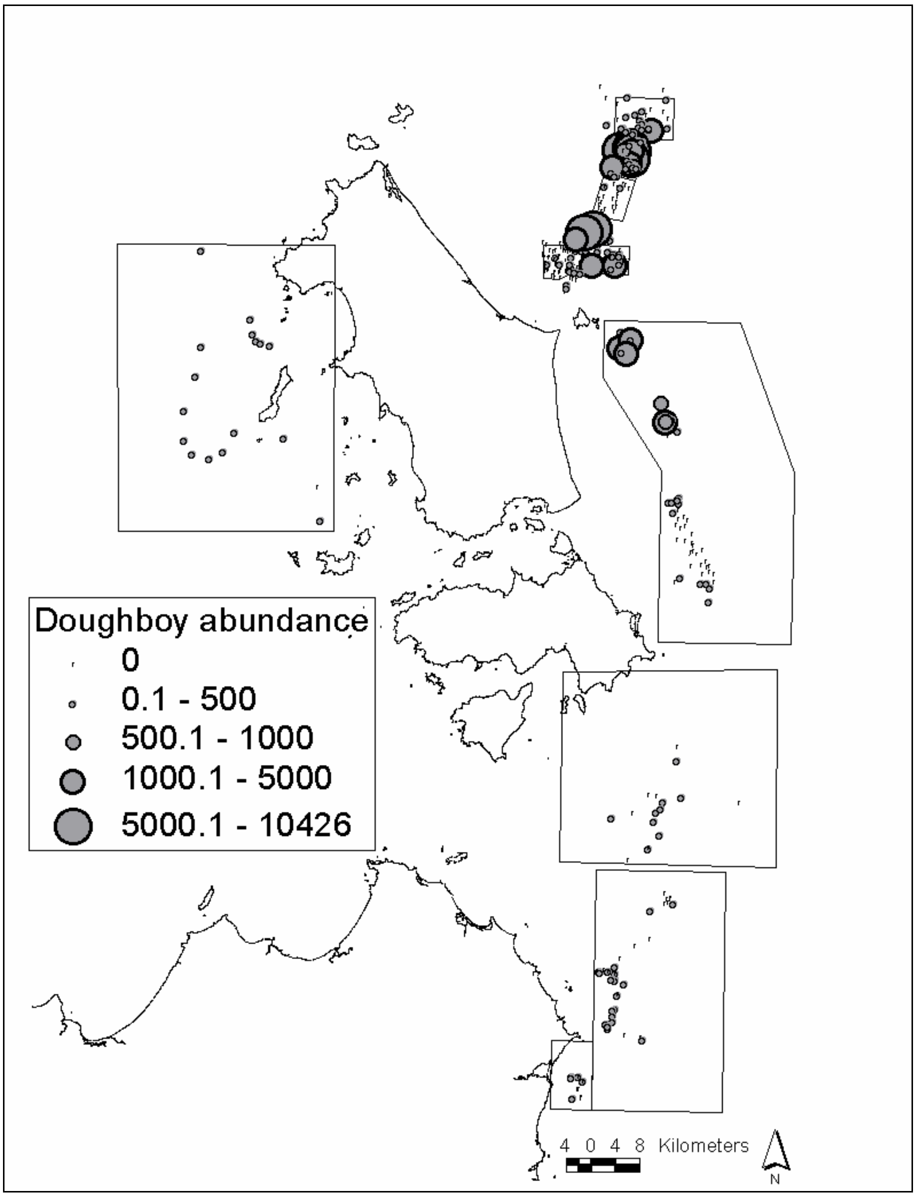

Figure 3.3. Distribution and abundance (numbers per 1000m^2 tow) of doughboy scallops caught within each of the 5 surveyed regions from 2001 to March 2004.

The high doughboy abundance within the Commonwealth fishery region may be due to the greater availability of hard substrate within this area (unpublished data), as this species can attach using byssus threads to hard surfaces. However, relatively high abundances of rock were also found to the west of Flinders Island, a region containing low catch rates of doughboy scallops.

During more recent surveys (November 2004 and March 2005) for which bycatch data is not presented within this chapter (Haddon *et al*., 2005), very high-density beds of doughboy scallops previously located towards the southwest sections of the NE Flinders (Commonwealth managed fishery) sample site were found to have greatly declined in density over a 6 month period. Edgar (2001a) describes an immense mobile population of dwarf animals 20-40 mm in length occurring within deeper waters of Bass Strait. However, the reasons behind why such an abundant population should get up and move are unknown. Movement is assumed because there was no evidence of even small amounts of dead doughboy scallop shells.

Mud Oysters

Oysters (*Ostrea angasi*) were also one of the most abundant species found, however, large numbers were only present in the NE Flinders area (Figure 3.4). No oysters were found at West Flinders (Figure 3.4). The species appeared to occur in dense aggregations over relatively small (100's meters) areas (pers. obs.).

Cockles

The dog cockle, (*Glycymeris striatularis*) was abundant but patchy within all areas surveyed (Figure 3.5). A related species of cockle, *Glycymeris grayana*, was found to have an abundant but patchy distribution within the NE Flinders sample area, with only very low abundances found further south (Figure 3.6).

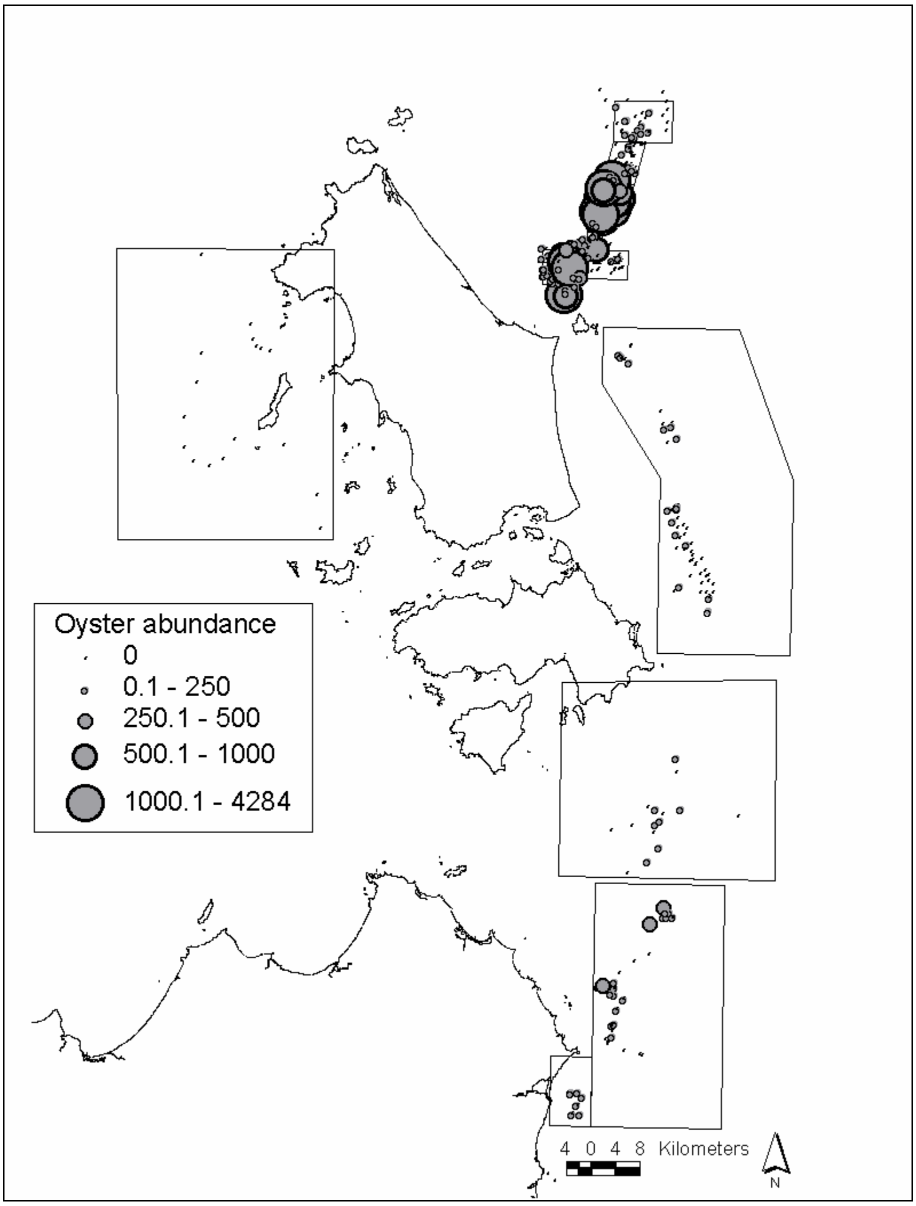

Figure 3.4. Distribution and abundance (numbers per $1000m^2$ tow) of oysters caught within each of the 5 surveyed regions from 2001 to March 2004.

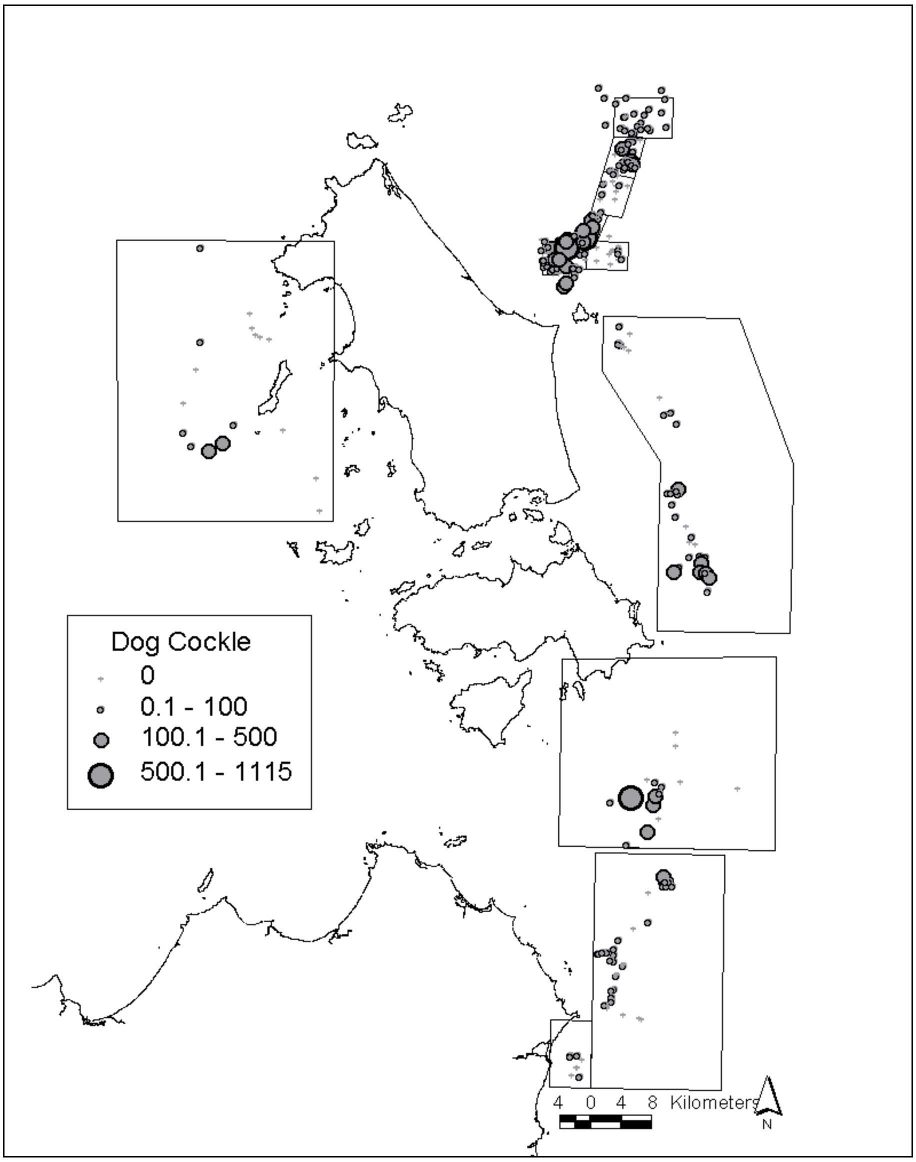

Figure 3.5: Distribution and abundance (numbers per 1000m^2 tow) of dog cockles (*Glycymeris striatularis*) caught within each of the 5 surveyed regions from 2001 to March 2004.

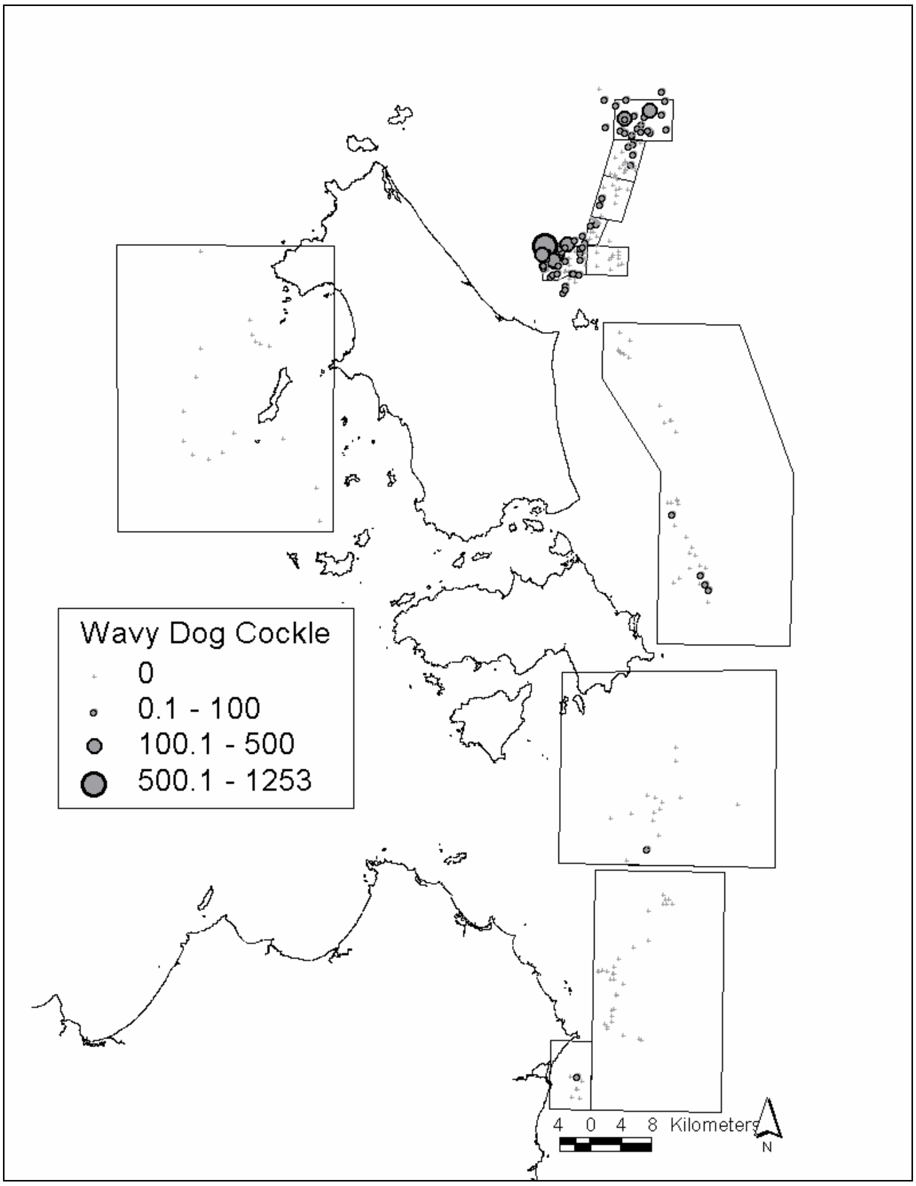

Figure 3.6. Distribution and abundance (numbers per $1000m^2$ tow) of the wavy dog cockles (*Glycymeris grayana*) caught within each of the 5 surveyed regions from 2001 to March 2004.

3.4 Conclusions

Commercial scallops, doughboy scallops, New Zealand screwshells (with and without associated hermit crabs), and the native oyster are all capable of dominating particular areas. Very large numbers of one of these species tends to preclude the presence of large numbers of the others, though as an exception, large numbers of commercial and doughboy scallops have been found together. All of these species are classified as epi-fauna living on the surface of the sediment with perhaps only a light covering. Other associated bycatch species, such as the dog cockles, can be abundant but were never found to dominate an area.

4. ‘GOOD’ AND ‘MARGINAL’ SCALLOP BEDS.

4.1 Introduction

Data presented in Chapter 3 identified gross differences in the distribution and abundance of the dominant benthic species found in the various survey areas. This result suggested that scallop beds may occur in a variety of habitats and ecological communities. Further dredge surveys, not described in Chapter 3, along with video survey work conducted within many regions have also suggested that scallop beds may occur as high scallop abundance areas containing very few other species; or as low scallop abundance areas containing a more diverse array of species, however, these observations are not quantitative. A more formal characterization of benthic species and communities that are associated with high and low scallop abundance areas would permit an improved assessment of the potential impacts of dredge fishing on different scallop habitats. Such knowledge would allow better decision making within management organisations, especially with respect to decision rules about spatial management, and minimising the impact of dredge fishing on the benthos while optimizing the harvest of scallops.

The main aims of this chapter were:

1) To identify the benthic assemblages found in areas of different scallop abundance within the Commonwealth and Tasmanian scallop fisheries; and
2) To compare the benthic assemblages found within high scallop abundance areas of the Commonwealth and Tasmanian managed fisheries near Flinders Island (East Flinders and NE Flinders).

4.2 Methods and Materials

In November 2004, a scientific dredge survey was conducted in an area of the Commonwealth Central Bass Strait scallop fishery known as Strata C4X and C5b; and within the Tasmanian scallop fishery east of Flinders Island (Figure 4.1). Although the main objective of this survey was to map the extent and size-structure of scallops on known scallop beds, benthic community data was also collected from scallop beds of varying densities within both areas. Individual sample tows could be grouped according to the relative abundance of scallops found.

The survey was conducted on board the chartered fishing vessel *Dell Richey II* using a standard commercial ‘toothed-dredge’, with a width of 4.26m and mesh dimensions of 46 x 70mm. A 23 x 35mm mesh liner was fitted to the dredge to allow the retention of small (juvenile) scallops and other small benthic taxa. All tows were five minutes duration and covered between 400 and 450 m, in depths ranging from 24 to 41 meters.

Upon completion of each dredge sample, the dredge contents were sorted and all animals identified to the lowest practicable taxon. Where numbers of individual taxa were low, all individuals were counted. Where numbers were large, a total count was estimated by counting all individuals in a randomly selected volumetric sub-sample, and then scaling up to 100%. Due to variation in the tow distance of each sample tow, the abundance of each taxon was standardised to the relative number caught per 1000m^2.

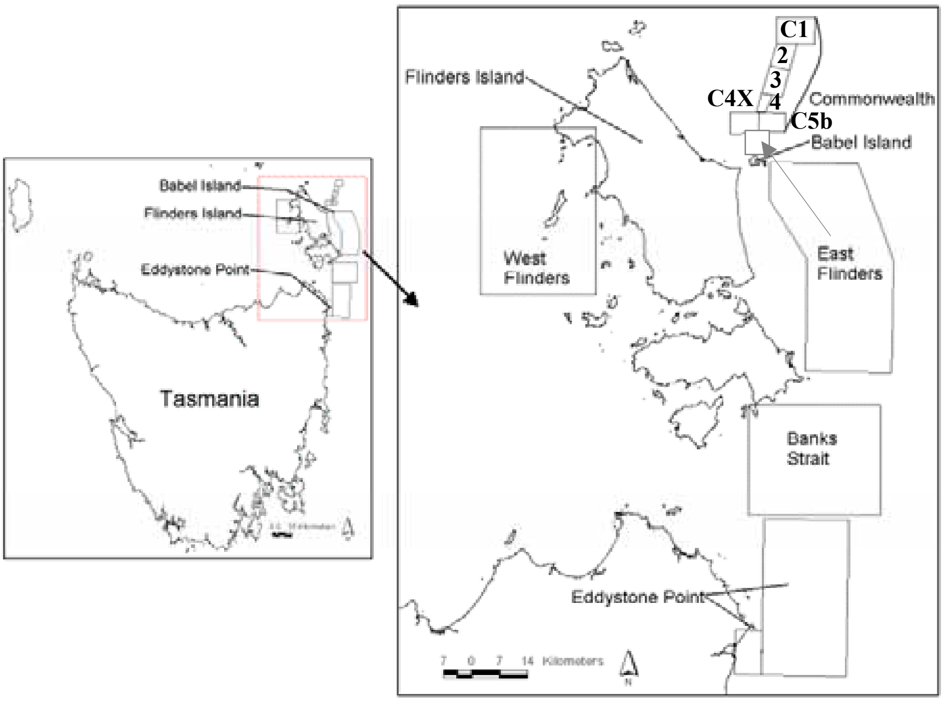

Figure 4.1: Location of the Commonwealth and East Flinders sample locations.

4.2.1 Between Scallop Bed Comparison

A comparison of the benthic communities found within scallop beds located within the Commonwealth and Tasmanian managed regions was completed by comparing the benthic species collected from the nine sample tows that featured highest scallop abundance from each area. Only nine samples could be compared, as this was the number of tows conducted within the only known dense scallop bed within the Commonwealth fishery (bed C4X) during the November 2004 survey.

4.2.2 Within Scallop Bed Comparisons

Benthic communities collected from low, moderate and high scallop abundance areas within each location were compared in order to determine differences in the benthic assemblages located within different scallop abundance areas. The criteria used to define low, medium and high scallop abundance for the within fishery comparisons are described in Table 4.1. The values for defining each area differed between each sample location because scallop density was considerably higher within the scallop bed located within the Commonwealth-managed fishery compared to the Tasmanian managed sample locations.

Within the sample site located within the Commonwealth fishery, the benthic communities collected in nine replicate stations from each scallop density category were compared; while in the sample site located within the Tasmanian fishery, the benthic communities collected from five replicate samples from each scallop density category were compared. The difference in the number of replicate samples within each fishery was a consequence of the time available to survey within each area, which limited the maximum number of dredge stations in each density area.

Table 4.1: Criteria used to define scallop abundance within the two scallop beds (Commonwealth and Tasmanian). The number of scallops represents the average number caught per 1000m^2. The high density categories start above the upper limits of the Moderate categories because there were no stations with intermediate densities.

	No. scallops Commonwealth study site	No. scallops Tasmania study site
Low	3 to 200	1 to 150
Moderate	200 to 500	150 to 800
High	1000 to 5000	1000 to 2000

4.2.3 Statistical analysis

All identified species were used in the comparisons except the commercial scallop, to avoid the scallop being automatically identified as determining differences between scallop density treatments. Comparisons were made using an array of univariate and multivariate statistics. In order to identify differences in the abundance and distribution of taxa, the univariate diversity indices, Species Richness, Shannon Wiener Diversity, Evenness and Simpson's Dominance were calculated for each fishery, and for each scallop density grouping within each fishery (as described in Begon *et al*., 1986).

Non-metric multi-dimensional scaling (MDS) was used to describe the 'dredged community assemblages' collected within high scallop abundance areas of each sampled scallop bed; and to compare the dredged benthic community data collected from the different scallop abundance areas within each scallop bed separately. Taxa found in two or less samples over the entire data set for each analysis were excluded from the multivariate analysis as such rare species do not add useful information and may bias the analyses by adding statistical noise. Data was fourth-root transformed to reduce the relative impact of highly abundant species.

Any patterns in the community assemblages were identified using MDS ordination plots of each '*a priori*' grouping (density grouping or fishery). One-way Analysis of Similarity (ANOSIM) tests were conducted on the *a priori* grouping 'location' or 'scallop abundance location' to test whether the observed differences between groups were greater than could be expected to occur by chance. The ANOSIM is a randomization test that examines the null hypothesis that "there are no differences between the dredged benthic communities found in the different 'a priori' groups". If the observed differences are greater than would be expected due to random variability for 5% of trials then a significant difference between groupings was assumed. Where significant differences were observed, a SIMPER (similarity percentages) analysis was used to determine which particular species, if any, were indicative of the patterns identified (Clarke and Warwick, 2001). All multivariate analysis techniques were completed using the Plymouth Routines in Multivariate Ecological Research (PRIMER) version 5 software package.

4.3 Results

4.3.1 Between Scallop Bed Differences

The dredged benthic assemblages found within the Commonwealth-managed high density scallop areas had fewer species, higher species dominance and corresponding lower species diversity and evenness, compared to the benthic assemblages found in the Tasmanian high density scallop areas (Figure 4.2).

The two-dimensional ordination plot (Figure 4.3) exhibits a general separation of the benthic assemblages collected from each location (top and left = Tasmanian managed bed, bottom and right = Commonwealth managed bed). Two samples from the Tasmanian dataset did overlap the Commonwealth benthic data, at least along the first or x ordination axis. However, these two samples were taken from areas north of Babel Island, and as such were spatially closer to the Commonwealth samples (Figure 4.1). One-way ANOSIM results also showed an overall significant difference between the benthic communities found within each sampled scallop bed (Sample statistic: Global R = 0.541; Significance level of sample statistic = 0.2%; *i.e.* two chances in a thousand this result could have occurred by chance).

SIMPER analysis identified the main contributors to approximately 36% of the observed differences, to be high abundances of the bivalve species *Chlamys asperrimus* (Doughboy scallops), *Glycermeris striatularis* (dog cockles), *Ostrea angasi* (mud oysters) and *Glycermeris grayana*, (wavy dog cockles) in the Commonwealth managed scallop beds (Table 4.2). Bivalves also contributed to approximately 73% of the within Commonwealth scallop beds similarities (Table 4.3). Within Tasmanian scallop beds, two bivalve species, two prosobranch gastropods, and two echinoderms contributed to approximately 70% of the within group similarity (Table 4.3).

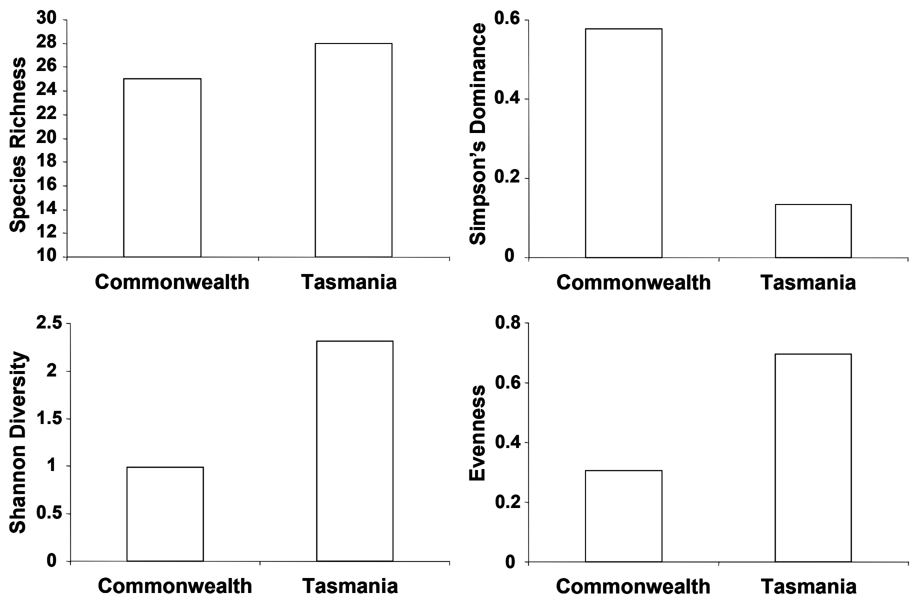

Figure 4.2. Univariate diversity indices for dredged benthic assemblages found within high scallop abundances areas (scallop beds) found within Commonwealth and Tasmanian managed areas.

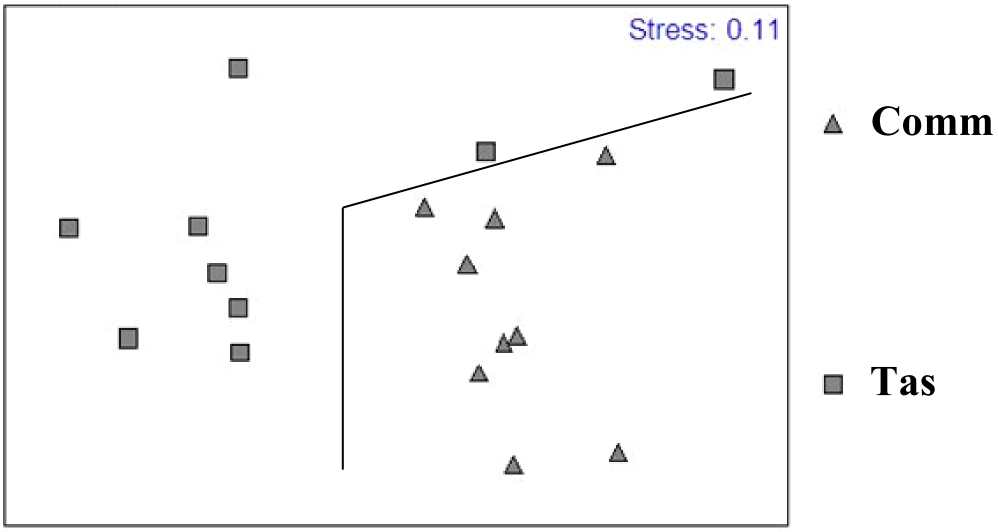

Figure 4.3: Ordination analysis – two-dimensional MDS plot dredged benthic community abundance data collected from scallop beds in the Tasmanian and Commonwealth managed areas. Stress = 0.11. The line separating the groups is simply for clarity.

Table 4.2: SIMPER (similarity percentages) output for the benthic data illustrating the average abundance of species found within each sample location (Commonwealth and Tasmania), ratio (average similarity / st. dev. similarity) and cumulative % similarity for those species contributing to approximately 50% of the differences identified between the high density scallop beds from each study location. Average abundances were fourth root transformed individuals per 1000 m^2.

Species Name	Av. Abund. Commonwealth	Av. Abund. Tasmania	Percent Similarity	Cumulative% Similarity
Between group differences				
Chlamys asperrimus	849.65	15.78	12.80	12.80
Glycermeris striatularis	76.29	14.57	9.25	22.05
Ostrea angasi	136.23	13.63	8.91	30.96
Glycermeris grayana	13.29	0.00	5.92	36.88
Pyura stolonifera	11.86	27.63	5.42	42.30
Eucrassatella kingicola	8.93	2.20	5.07	47.37
Leptomithrax gaimardii	14.95	0.40	4.75	52.12

Table 4.3: SIMPER analysis output for the benthic data illustrating average abundance per location, ratio (average similarity / st.dev. similarity), % similarity and cumulative % similarity of the six most important species from the high density scallop beds located within the Commonwealth and Tasmanian managed study locations.

Species Name	Av. Abund	Percentage Similarity	Cumulative % Similarity
Within group similarities			
Commonwealth Fishery			
Chlamys asperrimus	849.65	23.78	23.78
Glycermeris striatularis	76.29	21.75	45.53
Ostrea angasi	136.23	14.48	60.01
Eucrassatella kingicola	8.93	7.32	67.33
Glycermeris grayana	13.29	6.39	73.72
Fusinus novaehollandiae	4.74	6.39	80.11
Tasmanian Fishery			
Pleuroploca austalasia	12.21	21.35	21.35
Chlamys asperrimus	15.78	15.37	36.72
Bollinaster pectinatus	2.22	11.12	47.83
Strigopagurus strigimanus	3.03	10.45	58.29
Coscinasterias muricata	6.18	9.03	67.32
Fusinus novaehollandiae	4.60	8.51	75.83

4.3.2 Benthic Communities in Scallop beds located in Commonwealth managed regions

The highest scallop abundance areas found within the Commonwealth scallop fishery had slightly lower species richness compared to moderate and low scallop abundance areas (Figure 4.4). There was also an increase in species dominance, and a decrease in species diversity and evenness from low scallop abundance areas to the high scallop abundance areas (Figure 4.4).

A general separation of the benthic communities found in areas of different scallop abundance was observed in the two-dimensional ordination plot (Figure 4.5). The one-way ANOSIM analysis showed a significant separation of the 'a priori' groups scallop abundance (Global R = 0.339; Significance level = 0.1%), with pair-wise comparisons indicating highly significant differences between all 'a priori' combinations (low vs. moderate = 1.4%; low vs. high = 0.1%; moderate vs. high = 1.5%).

The main species contributing to approximately 45% of the observed significant differences are illustrated in Table 4.4. In general, there was a complete absence of screwshells and their associated hermit crabs from high scallop abundance areas; and a complete absence of sponge and relatively high abundance of doughboy scallops and dog cockles in moderate and high scallop abundance areas (Table 4.4).

The five most prominent species contributing to the within group similarities of high scallop abundance areas were bivalve species (Table 4.5). Within moderate scallop areas, 2 crustaceans, 2 bivalves and a prosobranch gastropod contributed to the within group similarities; while the most diverse array of animal categories were found within the low scallop abundance areas (2 crustaceans, 1 bivalve, 1 prosobranch gastropod and bushy sponge) (Table 4.5).

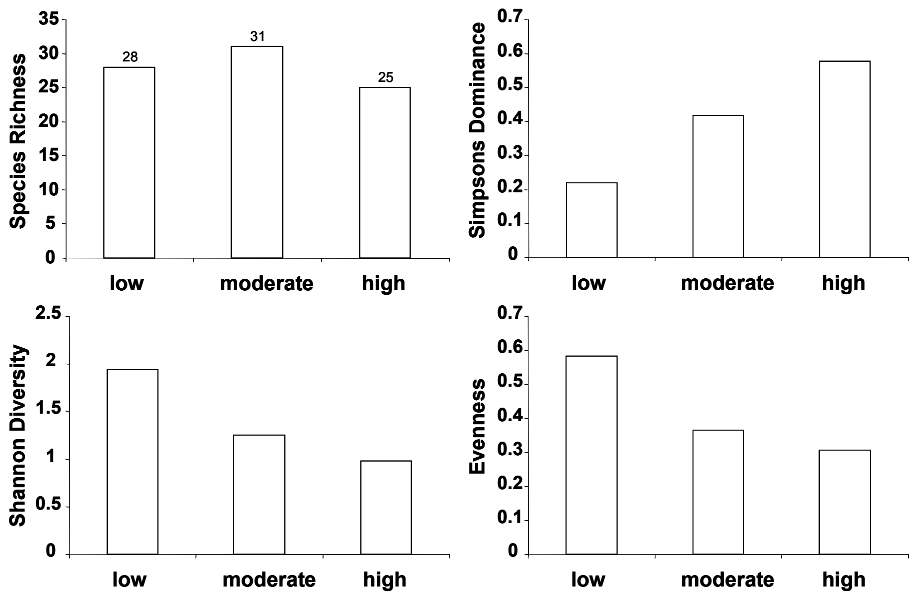

Figure 4.4. Univariate diversity indices for benthic communities found in areas of different scallop abundances within the Commonwealth fishery.

Figure 4.5. MDS plot for benthic communities collected in areas of different scallop abundance within the Commonwealth fishery. Stress = 0.18. L = low relative scallop density, M = moderate relative scallop density, and H = high relative scallop density.

Table 4.4: SIMPER analysis results illustrating the main species contributing to the between 'a priori' group differences observed in the benthic communities collected from high, moderate and low scallop abundance areas of the Commonwealth fishery.

Species Name	Av. Abund	Av. Abund	Percent Similarity	Cumulative % Similarity
Between group differences				
low vs. moderate	**low**	**moderate**		
Screwshell Hermit Crabs	190.25	357.74	10.38	10.38
Chlamys asperrimus	39.74	891.43	9.62	20.00
Glycermeris striatularis	3.93	80.38	8.27	28.27
Ostrea angasi	80.25	22.06	6.47	34.74
Bushy sponge	57.54	0.00	5.23	39.97
Maoricolpus roseus	11.89	22.36	5.19	45.16
low vs. high	**low**	**high**		
Chlamys asperrimus	39.74	849.65	10.72	10.72
Glycermeris striatularis	3.93	76.29	10.12	20.84
Ostrea angasi	80.25	136.23	9.63	30.47
Glycermeris grayana	3.82	13.29	5.36	35.83
Bushy sponge	57.54	0.00	5.33	41.16
Pyura stolonifera	54.45	11.86	5.15	46.31
moderate vs. high	**moderate**	**high**		
Chlamys asperrimus	891.43	849.65	11.46	11.46
Screwshell Hermit Crabs	357.74	0.00	11.16	22.62
Ostrea angasi	22.06	136.23	7.32	29.94
Maoricolpus roseus	22.36	0.00	5.58	35.52
Leptomithrax gaimardii	18.06	14.95	5.04	40.56
Glycermeris grayana	2.54	13.29	4.95	45.51

Table 4.5: SIMPER analysis results illustrating the main species contributing to the within 'a priori' group benthic communities of the Commonwealth fishery.

Species Name	Av. Abund	Percentage Similarity	Cumulative % Similarity
Within group similarities			
Low Scallop Abundance			
Strigopagurus strigimanus	10.36	23.33	23.33
Chlamys asperrimus	39.74	21.64	44.97
Pleuroploca austalasia	7.02	17.11	62.07
Pilumnus etheridgei	5.17	11.78	73.86
Bushy sponge	57.54	6.42	80.28
Moderate Scallop Abundance			
Chlamys asperrimus	891.43	18.18	18.18
Pleuroploca austalasia	18.86	14.93	33.10
Glycermeris striatularis	80.38	14.54	47.65
Strigopagurus strigimanus	14.17	11.19	58.84
Screwshell Hermit Crabs	357.74	10.92	69.75
High Scallop Abundance			
Chlamys asperrimus	849.65	23.78	23.78
Glycermeris striatularis	76.29	21.75	45.53
Ostrea angasi	136.23	14.48	60.01
Eucrassatella kingicola	8.93	7.32	67.33
Glycermeris grayana	13.29	6.39	73.72

4.3.3 Benthic Communities in Scallop beds located in Tasmanian managed regions

Within scallop beds located within the Tasmanian managed regions there was a general decline in species richness from low scallop abundance areas (28 species) to high scallop abundance areas (19 species). No clear trends in species dominance, diversity and evenness were evident (Figure 4.6).

The two-dimensional ordination plot suggested a separation of the benthic assemblages found in high and low scallop abundance areas, with the high abundance communities grouping close together near the middle of the MDS plot (Figure 4.7). Results from the one-way ANOSIM analysis showed only weak evidence for real differences between the 'a priori' groups (Sample statistic (Global R): 0.153; Significance level of sample statistic: 6.7%), with pairwise comparisons indicating that low and high scallop abundances were most likely to be significantly different (3.2%), with low and moderate scallop abundance areas (16.7%), and moderate and high scallop abundance areas (39.7%) being statistically similar.

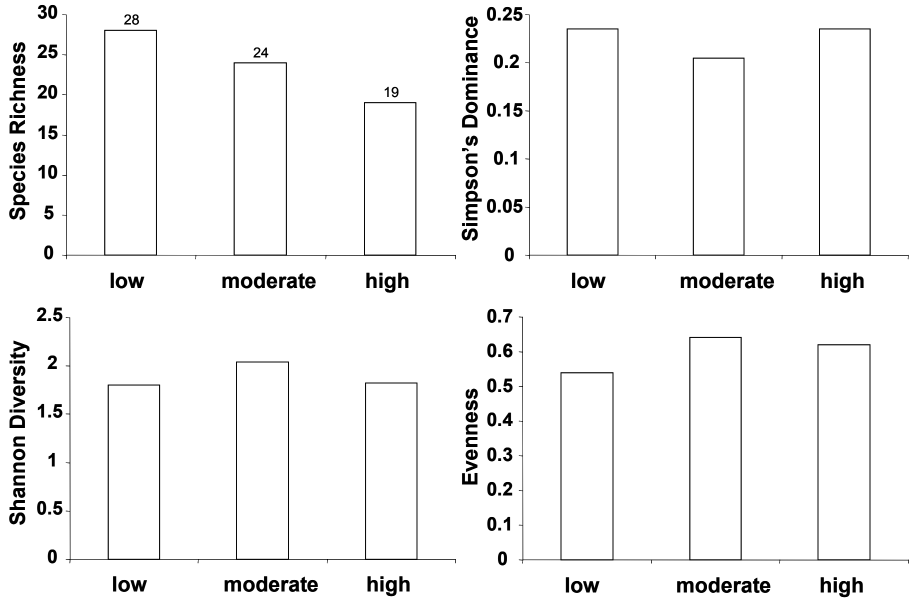

Figure 4.6: Univariate diversity indices for benthic communities found in areas of different scallop abundances within the Tasmanian fishery.

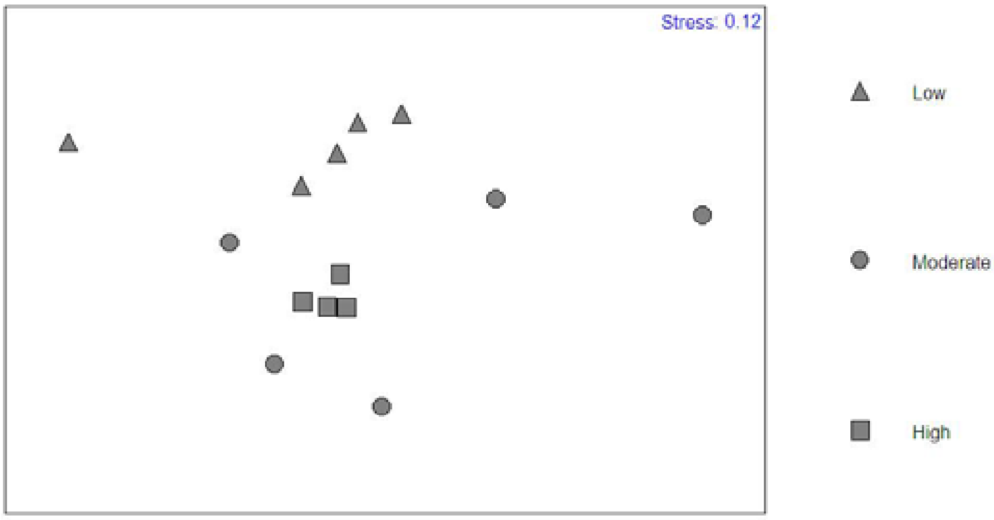

Figure 4.7. MDS plot for benthic communities collected in areas of different scallop abundance within the Tasmanian fishery. L = low relative scallop density, M = moderate relative scallop density, and H = high relative scallop density.

4.4 Discussion

4.4.1 Benthic Assemblages of Different Scallop Beds

Significant differences were found in the dredged benthic assemblages found within high scallop abundance areas located NE of Flinders Island (Commonwealth managed areas) compared to those found east of Flinders Island (Tasmanian managed areas). In general, relatively high abundances of bivalve species were found in scallop beds located within Commonwealth-managed regions; while relatively low abundances of a wide diversity of animal groups were typical of the benthic assemblages found in scallop beds to the east of Flinders Island in Tasmanian managed areas. Similarly, univariate diversity indices identified high species dominance within the Commonwealth fishery, and relatively high diversity within the east Flinders Island (Tasmanian) scallop beds.

Although the two sample locations were within reasonably close proximity, such differences in the underlying benthic assemblages found in spatially separate scallop beds is not an unexpected result, considering that physical, chemical and environmental parameters can change significantly over small spatial and temporal scales. For example, the two study sites are known to be influenced by strong water currents, which can be evidenced through large ripples in the sediment of the seafloor (Authors pers. obs.). However, observed variation in the proximity and height of these sediment waves suggests differences in the strength of currents and the sediment characteristics within both surveyed regions. Such differences in water currents and the correlations between typical current speeds and the type of sediment found in an area will directly affect patterns of animal settlement and the distribution of food particles (Edgar 2001b). Comparisons of the benthic communities found within other scallop beds situated within close proximity may show similar differences, irrespective of the managerial jurisdiction they fall within.

4.4.2 'Good' and 'Marginal' Scallop Beds

Results from this study showed that 'good' scallop beds sampled within the surveyed areas could be characterized by high abundances of commercial scallops and relatively high abundances of other bivalve species, particularly doughboy scallops (Commonwealth managed scallop bed); or relatively high abundances of scallops and low abundances of a wide diversity of crustaceans, bivalves, prosobranch gastopods and echinoderms (Tasmanian managed scallop bed). Similarly, lower abundance scallop areas within the sampled Tasmanian scallop bed were characterized by lower abundances of commercial scallops and low abundances of a wide diversity of crustaceans, bivalves, prosobranch gastopods and echinoderms. However, within scallop beds sampled within the Commonwealth managed region NE of Flinders Island, lower abundance scallop areas could be characterized by low abundances of commercial scallops, and high abundances of screwshells and their associated hermit crabs and a combination of oysters, dog cockles and sponge in varying abundances, and low abundances of other bycatch. Such areas could be termed 'marginal' scallop beds. These observed differences in the benthic assemblages found within different scallop abundance areas are most likely the consequence of differences in environmental and physical parameters, such as habitat complexity and previous recruitment success during previous years.

4.4.3 Scallop abundance: Implications for Scallop Fishery Management

Marginal scallop beds containing high abundances of an array of non-target species are unlikely to be attractive to scallop fishers, due to the time required to sort through the dredge hauls for a lower return of scallops. This is especially the case where the non-target species are large / heavy or exceptionally abundant (*e.g.* sponges, oysters, screwshells). A recent initiative by some fishers is the installation of sorting machines, or tumblers. These devices automatically sort catch, eliminating small items that fit through 90 mm diameter holes, which are built into the tumblers. Although fishing may have limited impact within some marginal scallop areas (*i.e.* screwshell and oysters if alive when caught, appear likely to exhibit high survivorship), there will be high impact within many marginal scallop habitats, particularly in sponge areas, which provide a habitat for a wide variety of organisms, many of which are fragile or inflexible.

Spatial management has the potential to focus fishing on good beds only, or those marginal habitats, which may not have high impacts caused by fishing, while conserving fragile marginal habitats. Such a spatial management strategy should benefit fishers, as they would be directed to high scallop abundance areas for their fishing operations. However, further research into the conservation of high scallop abundance areas as sources of increased recruitment into other areas of the fishery is needed (see Smith and Rago 2004).

4.4.4 Conclusions

Scallop beds found E / NE of Flinders Island can be sensibly classified as ‘good’ or ‘marginal’

Good scallop beds tended to be ‘cleaner’, or have less bycatch, in terms of their scallop catch than ‘marginal’ beds, however, other bivalve sp. may dominate some good scallop beds.

The benthic assemblages present within an area appear to be highly dependent on the geographical region, the physical attributes (sediment and currents) of the area, and the potential for recruitment of other species within that area.

Ultimately, if fishing is targeted by opening areas of ‘good’ scallop bed that contain a minimum of other species, this would limit the environmental impact of dredging even in the tiny areas that make up the scallop bed area.

5. THE CONSEQUENCES OF DIFFERING INTENSITIES OF SCALLOP DREDGE FISHING UPON BENTHIC COMMUNITIES.

5.1 Introduction

The current worldwide trend of declining fisheries and ecosystem change as a result of fishing (Pauly *et al.,* 1998; Jackson *et al.,* 2001; Myers & Worm, 2003) has prompted Australia to undertake risk assessments of their various fisheries, with a view to developing sustainable, low-impact fisheries and re-building ecosystems (Ecosystem Management approach). It is generally accepted that trawl and dredge fishing can have a high impact on benthic communities, both in the short-term (e.g. Kaiser *et al.,* 1998; Currie *et al.,* 1999; Bergman *et al.,* 2000; Dolmer *et al.,* 2001; and Guerra-Garcia, 2003) and the long-term (*e.g.* Beukema *et al.,* 1999; Ball *et al.,* 2000; Frid *et al.,* 2000; and Bradshaw *et al.,* 2001). Theoretical explanations of disturbance, such as the Intermediate Disturbance Hypothesis and Niche Diversification Hypothesis, suggest that large bodied, high-biomass species will dominate low disturbance areas (low fished), while scavengers and small-bodied organisms will dominate high disturbance (*i.e.* heavily fished) areas (Kaiser *et al.,* 2002). The expectation of these hypotheses is that dredge and trawl disturbance will result in a decrease in species richness, species diversity and evenness, with a corresponding increase in species dominance (Jones, 1992; Dayton *et al.,* 1995; Jennings and Kaiser, 1998; Collie *et al.,* 2000; Ocean Studies Board, 2002). However, the interaction between fishing disturbance and benthic community change is a complex process, and may be confounded by factors such as seabed type, fishing gear type, level of background natural disturbance, duration of fishing disturbance, the ratio of fished to unfished areas within a given community type and recovery time (Collie *et al.,* 2000; Bradshaw *et al.,* 2001).

The ability to detect potential impacts of fishing on benthic communities is greatly influenced by the geographical scale over which fishing occurs and whether benthic samples can be made in those areas experiencing the greatest fishing intensity. Many studies looking at the impact of fishing intensity on benthic communities within commercially fished areas have used fisheries logbook data (fisher catch returns) to define areas of different fishing intensity, with the spatial dimensions of intensity blocks being limited to the size of the assessment areas used by management organizations (*e.g.* 30 Nm^2 blocks used in ICES fisheries statistics, Rijnsdorp *et al.,* 1998; 5 Nm^2 blocks, Veale *et al.,* 2000). The use of Global Positioning System (GPS) technology permits much finer spatial resolution when defining areas of varying fishing intensity. For example, Rijnsdorp *et al.* (1998) installed an automated position recording system on a sub-set of the Dutch commercial beam trawlers fishing in the North Sea, to define areas of fishing intensity as small as 1 Nautical mile x 1 Nautical mile.

In Australia, within the Tasmanian and Commonwealth Central Bass Strait commercial scallop, *Pecten fumatus*, fisheries (Figure 5.1), it is a license requirement for all participating boats to be fitted with a Vessel Monitoring System (VMS). A component of this system is an Automatic Location Communicator (ALC) with an inbuilt GPS, which regularly transmits information on vessel position, course and speed to the appropriate management organizations via an Inmarsat communications satellite and Land Earth Station (LES). The primary role of VMS is to monitor industry compliance with spatial and seasonal fishery management regulations, however, the high-resolution position data can also be used to identify relatively small areas of different fishing intensity, such as 500 m^2 blocks. In addition, all vessels contribute to the dataset so the areas of different fishing intensity represent the activity of the entire fishing fleet.

After extended periods of fishing and more than one stock collapse through the 1980's and 1990's, both the Tasmanian and Commonwealth Central Bass Strait commercial scallop fisheries were closed to fishing during the late 1990's due to low scallop stocks (Haddon *et al.,* 2004). A scientific survey conducted in March 2003 concluded that scallop stocks had recovered to levels capable of supporting a commercial scallop fishery within both jurisdictions (Haddon & Semmens, 2003) and parts of both fisheries were opened to commercial fishing during 2003. The opening of these fisheries provided an opportunity to examine the potential impact of different levels of commercial dredge fishing on benthic communities at spatial scales not previously assessed in this area.

The objective of this present study was to compare the dredged benthic fauna from areas of differing commercial scallop fishing intensities within fished regions of the Commonwealth and Tasmanian managed fisheries to determine if differences in these benthic communities could be attributed to fishing disturbance and the level of this disturbance, or were more likely the result of pre-existing habitat differences and fisher behaviour within these habitats. The implications for developing management strategies for the scallop fisheries in Tasmania and the Commonwealth were also examined.

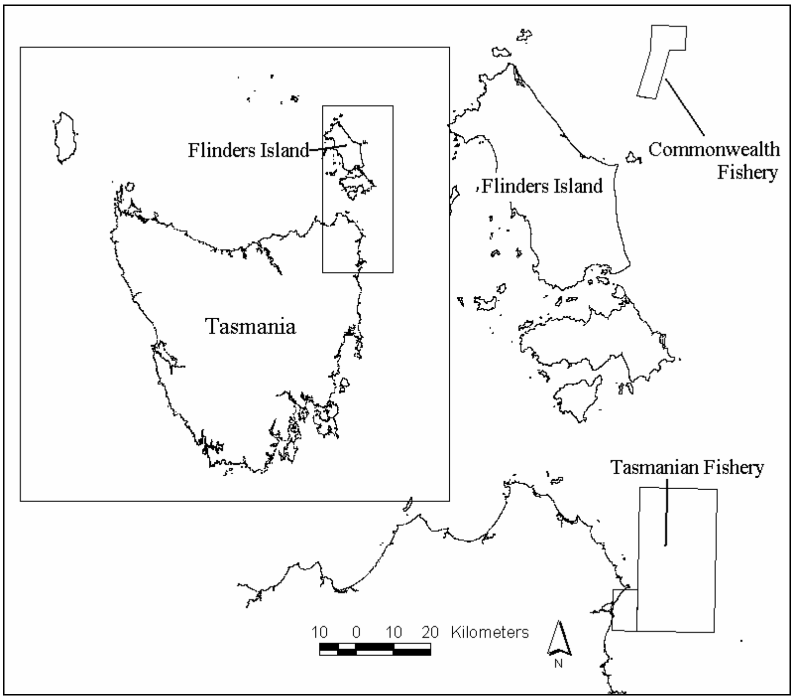

Figure 5.1. Locations of the areas fished during the 2003 Tasmanian and Commonwealth managed commercial scallop seasons.

5.2 Methods and Materials

5.2.1 Survey design and methods

VMS position data was available for all actively licensed scallop boats fishing the 2003 Commonwealth and Tasmanian scallop seasons. Coordinates were then mapped using the software package ArcView GIS 3.2a for Windows, with points considered to be travelling boats (high speed or outside legal fishing zones) being deleted from the dataset. After elimination of these data points, two relatively small discrete areas of fishing activity were identified in the Tasmanian fishery, and one in the Commonwealth fishery (see Chapter 2). A grid consisting of 500 x 500 meter cells was placed over each discrete fishing area, and a count of the total number of individual VMS 'polls' falling within each individual cell calculated. This grid size was chosen because previous dredge surveys from known scallop beds within the Tasmanian fishery suggested relative uniformity of habitat types at this scale. Furthermore, an individual five minute scientific dredge tow covers approximately 400 - 450m, and could subsequently fall within an individual defined intensity cell if required. These counts were used to define different levels of fishing intensity, relative to the fishing effort within fished areas of the 2003 Tasmanian and Commonwealth fisheries (Table 5.1). The actual values used to define intensity cannot be published due to security and confidentiality agreements with the respective management organisations, however, heavily fished areas had at least 2.5 times the number of VMS polls relative to moderately fished areas, and moderately fished areas had at least two times the number of VMS polls relative to low fished areas.

A fishery-independent dredge survey was conducted in November 2003 within both the Tasmanian and Commonwealth regions following the completion of the commercial fishing seasons. Within the sample location within the Commonwealth managed fishery, five replicate dredge samples were collected from each of the low, moderate, heavy and non-fished areas (Table 5.1); in addition, five replicate samples were collected from each of the low, moderate and heavy fishing intensity areas within the Tasmanian managed fishery sample location (Table 5.1).

Table 5.1. Description of each of the *a priori* fishing intensity categories used to describe the Commonwealth and Tasmanian benthic community data.

Category	Description
Not fished	Areas where generally no fishing occurred during the 2003 commercial scallop season as defined by VMS data
Low	Areas where boats were present in relatively low frequencies as defined by VMS data
Moderate	Areas where boats were present in relatively moderate frequencies as defined by VMS data
Heavy	Areas where boats were present in relatively high frequencies as defined by VMS data

Benthic samples from both surveys were collected on board the chartered fishing vessel *Dell Richey II* using a standard commercial 'toothed-dredge', with a width of 4.26 m and mesh dimensions of 46 x 70 mm. A 23 x 35 mm mesh liner was fitted to the dredge to allow for the retention of small scallops and other small benthic taxa. All tows were of five minutes duration and covered between 400 and 450 m, in depths ranging from 18 to 42 m in Commonwealth waters, and 40 to 60 m in Tasmanian waters.

Upon completion of each sample tow, the dredge contents were sorted and all animals identified to the lowest practical taxon. Where numbers of individual taxa were low, all individuals were counted. Where numbers were large, a total count was estimated by counting all individuals in a randomly selected sub-sample, and then scaling up to

100%. Due to variation in the tow distance of each sample tow, the abundance of each taxon was standardised to the relative number caught per 1000 m^2.

5.2.2 Statistical analysis

The potential impact of fishing intensity on benthic communities was examined in the Commonwealth-managed fishery sites by comparing benthic communities from heavy, moderate, low and non-fished areas. A separate analysis of the Tasmanian fishery data further aimed to determine whether the level of fishing intensity influences benthic communities by comparing the benthic communities found in areas of heavy, moderate and low fishing.

The univariate diversity indices, Species Richness, Shannon Wiener Diversity, Evenness and Simpson's Dominance were calculated to identify differences in the abundance and distribution of taxa found in each study site and fishing intensity class separately (Begon *et al.*, 1986). In each case the average number of each taxa caught per dredge tow was used from each defined fishing intensity area. Similarly, multivariate analyses were used to assess differences in the 'dredged community assemblages' between each fishing intensity area, and in the case of the Commonwealth fishery, non-fished areas. Taxa found in two or fewer samples over the entire data set (*i.e.* all intensities combined) were excluded from the multivariate analysis to reduce statistical noise and avoid biasing the analyses. Data was fourth-root transformed to reduce the influence of a few highly dominant species.

Any patterns in the community assemblages were identified using multi-dimensional scaling (MDS ordination plots of each defined category) of the Bray-Curtis ecological distance measure applied to the species composition of each of the replicate samples from each of the fishing intensity treatments. One-way analysis of similarity tests (ANOSIM) were also conducted for all data from each fishery to test the null hypothesis that there are no differences in the 'dredged benthic communities' found in the different fishing intensity areas'. SIMPER analysis (Percentage Similarity) was used to determine if any particular species were indicative of the patterns identified, as per Clarke and Warwick (2001). All multivariate analysis techniques were completed using the Plymouth Routines in Multivariate Ecological Research (PRIMER) version 5 software package.

5.3 Results

5.3.1 Commonwealth-managed fishery

Although no clear differences in species richness were evident, heavy and moderately fished areas had slightly lower species richness compared to low fished and non-fished areas (Figure 5.2). Despite the slightly lower species richness in heavy and moderate fished areas they also exhibited higher measures of species diversity and evenness, while high species dominance, and relatively low diversity and evenness, was observed in low and non-fished areas (Figure 5.2).

The two dimensional ordination analysis identified a general grouping of the fished areas (heavy, moderate and low fished), although the heavy and low intensity groups each had one outlier. The non-fished category showed greater spread between replicate samples and three samples showed some degree of separation from the fished groups (Figure 5.3). One-way ANOSIM analysis failed to detect any significant differences between the different fishing intensity groups within the Commonwealth fishery (Global statistic R = 0.073; $P = 0.132$). Given the apparent separation of the non-fished group, pair-wise tests were considered, with evidence of some differences between moderate and non-fished areas (P = 0.024).

To define the main community types found in the Commonwealth fishery, the sample tows were categorised into two groups according to the spatial similarities identified on the MDS plot. Group 1 corresponded to the majority of the fished samples, while Group 2 comprised three of the five non-fished samples plus a single low fished sample (Figure 5.3). Commercial scallops, *Pecten fumatus*, doughboy scallops, *Chlamys asperrimus* and dog cockles, *Glycymeris striatularis* were found to contribute to 41% of the within groups similarities found within Group 1 (fished areas) (Table 5.2a). Hermit crabs, primarily *Paguristes tuberculatus*, associated with empty New Zealand screwshells, *Maoricolpus roseus*, New Zealand screwshells and *C. asperrimus* contributed to 71% of the within group similarity found within Group 2 (predominately non-fished samples). The observed differences between the two groups was controlled by the very high abundances of the non-target species *P. tuberculatus* and *M. roseus* within Group 2 (non-fished samples) and their complete absence in Group 1 (Fished areas) (Table 5.2b).

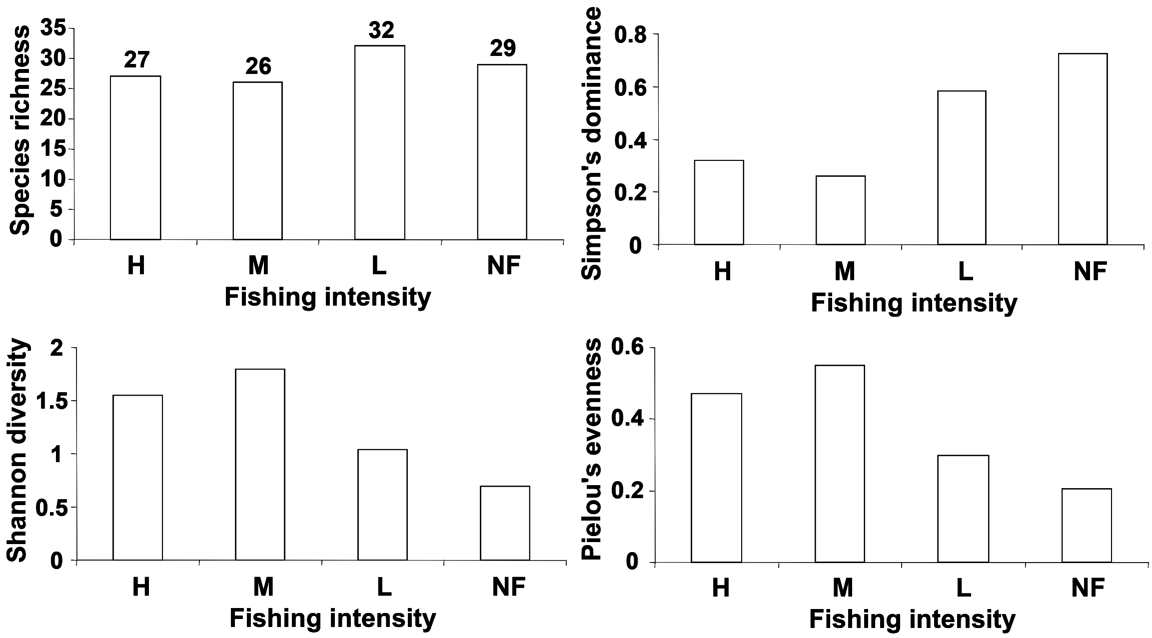

Figure 5.2: Univariate diversity indices for each fishing intensity area of the Commonwealth fishery. H = heavily fished, M = moderately fished, L = low fished, NF = non-fished as explained in the methods. The values above the species richness bars represent the value of that bar.

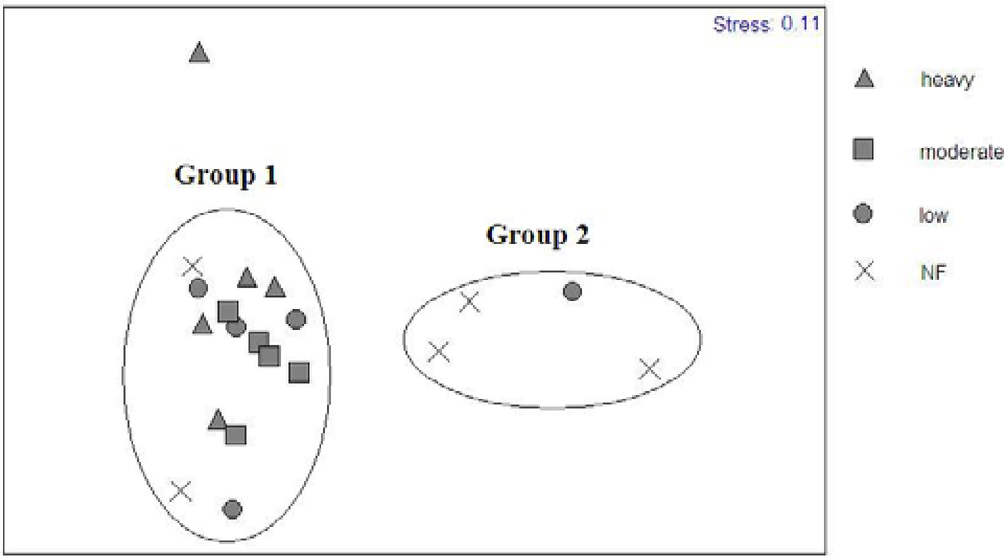

Figure 5.3. Two-dimensional ordination analysis (MDS plot) of species abundance data within each of the fishing intensity groupings of the Commonwealth fishery. Stress = 0.11. The groups shown on the diagram identify the categories used in the SIMPER analysis.

Table 2a: SIMPER output for the benthic community data indicating average abundance per sample, ratio (average similarity / st. dev. similarity), % similarity and cumulative % similarity of the three most important species within each of the groupings applied to the Commonwealth fishery data. **2b** SIMPER output for the benthic community data indicating average abundance per sample from each group comparison, ratio (average similarity / st. dev. similarity) and cumulative % similarity of the three species which most clearly distinguish the main groups identified.

Species Name	Av. Abund.	Ratio	Percentage Similarity	Cumulative % Similarity
a) within groups				
Group 1				
Pecten fumatus	130.22	8.28	17.48	17.48
Chlamys asperrimus	180.51	2.04	13.26	30.74
Glycymeris striatularis	59.75	2.71	10.44	41.19
Group 2				
Screwshell Hermit Crabs	9987.81	3.74	40.30	40.30
Maoricolpus roseus	624.05	3.74	20.15	60.45
Pecten fumatus	110.47	6.17	11.18	71.63
Species Name	**Group 1 Av. Abund**	**Group 2 Av. Abund**	**Ratio**	**Cumulative % Similarity**
b) Between groups				
Screwshell Hermit Crabs	0.00	9984.81	3.65	27.11
Maoricolpus roseus	0.00	624.05	3.65	40.67
Chlamys asperrimus	180.51	50.32	1.32	45.59

5.3.2 Tasmanian-managed fishery

There were no clear differences in species richness observed between areas of different fishing intensity in the Tasmanian fishery, however, heavy fished areas did have a slightly lower number of species compared to moderate and low fished areas (Figure 5.4). A general decrease in species dominance, and corresponding increases in species diversity and evenness was evident from heavy to low fished areas (decreasing fishing intensity) (Figure 5.4).

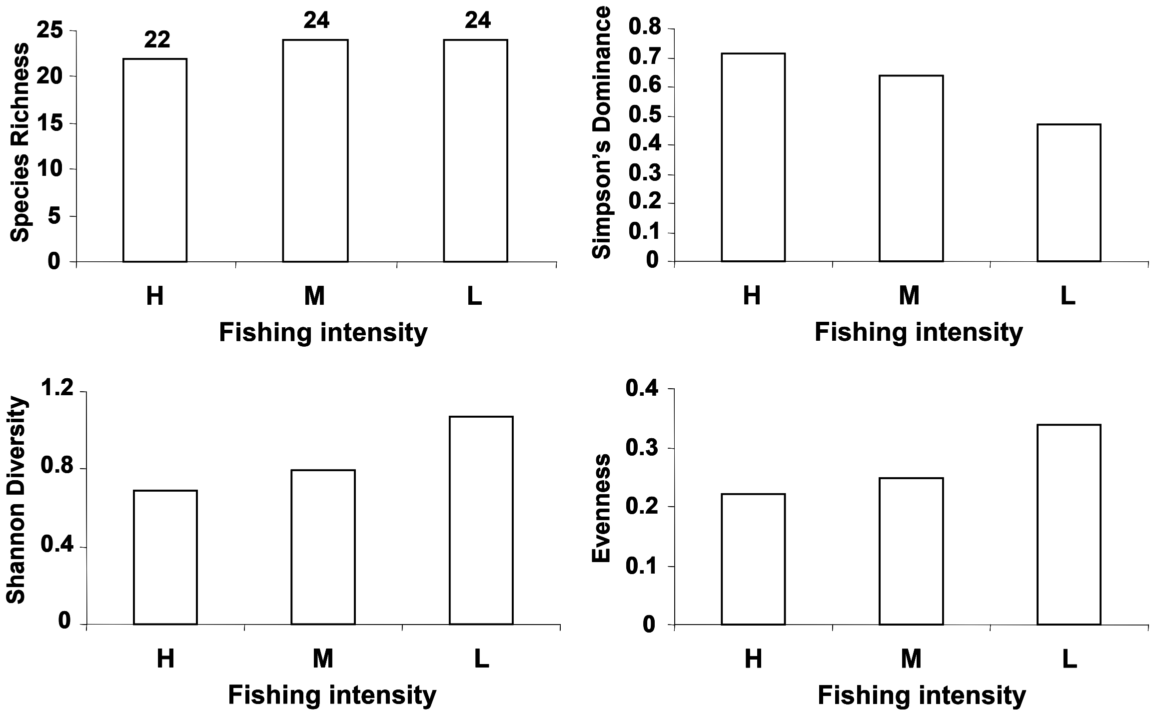

Figure 5.4. Univariate diversity indices for each fishing intensity area of the Tasmanian fishery. H = heavily fished, M = moderately fished, L = low fished as explained in the methods. The values above the species richness bars represent the value of that bar.

The two-dimensional ordination analysis separated the heavily fished benthic communities from the moderate and low fished areas, with the lower intensity fishing areas demonstrating a greater spread among replicates (Figure 5.5). One-way ANOSIM analysis of the *a priori* fishing intensity groups identified significant differences between the groups (Global statistic (Global R) = 0.424; $P = 0.008$), with pair-wise comparisons showing the differences to be between heavy and low fished areas ($P = 0.008$); and heavy and moderate fished areas ($P = 0.032$). The moderate and low comparison was not significant (P = 0.627).

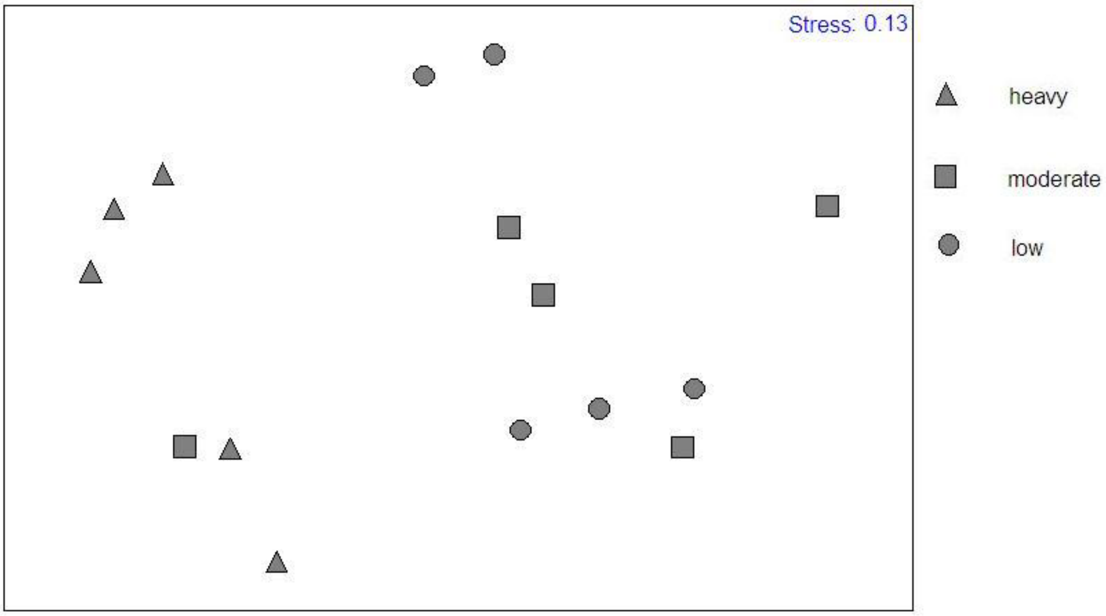

Figure 5.5. Two-dimensional ordination analysis (MDS plot) of species abundance data within each of the fishing intensity groupings for the Tasmanian fishery data. Stress = 0.13.

SIMPER analysis identified the main species contributing to the similarities within heavily fished sites as being *Pecten fumatus*, large hermit crabs, primarily *Strigopagurus strigimanus* but also another unidentified hermit crab species, and dog cockles, *Glycymeris striatularis*; while *P. fumatus*, *Paguristes tuberculatus*, *S. strigimanus* (and another unidentified hermit crab species), and *Maoricolpus roseus* accounted for the majority of the within group similarities within moderate and low fished areas (Table 5.3a). The main species contributing to the between group differences were high abundances of *P. tuberculatus* and *M. roseus*, within moderate and low fished areas, but their complete absence in heavily fished areas (Table 5.3b).

Table 3a: SIMPER output for the benthic community data indicating average abundance per sample, ratio (average similarity / st. dev. similarity), % similarity and cumulative % similarity of the three most important species in each of the a priori groups from the Tasmanian fishery data. **3b** SIMPER output for the benthic community data indicating average abundance per sample for each a priori group comparison, ratio (average similarity / st. dev. similarity) and cumulative % similarity of the three species which most clearly distinguish the main significantly different a priori groups of the Tasmanian fishery as identified in the ANOSIM.

Species Name	**Av. Abund.**	**Ratio**	**Percentage Similarity**	**Cumulative % Similarity**
a) ***within groups***				
Heavy				
Pecten fumatus	553.93	26.97	33.53	33.53
Hermit Crabs	13.55	18.30	13.47	47.00
Glycymeris striatularis	12.02	6.39	11.90	58.90
Moderate				
Pecten fumatus	371.45	3.76	19.85	19.85
Screwshell Hermit Crabs	2239.85	1.15	18.72	38.58
Other Hermit crabs	27.36	4.77	10.67	49.25
Maoricolpus roseus	139.93	1.15	9.36	58.61
Low				
Pecten fumatus	344.87	4.40	22.18	22.18
Screwshell Hermit Crabs	896.46	3.90	21.88	44.07
Other Hermit crabs	14.72	5.59	10.97	55.04
Maoricolpus roseus	56.03	3.90	10.94	65.98
	Av. Abund	Av. Abund.		
Species Name	**Heavy**	**Moderate**	**Ratio**	**Cumulative % Similarity**
b) ***Between groups***				
Screwshell Hermit Crabs	0.00	2238.85	1.78	24.59
Maoricolpus roseus	0.00	139.93	1.78	36.88
Chlamys asperrimus	60.84	6.55	1.63	43.44
	Heavy Av. Abund.	**Low Av. Abund.**	**Ratio**	**Cumulative % Similarity**
Screwshell Hermit Crabs	0.00	896.46	3.55	23.07
Maoricolpus roseus	0.00	56.03	3.55	34.60
Chlamys asperrimus	60.84	1.55	1.39	42.77

5.4 Discussion

Univariate indices of diversity and evenness from the sample site located within the Tasmanian managed scallop fishery found that species richness, species diversity, and species evenness were inversely related to fishing intensity and the implied disturbance. Furthermore, as fishing intensity increased there was a corresponding increase in species dominance. Such patterns of univariate indices are predicted by the Intermediate Disturbance Hypothesis, which further suggests that large bodied, high-biomass species will dominate low disturbance areas (high dominance), while scavengers and small-bodied organisms will dominate high disturbance areas (Kaiser *et al.* 2002). Similar results have been demonstrated in a range of studies looking at the impact of trawl and dredge fishing disturbance on benthic organisms (Dolmer *et al.* 1990; Currie *et al.* 1999; Collie *et al.* 2000; Veale 2000; Bradshaw *et al.* 2001; Robinson *et al.* 2001). Furthermore, Collie *et al.* (2000), in their meta-analysis of 39 published fishing impact studies, concluded that intuitions about how fishing ought to affect benthic communities (disturbance hypotheses) are generally supported by the literature.

Having said that, the univariate indices of diversity and evenness from the sample sites located within the Commonwealth managed fishery indicated that areas exposed to higher levels of fishing disturbance had lower species richness, lower species dominance and higher levels of species diversity and evenness compared to low fished and non-fished areas. In effect these results contradict the predictions of the Intermediate Disturbance Hypothesis. It has been suggested that condensing complex data with high levels of variability into single indices may mask clear trends in community change (Bradshaw *et al.* 2001). Consequently, univariate trends must be compared with multivariate results to gain a better understanding of the processes occurring.

The multivariate analyses showed that fished areas within the Commonwealth managed fishery were generally relatively similar to each other (possibly had similar habitats), but non-fished areas showed not only greater spread within the MDS space, but in some cases a small degree of separation from the fished samples. For the samples collected within the Tasmanian fishery, heavily fished areas differed from moderate / low fished areas in the ordination. These results suggest that the level of fishing disturbance has little influence on benthic communities, but disturbance itself may still impact the benthos. When comparing the species causing the observed separations it was found that non-fished areas of the Commonwealth fishery, and moderate / low fished areas of the Tasmanian fishery contained very high abundances of non-target (discard) species, in particular screwshells with their associated hermit crabs, and live screwshells, while fished areas of the Commonwealth and heavily fished areas of the Tasmanian fishery generally contained neither the screwshells nor their associated hermit crabs. This suggests that fishing is focussed on good scallop beds that contain few if any screwshells (*Maoricolpus roseus*) or large numbers of other non-target species. In other words the differences in community diversity and complexity between areas of different fishing intensities appear to have been there before fishing. This supports the notion of fishers targeting ‘good’ scallop beds in preference to ‘marginal’ scallop beds (see Chapter 4).

If fishing disturbance was impacting the benthos it would be reasonable to expect that any scallops within the most disturbed areas (i.e. heavy in Tasmanian managed and heavy / moderate / low in Commonwealth managed fished areas) would also be caught and removed. This does not appear to have occurred as scallops were a major contributing species characterizing the group within the most highly disturbed areas. Although it is plausible that scallops have relocated from adjacent areas into the more heavily fished areas post-commercial fishing, it is more likely that the observed differences are due to pre-existing habitat and / or benthic community differences, which occur potentially over smaller spatial scales than the defined fishing intensity areas. It also possible that the development and presence of dense, but intermittent, scallop populations may create a transient environment or habitat that leads to the formation of an identifiable community.

One of the assumptions of this study was that different habitat types would be homogenous over the 500 x 500 m spatial scale, such that VMS data could be used to define areas of differing fishing intensity. Although this assumption appears to hold in some areas surveyed in this study, in particular the Tasmania fishery, more recent unpublished video surveys conducted in the Commonwealth fishery have suggested variation in habitats may occur over spatial resolutions less than 500 x 500 m. This dynamic patterning of habitats within very small areas may have resulted in VMS data defining fisher behaviour over pre-existing different habitat types, with fishers spending proportionally more time in areas of higher scallop abundance (heavy fished areas in Tasmania / heavy, moderate and low fished areas in the Commonwealth) and less time in lower abundance scallop habitats (low fished in Tasmania / non-fished areas in the Commonwealth).

Rijnsdorp *et al.* (1998) also illustrated the importance of spatial resolution on the micro-scale distribution of beam trawl effort in the southern North Sea in relation to trawling frequency of the seabed and the impact on benthic organisms. Using ICES logbook data and Automated Position Recording (APR) data they were able to determine the distribution, and subsequent impact of trawling on benthic organisms in overlapping blocks ranging in size from 30 x 30, 10 x 10, 3 x 3 and 1 x 1 Nm. In 30 x 30 and 10 x 10 Nm plots, fishing was patchily distributed; within 3 x 3 nautical mile squares, beam trawling was randomly distributed in some parts of the most heavily fished areas, but patchily distributed in others; while in 1 x 1 nautical mile squares, the distribution became random within more than 90% of the squares. This result implies that benthic communities differ over spatial scales greater than 3 x 3 Nm, resulting in patchy effort, while at 1 x 1 Nm resolution benthic communities are dominated by habitat where the target species is found (random effort, homogenous habitat)

It has been suggested that the usefulness of results from studies looking at the impact of fishing on benthic communities are to some extent limited by factors such as the specific location, type of gear used and season during which the study in question was undertaken (Collie *et al.* 2000; Kaiser 2002). Therefore, the broader results of such work can only be used to predict the outcome of fishing activities in a restricted number of situations. Although this statement is to some extent true, the results of this study, supported by the findings of Rijnsdorp *et al.* (1998), show that the spatial scale of fishing intensity blocks needs to be defined relative to the spatial distribution of habitat types in any given study area. Although manipulative experimental studies looking at the impact of trawl or dredge fishing on benthic communities allows experimenters to examine very small areas (e.g. 1 m^2 for intertidal dredging, 20 m^2 for scallop dredging and trawling - Collie *et al.* 2000) with high precision and spatial scales of habitats, these studies are usually in areas closed to fishing, with the relevance of such results to commercially fished areas uncertain (Veale *et al.* 2000). The methodologies of most other fishing impact studies do not take into account the spatial scale of different habitat types within areas. Even with random stratified designs, the distribution of different habitat types may have a large impact on overall results, leading to incorrect conclusions.

5.4.1 Defining Scallop Beds – Discrete vs. Patchy

For sample regions within the Tasmanian fishery, scallop beds (heavily fished areas) appeared to be relatively small, discrete areas (100's meters to kilometres), with low species diversity but very high numbers of commercial scallops (discrete or good scallop bed). For benthic communities within the Commonwealth sampled regions, scallop beds (heavy, moderate and low fished areas) were far less well defined, with much lower abundances of commercial scallops and relatively high species diversity (patchy or marginal scallop bed). This difference between scallop beds is most likely being driven by the greater variation in substrate types, complexity of habitat, water depth, wind and tidal currents, and previous recruitment success of different species which occur in the region of the Commonwealth fishery.

It is generally accepted that more complex habitats support more diverse benthic communities (increased species numbers). Furthermore, factors such as substrate type, depth and water currents are known to influence the distribution of filter-feeding benthic invertebrates and the successful recruitment of scallops and other species with a larval phase (Brand 1991). In order to gain a better understanding of the processes that control the distribution of scallops and 'discard species' in the Tasmanian and Commonwealth fisheries, further research focusing on the physical attributes of each habitat type and the recruitment of scallops and other benthic species is required.

5.4.2 Implications for Management

The discrete nature of what could be termed 'true' or 'good' scallop beds, as generally found in the Tasmanian fishery, combined with the small spatial scale over which they occur relative to other surrounding habitats, can be incorporated into spatial management recommendations. Although the Tasmanian scallop fishery has already adopted a spatial management regime, with most areas of the fishery being closed and small areas open to fishing, the size of the open areas remain large relative to the size and discrete nature of the scallop beds'. If scallop beds can be identified and their boundaries defined, then the resource could be spatially managed on a 'bed by bed' approach. Such an approach would maximise the long-term sustainability of the scallop resource by protecting the majority of scallop beds from fishing, while at the same time allowing already fished beds time to recover. 'Bed by bed' management of scallop beds will also reduce the impact of dredges on other benthic habitats, an issue of major environmental concern worldwide.

6. SEQUENCE OF SURVEYS: OVERVIEW OF SURVEY RESULTS.

6.1 Introduction

In 1998, approximately 900 tonnes (shell-weight) of the commercial scallop (*Pecten fumatus*) was landed in the Bass Strait Central Zone Scallop Fishery (BSCZSF) from just over 7,000 hours dredging effort (0.129 t/h). This compared poorly with over 6,000 tonnes landed in 1997, caught from almost 20,000 hours dredging (0.3 t / h). In response to the declining catches and catch rates during 1998 and a decline in the value of the fishery, the forerunner of the Commonwealth Scallop Resource Assessment Group (ScallopRAG), the Bass Strait Scallop Consultative Committee (BSSCC), recommended to the Australian Fisheries Management Authority (AFMA) that the fishery should be closed for between 1 and 2 years. The AFMA board endorsed this suggestion and the fishery was closed for what would have been the 1999 season, with decisions about any subsequent opening being reliant on the results of a formal survey of the scallop beds. In June 2000, a stratified survey was conducted in the area of the Commonwealth fishery east/northeast of Flinders Island (Figure 6.1). The area surveyed was selected with Industry advice as it was thought to contain commercial beds of scallops (Anon, 2000). Only a single, relatively small scallop bed was found during the survey, while north of the scallop bed only 11 individual scallops were found in 110 dredge shots (Figure 6.1; Semmens *et al*. 2000). The decision was made to close the only known bed, but to open the rest of Bass Strait to exploratory fishing by Industry members in case the scientific survey had failed to locate any other bed(s) of scallops. The small amount of exploratory fishing that occurred did not locate any scallops, which was consistent with the findings of the 2000 scientific survey.

Also during 2000, a survey was conducted in Tasmanian waters north of Babel Island (Figure 6.1) (Semmens, 2000). Only one small bed of scallops was discovered, which was thought to be a part of, and perhaps bigger than, the bed identified in the 2000 Commonwealth waters survey, referred to above. Information from commercial fishers also suggested that there were no commercially exploitable beds of legal sized scallops elsewhere in Tasmanian waters, although later catches on the east coast of Tasmania suggest there most likely would have been at least some beds of juvenile scallops present. Given this situation, the Tasmanian scallop fishery was subsequently closed during 2000.

Regular surveys within both the Commonwealth and Tasmanian jurisdictions have been conducted since the 2000 survey in an attempt to monitor the re-population of the scallop grounds. Since 2003, the Commonwealth and Tasmanian scallop grounds have been surveyed twice annually as part of the current project (FRDC 2003/017). The main objective of this chapter was to describe the sequence of surveys conducted since 2000 and provide a report of the main findings from each survey.

6.2 General Methods

A total of nine fishery independent surveys have been conducted within Commonwealth and Tasmanian waters since 2000 (Table 6.1), with several industry surveys occurring within some years. In this chapter we are concentrating on annual growth rates and clear identification of cohorts, so length frequency results from the November surveys conducted in 2004 and 2005 will not be discussed here.

During the scientific surveys, the stratification boundaries used have altered to reflect changes in knowledge of scallop stocks available (see Figure 6.1 and 6.2). Other areas outside those strata identified in Figure 6.2 have also been surveyed, as described in later sections (also see Figure 6.3). Since 2003, fishery independent scientific surveys have been conducted twice annually as part of the FRDC project 2003/017. Not all strata were sampled in all surveys. The area covered in each survey was a function of the particular objectives for each individual survey, combined with the exigencies of the weather and sea state.

Commercial dredge fishing restarted in 2003 in both Commonwealth and Tasmanian waters. Within the Commonwealth fishery only areas north of stratum 4 were open, with fishing focussed in Strata C1, C2, and C3; while in the Tasmanian fishery, fishing was restricted to T1S and Eddystone Point (Figures 6.2 and 6.3). Commercial fishing again occurred within the Commonwealth and Tasmanian fisheries during 2004, with most fishing within the Commonwealth being restricted to C1 – 3 and C5b, while relatively large expanses of the east coast of Tasmania were fished. These open seasons certainly influenced the subsequent findings in some of the strata by depleting the scallops present.

6.2.1 Dredge Surveys

All scientific dredge surveys from 2001 were conducted on-board the commercial fishing vessel the *Dell Richey II*. This vessel was selected because it provided an excellent working platform. Also, by using the same vessel and gear in each survey, comparisons between surveys could be made validly without having to allow for changes in fishing power. The dredge width for all tows on the *Dell Richey II* was 4.26 metres. During the 2000 and 2001 survey, the dredge contained an unmodified mesh size of 50 x 70 mm. From 2002, the dredge was fitted with a mesh liner, giving mesh dimensions of approximately 25 x 35 mm. This liner was used in an effort to increase the catchability of juvenile scallops in the dredge. More details of the dredge survey methods are given in Chapter 3.

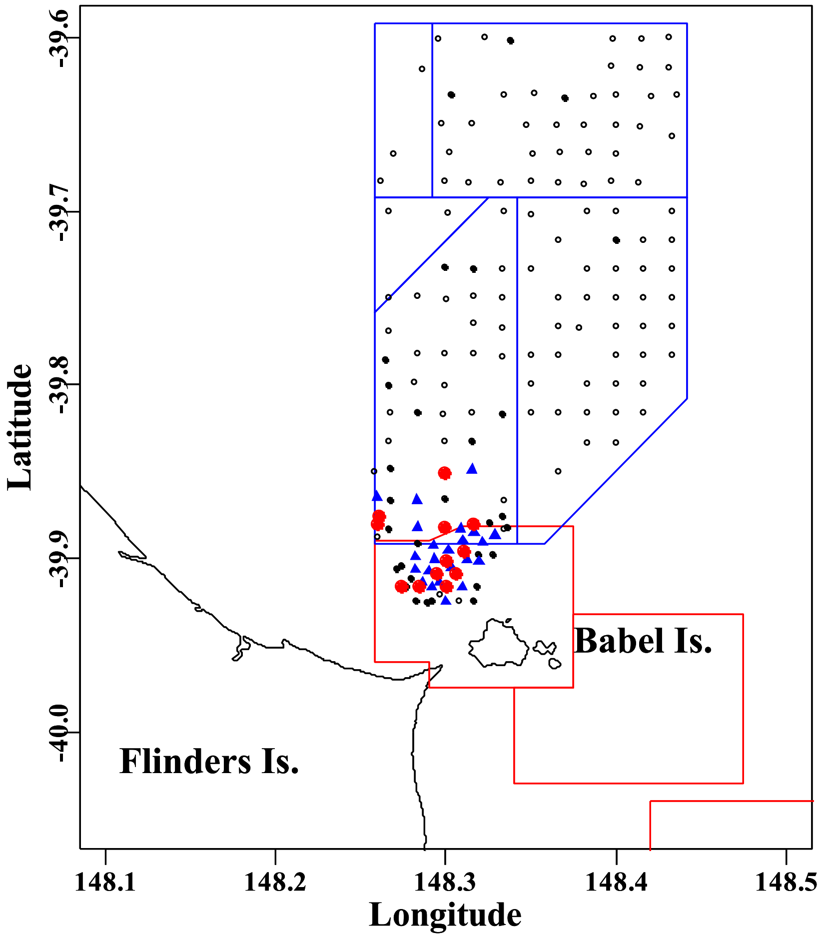

Figure 6.1. Design and results from the June 2000 survey in Commonwealth and Tasmanian waters N / NE of Flinders Island. The small black circles relate to zero scallops, black dots relate to shots with less than 1 scallop per 10 m^2, blue triangles relate to densities of less than 1 scallop per $2m^2$, while red filled circles relate to densities greater than 1 scallop per $2m^2$. The block outlines represent the strata used in this first survey.

6.2.2 Modal Groups and Length Frequency

Young *et al.* (1989) provided a table of sizes with inferred ages for a number of different areas in Victoria and Tasmania (Table 6.2). These results, combined with observations on the recovering scallop beds in Tasmania and Commonwealth waters conducted since 2000, made it possible to ascribe ages to the different modes observable in the frequency counts of lengths (length frequency samples). However, not all size-frequency data from surveys in all strata could be used to identify clear modal groupings. Sometimes the numbers of scallops captured were small relative to the number of size classes present so that the size distributions did not always follow recognizable or structured distributions, making the identification of cohorts difficult.

Table 6.1. Dredge surveys conducted in the Bass Strait scallop fishery since 2000. For strata labels and locations see Figure 6.2. The FRDC funded surveys began in Nov 2003 in both Commonwealth and Tasmanian waters.

Year	Report	Area Surveyed	Comments
June 2000	Semmens *et al.* (2000)	Commonwealth	Discovered Area X in stratum C5a
June 2001	Haddon & Semmens (2001)	Commonwealth	Only stratum 5a
Oct 2001	Haddon (2001)	Commonwealth	Industry survey of strata C4 and C3
Mar 2002	Haddon & Semmens (2002)	Commonwealth	Formally defined strata 1 - 5a
Mar 2003	Haddon & Semmens (2003)	Commonwealth	Re-surveyed 1 - 5a + 5b
Nov 2003		Commonwealth	FRDC formal surveys , from Nov
Mar 2004	Haddon *et al.* (2004)	Commonwealth	2003, covered both Commonwealth
Nov 2004		Commonwealth	and Tasmanian waters see (Figure 2).
Mar 2005	Haddon *et al.* (2005)	Commonwealth	Final FRDC sponsored survey.
June 2000	Semmens (2000)	Tasmanian	Only north of Babel Island
Mar 2002	Semmens and Lawler (2002)	Tasmanian	East and West Flinders; Banks Strait
Mar 2003		Tasmanian	East Flinders
Nov 2003		Tasmanian	Eddystone Point; East Flinders
Mar 2004		Tasmanian	Eddystone Point; East Flinders
Nov 2004		Tasmanian	Eddystone Point; East Flinders
Mar 2005		Tasmanian	Banks Strait; East Flinders

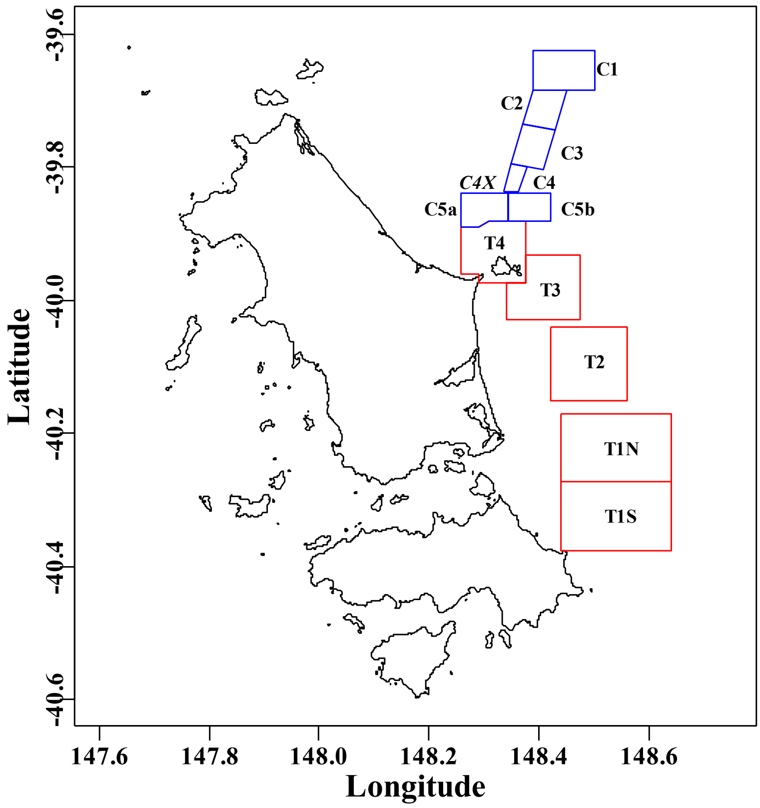

Figure 6.2. The strata labels used in the surveys from 2001 onwards. The original stratum T1 was divided into a northern and southern part to reflect two beds of scallops found there.

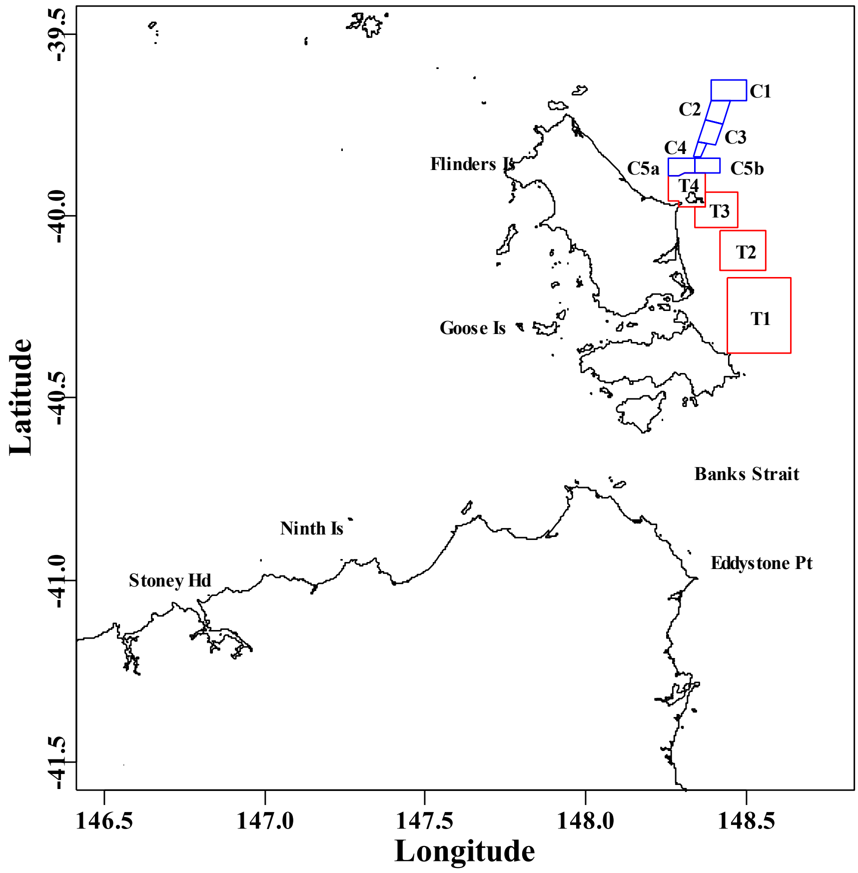

Figure 6.3. Smaller scale map of North East Tasmania with Flinders Island and the Central Bass Strait scallop grounds with some of the place names and strata labels discussed in the text.

Table 6.2. Transcription of observed shell heights given by Young *et al*. (1989). The shell lengths were calculated using the relationship obtained from the morphometric data discussed in Chapter 6: Length = 1.18988 * Height – 4.16963. For locations see Figure 6.3.

Location	1 year + Height	1 year + Length	2 year + Height	2 year + Length
Port Philip Bay	50-70	55-79	71-87	80-99
Lakes Entrance	45-65	49-73	64-80	78-91
Goose Island	34-51	36-56	52-70	57-79
Banks Strait	40-62	43-69	65-83	73-94
Ninth Island	39-57	42-63	60-80	67-91
Stoney Head	30-46	31-50	50-70	55-79

6.3 Results

6.3.1 Findings from the Sequence of Surveys

A total of 15 areas or strata were sampled during all surveys conducted within Tasmanian and Commonwealth waters between June 2000 and March 2005 (Table 6.3).

Early surveys: 2000 / 2001

The main objective of the June 2000 survey was to survey remaining scallop stocks after the fishery had been shut for the 1999 season (Commonwealth only). The survey of the area to the north of Babel Island found only a single scallop bed that extended across the jurisdictional border between Commonwealth (C5a) and Tasmanian (T4) waters (Figure 6.1). This bed contained a single modal group of scallops centred around 96.1 mm shell length (Figure 6.4). Elsewhere in Commonwealth waters, only 11 individual scallops were found in the 110 dredge shots conducted (Figure 6.1). Although no formal survey was conducted within the remaining strata of the Tasmanian fishery, industry feedback suggested that very few legal sized scallops remained in the Tasmanian fishery east of Flinders Island (pers. comm. Hilary Revill).

The major objective of the 2001 TAFI survey was to investigate mortality of scallops larger than 80 mm shell length. There had been repeated claims by various industry members that scallops larger than 80 mm suffered massive mortalities and, therefore, prohibiting the fishing of such beds represented a significant potential cost to the industry. As such, the 2001 survey was confined to the known bed in C5a (known to industry and fishery managers as Area X), which was surveyed in 2000, with no observations in Tasmanian waters during the 2001 survey. The survey in C5a discovered a previously undiscovered small size class centred on 51.4 mm (Figure 6.4). The spatial extent of this settlement was unknown because the June 2001 survey was limited to C5a. Most importantly, the cohort identified during 2000 (now at least 4 years old and centred around 100 mm) had not died during the 12 months since the 2000 survey.

An additional Industry survey conducted in what would become strata C4 and C3 (an area spatially separate to C5a) found two modal groups of scallops, one at 62 mm shell length and the other at 81.25 mm (Figure 6.4). These results provided evidence that the settlement of 1+ animals observed in C5a during the June survey extended at least into C3. The modal group at 81.25 mm suggested there had been a settlement sometime in 1998, but in subsequent surveys no sign of this mode was found again.

In March 2002, a survey was conducted within the five Commonwealth strata (Figure 6.2), and in Tasmanian waters east of Flinders / south of Babel Island (Figure 6.2), Banks Strait and the West Coast of Flinders (Figure 6.3). In all strata of the Commonwealth there was a distinct 2+ cohort of approximately 80 mm shell length (Figure 6.5; Table 6.4). In Stratum C1 there was evidence of 0+ and 1+ scallops, with 1+ scallops also appearing at relatively low densities in strata C2, C3, and C4 (Figure 6.5; Table 6.4). Stratum C5a, which contained the remaining scallop bed found in 2000, exhibited evidence of larger scallops that could have been 3+, 4+ and older, but no 1+ scallops (Figure 6.5; Table 6.4).

Table 6.3. Sequence of surveys providing data on size frequency in each stratum since June 2000. Strata beginning with C relate to Commonwealth waters, and T relate to Tasmanian waters. CX4 is the large and dense scallop bed identified in Commonwealth waters in March 2004. Strata labels as in Figures 6.2 and 6.3. The October 2001 survey was conducted by Industry with advice from the ScallopRAG (Haddon, 2001), all the other surveys were conducted by the TAFI scallop team (Table 6.1).

Stratum	June 2000	June 2001	Oct 2001	Mar 2002	Mar 2003	Nov 2003	Mar 2004	Nov 2004	Mar 2005
C1	X			X	X	X	X	X	X
C2	X			X	X	X	X	X	X
C3	X		X	X	X	X	X		
C4	X		X	X	X		X	X	X
C5a	X	X		X	X	X	X	X	X
C5b	X			X	X	X	X	X	X
C4X	X						X	X	X
T4	X			X	X	X	X	X	X
T3				X	X	X	X	X	X
T2				X	X	X	X	X	X
T1N				X	X	X	X	X	X
T1S				X	X	X	X	X	X
West Flinders				X					
Banks Strait				X					X
Eddystone						X	X	X	

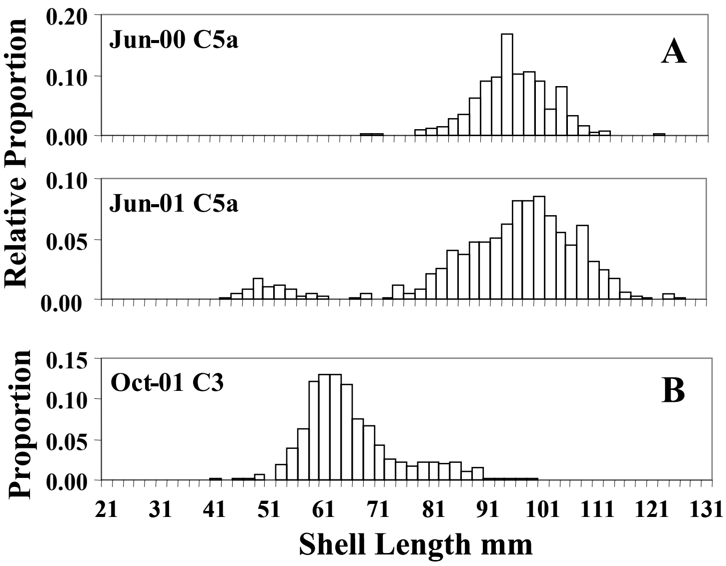

Figure 6.4. Length frequency of scallops from the surveys in (A) stratum C5a for 2000 and 2001 and (B) in stratum C3 in 2001, with the dates and strata surveyed.

2002 survey

In the Tasmanian strata, T1 to T3 all exhibited a single cohort centred at approximately 75 mm shell length (2+) with only traces of 1+ animals in stratum T1 (Figure 6.6; Table 6.4). Stratum T4, which also contained remnants of the bed found in 2000, was found to contain very few scallops in and around 75 mm, but had large numbers of scallops greater than 90 mm shell length (Figure 6.6; Table 6.4). Banks Strait contained scallops covering a range of sizes, from 30 mm (0+) to 115 mm (>4+) (Figure 6.7). The main modal group centred around 95 mm. In the survey area to the West of Flinders Island, the main modal group centred around 65 to 80 mm (Figure 6.7).

2003 survey

The March 2003 survey covered the Commonwealth strata, including stratum C5b for the first time (Figure 6.2), and the east coast Flinders strata (Figure 6.2). Results indicated signs of recruitment (0+ and 1+ scallops) in Strata C4, C5a, and T4, but only traces in other strata (Figure 6.5 and 6.6; Table 6.4). In C5b, there were mostly larger scallops 3+ and greater in age, though there were traces of smaller, possibly 1+ animals (Figure 6.7).

2004 survey

In March 2004, all Commonwealth strata were surveyed, along with east Flinders and Eddystone Point. The survey found far fewer scallops in strata C1 – C3 and T1S, following commercial fishing, but the beds were not fully exhausted (Figure 6.5). There was almost no sign of recruitment during the survey, although there were some 2+ animals observed in T1S_04 and T1N_04 (Figure 6.6). In Tasmanian strata, growth continued slowly and the potential discard rate of undersized scallops was greater than 20% in all strata east of Flinders Island. In the Commonwealth, the average scallop numbers per dredge were down to one third those observed in 2003 but there were indications of some 2+ scallops in C2_04 (although 1+ scallops had not been visible in C2_03). This suggests that the assumption that fishing destroys all undersized scallops (and sized scallops) is not always true.

An important discovery in the March 2004 survey was scallop bed C4X just to the west of C4. This was an extremely dense bed of scallops, the first of such density observed in Commonwealth-managed waters. Given the size of the scallops observed (Figure 6.7), combined with their density (which was akin to that in Tasmanian waters), the scallops were assessed as being a 3+ cohort.

2005 survey

The March 2005 survey covered all Commonwealth strata except C3, as well as the Tasmanian strata east of Flinders Island, and areas of Banks Strait. Apart from the remnants of the larger scallop cohorts previously present there were only slight signs of recruitment (small numbers of 0+ scallops), which were observed in strata C5a, C5b, and further south in T1S (Figures 6.5 and 6.6).

6.3.2 Recruitment Events: Overview

An extensive recruitment event, which incorporated all surveyed strata except C4X, occurred around November 1999 (Table 6.4). Relatively extensive recruitment was believed to have occurred in 2000 and 2001 within both the Commonwealth and Tasmanian fisheries. In particular, during 2000, recruitment/settlement was exceptionally abundant in C4X. Observed successful settlement and recruitment was limited to small, isolated areas during 2002, 2003 and 2004 (Table 6.4), however, there were anecdotal reports of new recruits in other areas, but as these were unsubstantiated they will not be discussed in detail.

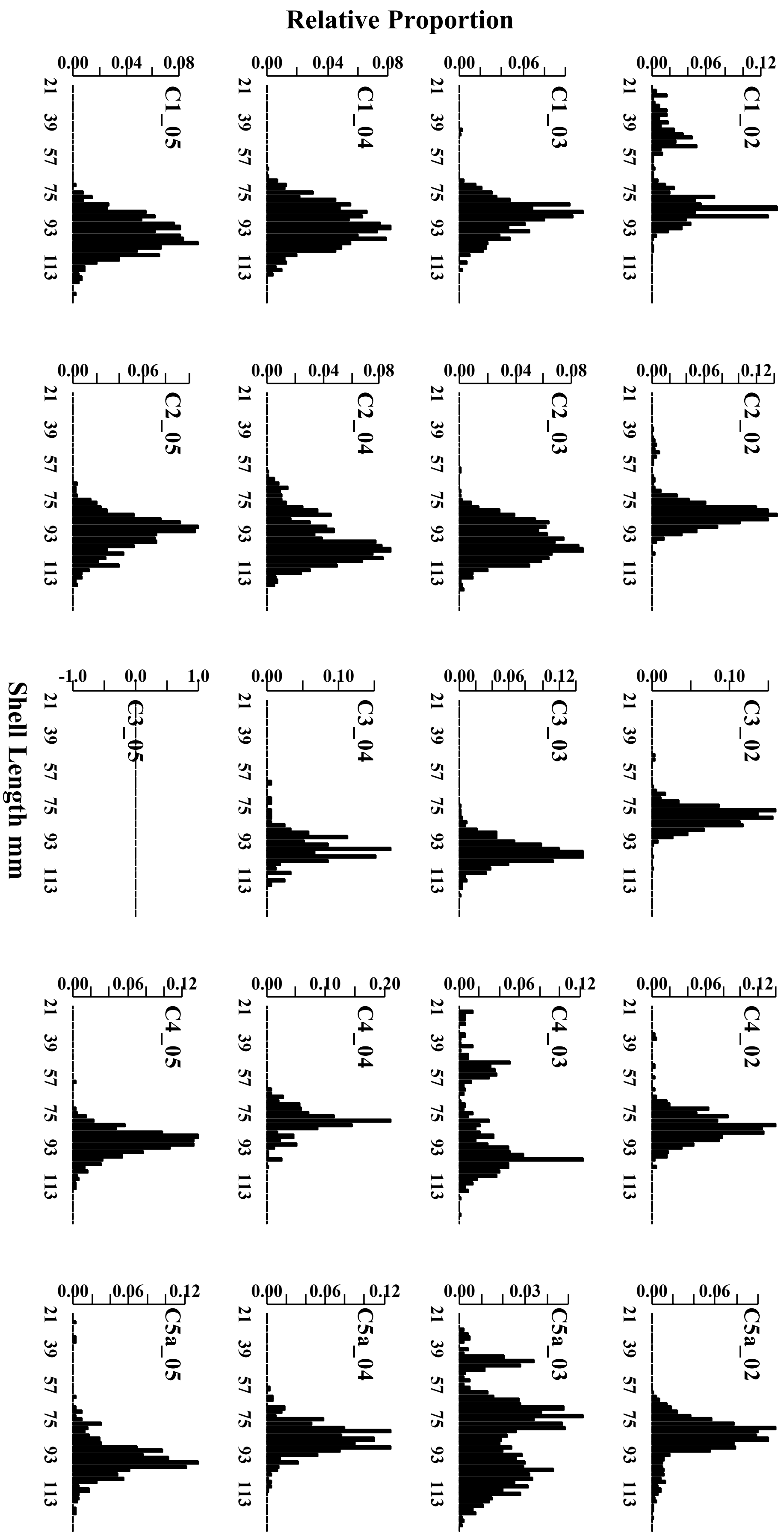

Figure 6.5. Length frequency histograms for the five Commonwealth strata in four of the March surveys. No samples were taken in C3_05 because after it was fished in both 2003 and 2004 numbers of scallops were expected to be extremely low.

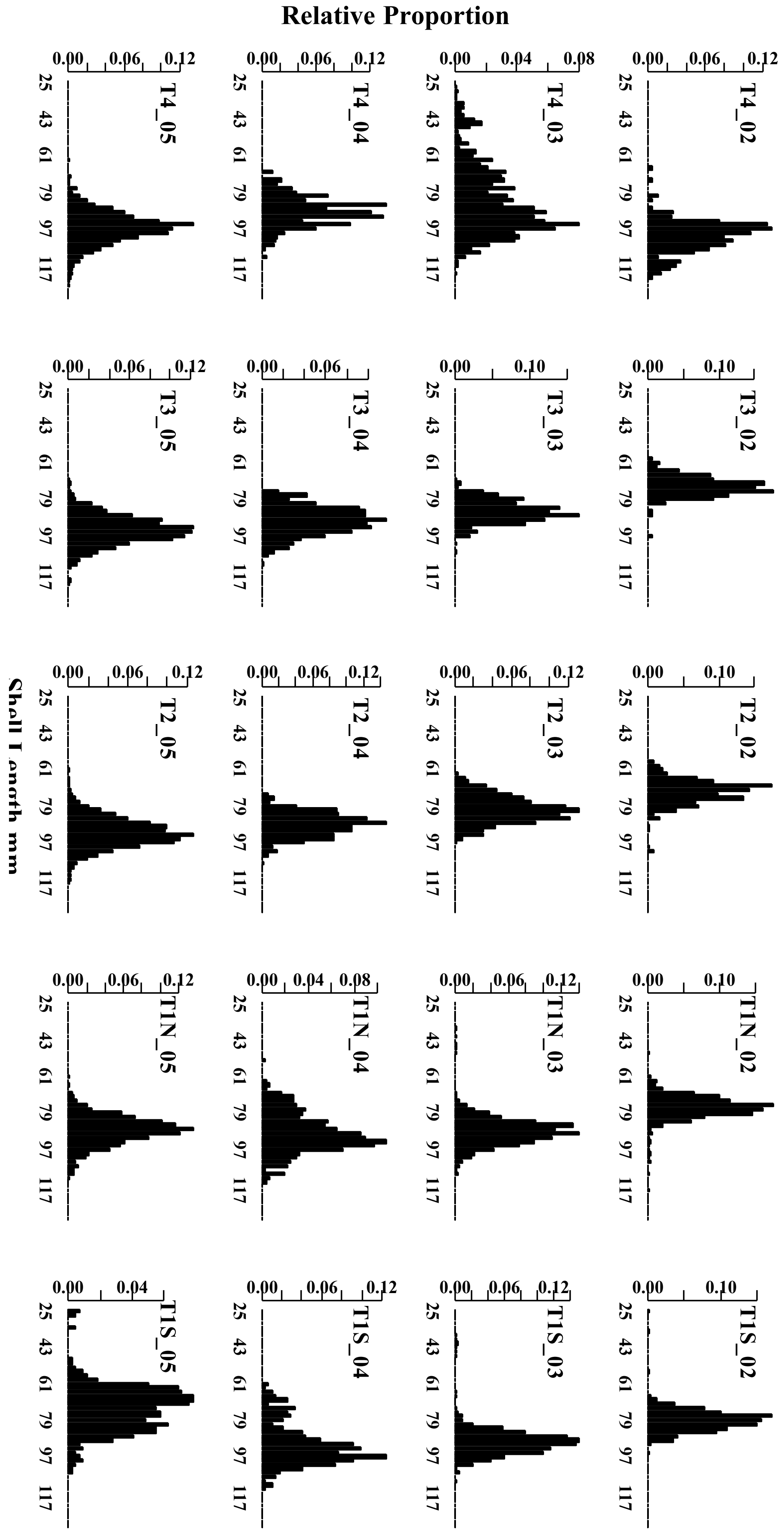

Figure 6.6. Length frequency histograms for four of the four Tasmanian strata in four of the March surveys.

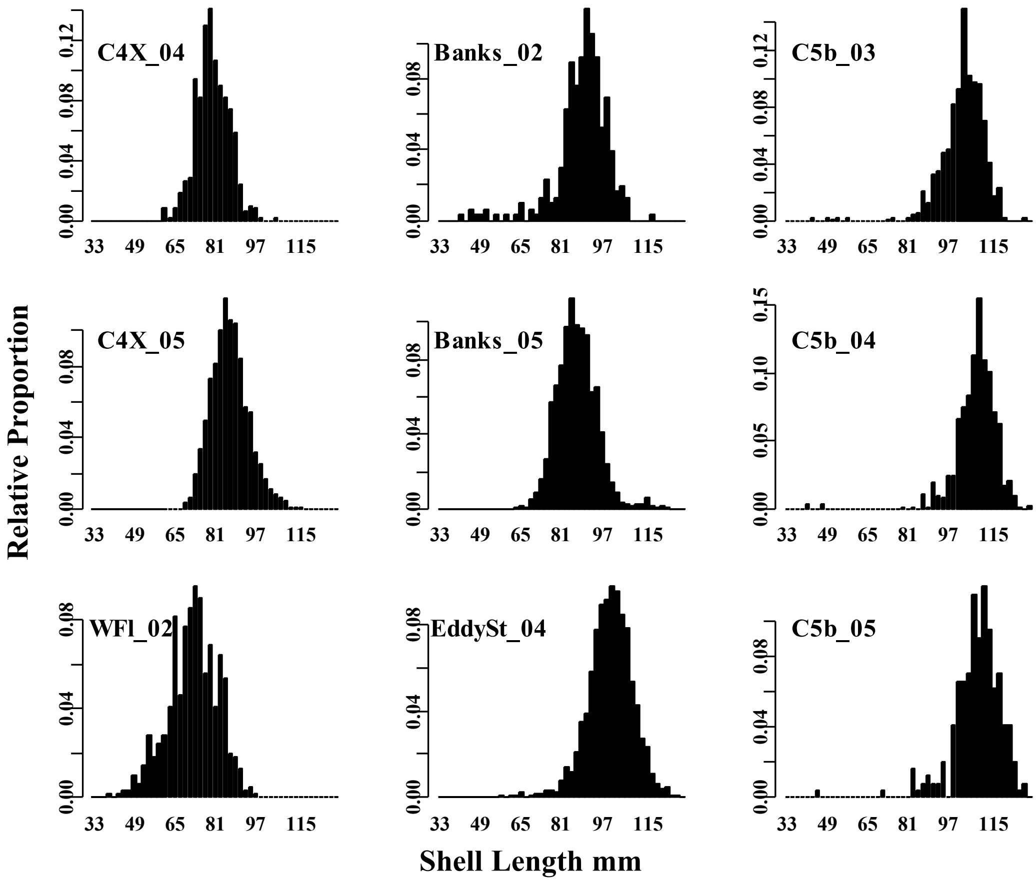

Figure 6.7. The length frequency distributions of commercial scallops taken from Strata that were visited less frequently than elsewhere. WFl relates to Western Flinders, EddySt relates to Eddystone, and Banks relates to Banks Strait.

Table 6.4. Observed age classes in each annual survey for the main strata (upper section) with the implied period of settlement/recruitment for each cohort (lower section). Not all inferred cohorts are visible in the sampling at the time; for example, the 2+ scallops visible in C3_04 (Figure 6.5) are not visible in C3_03 as 1+ or as 0+ in C3_02, but they imply some settlement in C3_01. The recruitment events are assumed to lag to the November before from 0+ animals. The ns relate to not-surveyed.

Stratum	Jun-00	Jun-01	Mar-02	Mar-03	Mar-04	Mar-05
C1			1+, 2+	2+,3+	3+, 4+	4+, 5+
C2			1+, 2+	1+, 2+,3+	2+, 3+, 4+	3+, 4+, 5+
C3			1+, 2+	2+, 3+	2+, 4+	3+, 5+
C4			1+, 2+	1+, 2+, 3+	2+, 3+, 4+	3+, 4+, 5+
C5a	<1999	1+, ??	1+, 2+	0+, 1+, 2+, 3+, 4+	2+, 3+, 4+	0+, 3+, 4+, 5+
C5b				1+, 3+, 4+	0+, 2+, ?	0+, 2+, 3+, ?
C4X					3+	4+
T4	<1999		1+,?	1+, 2+, 3+	2+, 3+, 4+	3+,4+, ?
T3	ns		2+	3+	4+	5+
T2	ns		2+	3+	4+	5+
T1N	ns		2+	1+, 3+	2+, 4+	3+, 5+
T1S	ns		2+	1+, 3+	2+, 4+	0+, 2+, 3+, 4+
West Flinders	ns		1+,2+,?			
Banks Strait	ns		0+,1+,2+,?			2+, 3+, ?
Stratum	**Nov-99**	**Nov-00**	**Nov-01**	**Nov-02**	**Nov-03**	**Nov-04**
C1	X	X				
C2	X	X	X			
C3	X	X	X			
C4	X	X	X			
C5a	X	X	X	X		X
C5b	X		X		X	X
C4X		X				
T4	X	X	X			
T3	X					
T2	X					
T1N	X		X			
T1S	X		X			X
West Flinders	X	X				
Banks Strait	X	X	X	X		

6.4 Discussion

Several important inferences can be made from the broad results presented in this chapter.

6.4.1 Scallops do not Die at 80 mm Shell Length

A commonly expressed belief among industry, particularly before the earlier surveys were completed, was that scallops (scallop beds) will all die-off once they have reached 80 mm shell diameter; they should thus be harvested as soon as the scallops reach that length. Results presented in this chapter clearly show that scallops and scallop beds can grow much larger than 80 mm, and that survival from the age of 3+ to 4+ is high, at least in the sample areas, when beds remain unfished. This observation is consistent with must earlier observations made by Fairbridge (1953) who recorded an appreciable number of cohorts in the fished population of the Derwent estuary from about 1920 onwards.

The initial concept that scallops will die at 80 mm may have stemmed from a bed of scallops located near Deal Island during the early 1990's This bed was closed to fishing, with scallops being approximately 80 mm in shell length, however, 12 months later numbers of scallops in this bed had become negligible. A similar situation occurred more recently with two scallop beds to the east of Flinders Island. In March 2005, these scallops did not meet the trashing rate requirements for opening, as greater than 20% of scallops were less than 90 mm. Within three months one bed had undergone a major die-off, while the other bed was showing signs of dying off. Such occurrences seem to be one-off events and may be triggered by a number of environmental, pathological, biological or chemical parameters.

Regardless, many scallop beds within the Commonwealth and Tasmanian fisheries have been observed to reach sizes much greater than 80 mm, and survived for more than 3 years, and as such have produced more marketable scallops.

6.4.2 Broader Scale Settlement of Scallops can Occur

The results of surveys have shown that scallop settlement and subsequent recruitment can occur over both broad and fine scales. There were instances of settlement over relatively large areas (the settlement to the east of Flinders Island) while other instances indicate small spatial settlement (C5a in 2005).

Dredge selectivity

Owing to the limited selectivity of the gear for small scallops, small amounts of younger animals were sometimes indicative of large amounts of recruitment (*e.g.* C2_02 – C2_03 in Figure 6.5 and T1S_03 – T1S_03 in Figure 6.6). On the other hand, small amounts in 1+ sizes sometimes were not seen again (*e.g.* C3_02 – C3_03 in Figure 6.5 and C5b_03 – C5b_04 in Figure 6.7).

6.4.3 Commercial Fishing does Not Kill all Scallops

Post commercial fishing surveys conducted within both the Commonwealth and Tasmanian fisheries have shown that scallop dredging is not necessarily detrimental to all scallops living on the bed. For example, surveys conducted at Eddystone Point post commercial fishing (November 2004) found relatively high abundances of residual scallops following commercial fishing operations.

7. VARIABLE GROWTH OF SCALLOPS.

7.1 Introduction

Commercial scallops have been fished in Bass Strait and around Tasmania since the beginning of the 20th century. During most of that time one of the standard management regulations has been a legal minimum size (LMS). In Tasmania, size restrictions were first introduced in 1925 when the LMS for *Pecten fumatus* (then known as *P. meridionalis* in Tasmanian waters) was 88.9 mm (3.5 inches) shell length (Figure 7.1). In 1935, the LMS was increased to 88.9 cm (3.5 inches) shell height (Fairbridge, 1953). Sometime before the mid 1980s the LMS was set at 90 mm shell length. However, in 1987, with the scallop stock collapsing and compliance breaches related to size limits common, the LMS of commercial scallops was reduced to 80 mm shell length (Young *et al*., 1989). Since its introduction, the LMS has been set with respect to meeting a variety of criteria, including apparent market preferences, availability of stock, and even to allow scallops to undergo “two major spawnings” (McLoughlin, 1994; Zacharin, 1994) The suggested biological criterion of two major spawnings relates to fecundity, and required scallops to be at least 3+ years old, which in Bass Strait meant that on average they have to be greater than 80 mm shell height (McLoughlin, 1994); although slower growth in dense beds means that smaller animals may be 3+ and older so a simple size limit may fail to capture the underlying dynamics of spawning and maturity. It appears that during the 1980’s there was some confusion over shell height and shell length, because the same argument of “two major spawnings” was used to defend a LMS of 80 mm shell length (Zacharin, 1994), despite a shell height of 80 mm being equivalent to a shell length of approximately 90 mm.

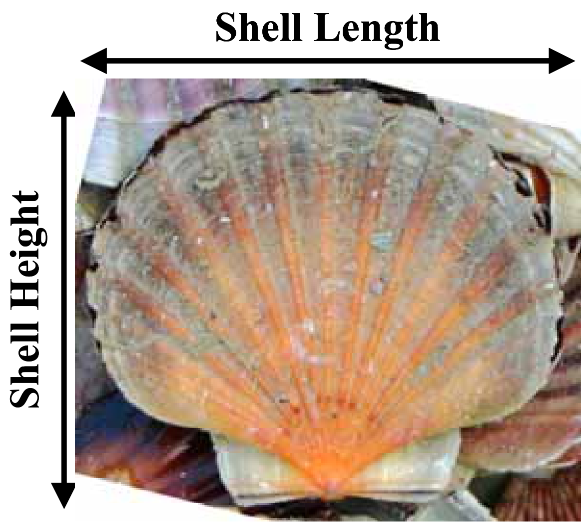

Figure 7.1. Image of a typical commercial scallop *P. fumatus* shell, looking at the right shell, depicting the different measurements that have been used when setting minimum legal sizes. The shell length is the same as the maximum diameter, and is always greater than the shell height.

The changes in LMS that have occurred suggest that characterizing shell growth in the commercial scallop would permit greater confidence in the use of relationships that exist between the various measures used. In addition, such a study would permit an examination of the potential for variation in such measures from spatially different parts of the fishery. This concept is related to variation in the physical development of spatially separate scallop beds, which has been documented for other pectinids (e.g. *Pecten maximus*, Mason, 1957, *Chlamys opercularis*, Taylor & Venn, 1978).

Observations made during the series of surveys conducted in Commonwealth and Tasmanian waters since 2000 generated an expectation that both the rate of scallop growth and the growth pattern (shape and character of the shell) of *Pecten fumatus* can differ between scallop beds. For example, during surveys in stratum T3 (Figure 7.2) scallops were found to be extremely fragile so that during survey dredging a very high proportion of the scallops caught had smashed shells, something that did not happen anywhere else in the fishery. Other areas, especially in parts of the Commonwealth appeared to have relatively deeper shells than elsewhere.

The objectives of this chapter are to:

1. Characterize some of the morphometric variation exhibited by *Pecten fumatus* taken from different areas of Commonwealth and Tasmanian-managed waters.
2. Discuss implications of site-specific growth variation for effective management of scallop fisheries.

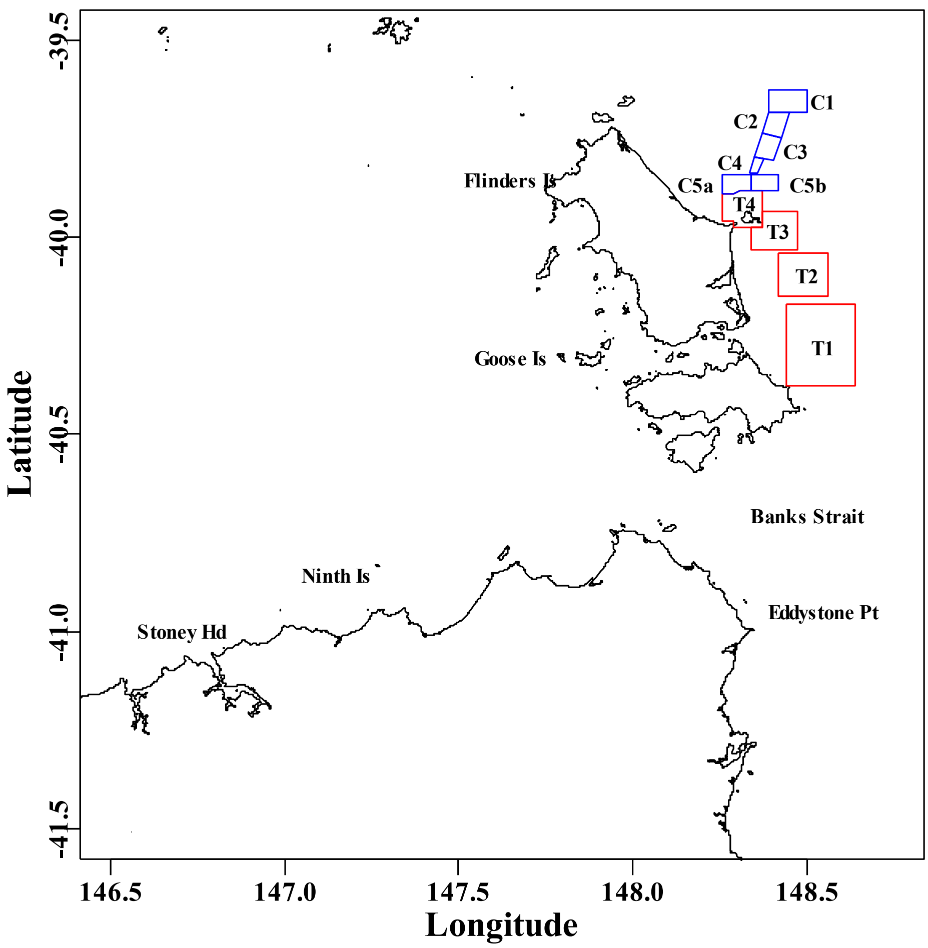

Figure 7.2. Map of North East Tasmania with Flinders Island and the Central Bass Strait scallop grounds with some of the place names and strata labels discussed in the text.

7.2 Methods

7.2.1 General Methods

In March 2004, samples of approximately 100 scallops were obtained from dredge samples from each of six locations around the east coast of Flinders Island and off Eddystone Point (Figure 7.2; Figure 7.3). All specimens were frozen and returned whole to the laboratory where detailed measurements of shell length, height, and depth were made to the nearest 0.5 mm. Shell height and length are defined in Figure 7.1, while shell depth relates to maximum distance between the outside extremities of the flat and curved valves. In addition, the drained meat weight and the blotted dry shell weight of each valve were measured to the nearest 0.1 gram.

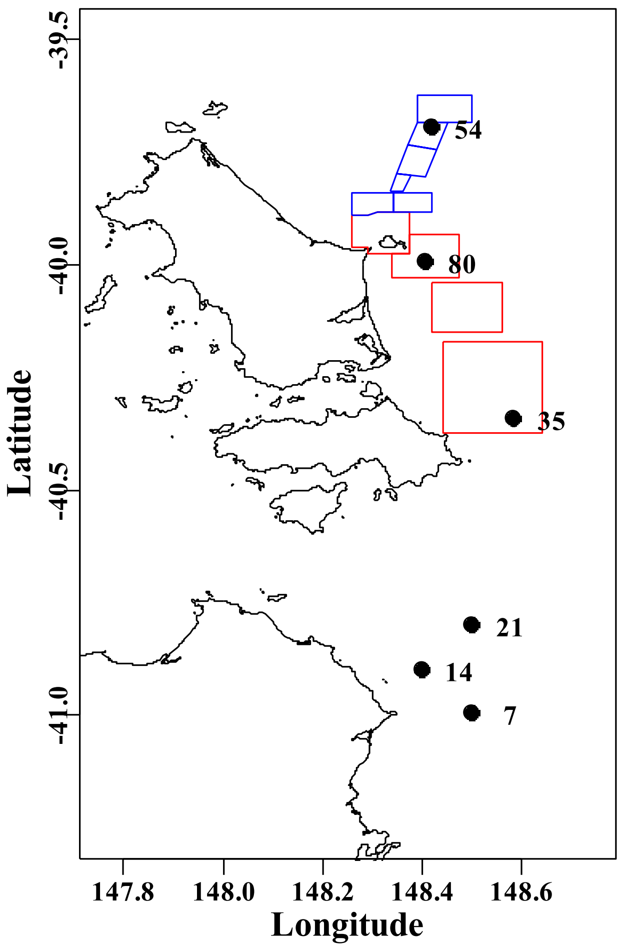

Figure 7.3. Location map for the six scallop samples taken in March 2004 for morphometric analysis of shell characteristics. The station numbers for the March 2004 survey are given next to the large dots denoting the location. They include a sample from Commonwealth waters (shot 54), two shots in Tasmanian strata (shots 35 and 80), and three shots around Eddystone Point. Station 7 was in 80 m of water (Table 7.1).

7.2.2 Statistical Analyses

Bivariate plots (*e.g.* Figure 7.4) were used to identify and characterize the relationships between the five variables measured from the shells (Shell length, height, depth, upper (right hand valve) shell weight and lower (left hand valve) shell weight).

The relationships between the different morphological measures were described using simple linear regression. In the cases where shell weights were dependant on other shell dimensions, natural logarithmic transformations were first required to linearize the power relationships. Analysis of Covariance (ANCOVA) was used to compare the regression lines produced for the various relationships examined. In these analyses, differences between the intercepts of the regression lines were only explored if no significant differences were found between the gradients.

Top (Right) Valve Weight and Lower (Left) Valve Weight

To determine whether the gradients differ between the regressions two linear models were compared, one included an interaction term between the shot number and the independent variable (in this case the bottom valve weight), and a second model without the interaction term. If a comparison of these two models indicates no significant difference then the differences between the regression gradients for each shot do not contribute significantly to the overall relationship and the gradients can be judged to be not significantly different. The two models compared were:

Model 1: Top Valve = Bottom Valve + Shot + Shot*Bottom Valve and

Model 2: Top Valve = Bottom Valve + Shot

Height predicted by Length

To determine if there were spatial differences in the relative shell growth, a comparison was made of how well the shell length was able to predict the shell height and depth in scallops from the different sampling stations. Once again, ANCOVA was used to compare the array of regression lines produced in each case.

For Height as predicted by Length the models compared were:

Model 1: Height = Length + Shot + Shot*Length and

Model 2: Height = Length + Shot

Shell Depth predicted by Length

Some areas were believed to have relatively deeper shells for a given length so to test for this difference the ability to predict shell depth from shell length was considered for each sampled site:

The two models were compared within an ANCOVA and these were:

Model 1: Depth = Length + Shot + Shot*Length and

Model 2: Depth = Length + Shot.

Scallop Shell Weight vs. Shell Length

The shells in Tasmanian stratum T3 were unusually fragile so the relative weight for a given sized scallop was explored to see if the fragility could be explained mostly in terms of shell thickness (weight). As the relationship between Length and total weight appeared to be a power function then to apply an ANCOVA it is necessary to use natural logarithm transformed data. The models compared were therefore:

Model 1: Log(TotalWt) = Log(Length) + Shot + Shot*Log(Length) and

Model 2: Log(TotalWt) = Log(Length) + Shot

Meat Weight as Predicted by Shell Length

An important variable concerning the relative condition of scallops relates directly to the meat weight. To determine how well shell length can be used to predict the meat weight a further ANCOVA was performed on the laboratory data from the field samples by comparing two linear models:

Model 1: log(MeatWt) = log(Length) + Shot + Shot*log(Length) and

Model 2: log(MeatWt) = log(Length) + Shot

7.3 Results

The bivariate plots indicate that the relationships between the Length, Height, and Depth appear to be linear, while those between the two valve weights and the shell dimensions appears to be best described by a power function (Figure 7.4). The relationship between the upper and lower shell valve weights also appears to be linear (Figure 7.4).

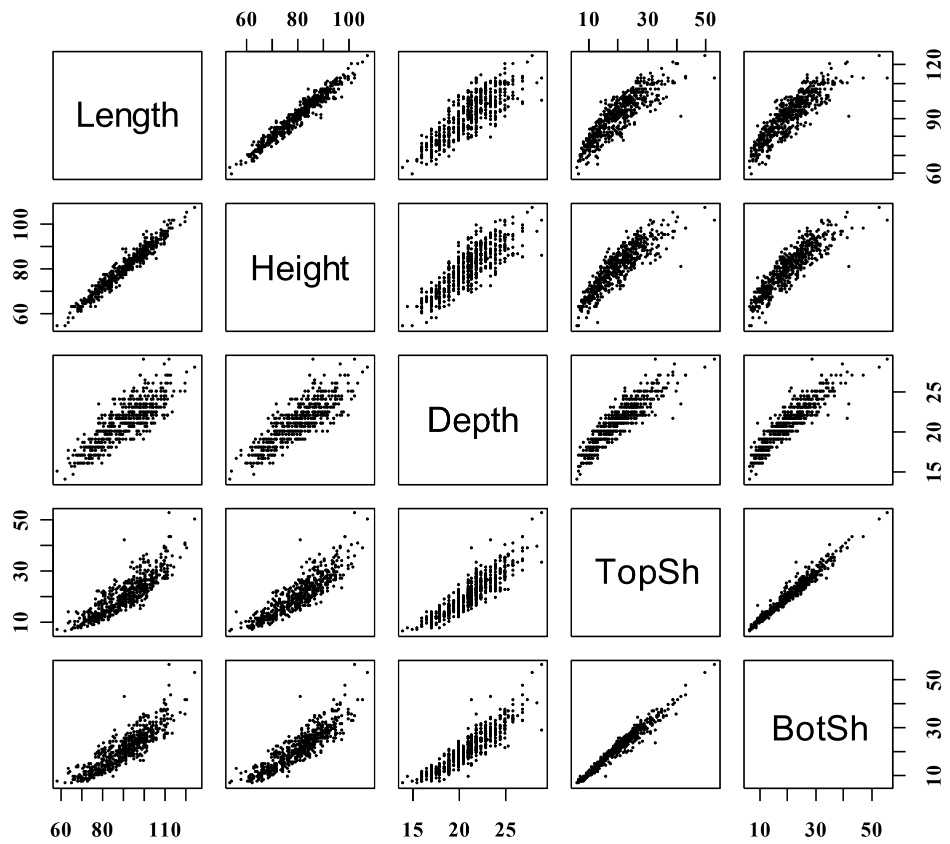

Figure 7.4. A scatterplot matrix of the continuous variables that were measured from the different scallop shells; all samples shown combined. TopSh and BotSh relate to the weight of the upper and lower shell valves in grams respectively.

7.3.1 Top (Right) Valve Weight vs. Lower (Left) Valve Weight

The flat upper shell valve weight (visible in Figure 7.1) was linearly related to the weight of the curved lower shell valve (Figure 7.5; Table 7.1). The ANCOVA comparison of the two models indicated that there was no significant difference between the models, which implies that the interaction terms between the gradients and shot location contributed little to the overall variance (i.e. the gradient of the regression lines were not significantly different) (Table 7.2). When comparing for differences in the intercepts for the model 2 analysis, the intercepts for shot 7 (found in 80 metres of water; Tasmanian waters) and shot 54 (34 meters depth Commonwealth waters; Figure 7.3; Table 7.1) were significantly different to all other sites (Table 7.3). The upper shell valves in stations 7 and 54 were relatively lighter than the lower shell valves from other stations.

Table 7.1. Characteristics of the six stations sampled for morphometric measurement with the intercepts and gradients for the regressions of top-shell weight onto the bottom shell weight. All of the regressions were significant.

Shot	Depth m	Longitude	Latitude	Intercept	Gradient
7	80	148.4665	-40.9963	-0.2223	1.0456
80	33	148.3937	-40.8982	1.2706	0.9094
14	55	148.4047	-39.7032	0.1299	0.9394
21	58	148.524	-40.7988	0.3237	0.965
54	34	148.4187	-39.695	0.3316	0.9595
35	31	148.5842	-40.3395	0.2623	0.9629

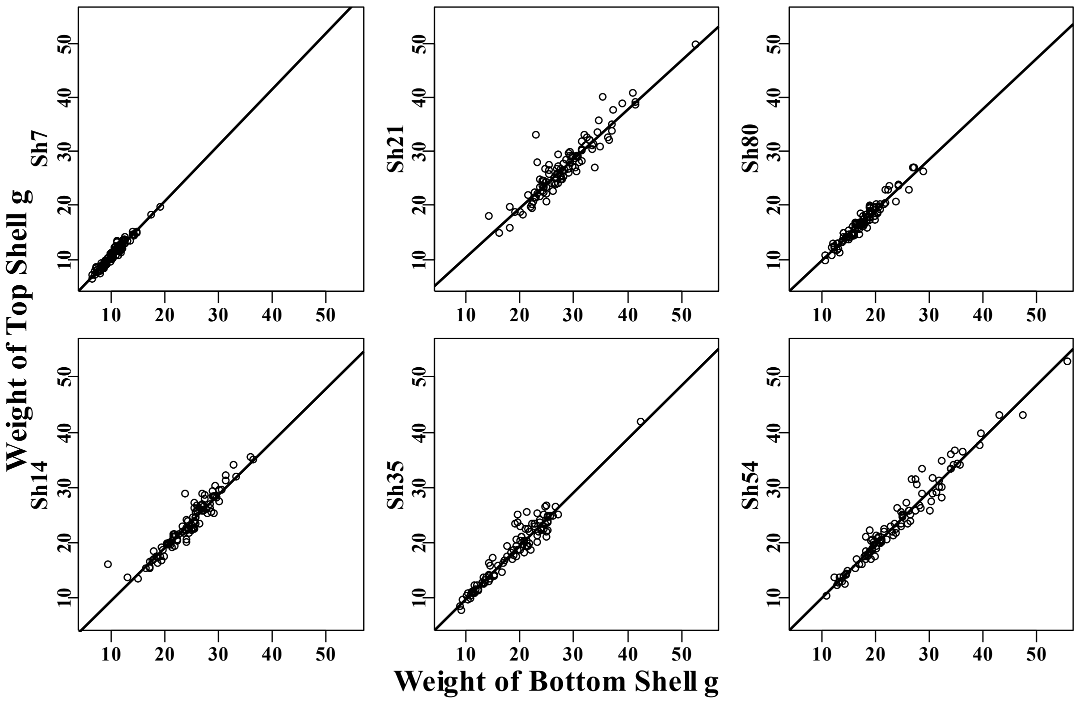

Figure 7.5. Plot of the weight of the upper or top shell relative to the weight of the lower or bottom shell. The regression relationships are listed in Table 7.1.

Table 7.2. Analysis of variance comparison of the two models. Res. Df is the residual degrees of freedom, RSS is the residual sum of squares, Df is difference in the degrees of freedom between the two models, SSQ is the difference in residual sum of squares between the models, F is the F-statistic and P is the probability of significance.

	Res.Df	RSS	Df	SSQ	F	P
Model 1	572	1293.51				
Model 2	577	1305.09	-5	-11.58	1.0244	0.4023

Table 7.3. Summary of the output from Model 2 (Top Shell = Bottom Shell + Shot). BotSh is the gradient multiplier on the bottom shell valve weight for all lines (highly significant). Intercept relates to shot 14, while the parameters for each of the other shots are added to the Intercept for shot 14 to obtain the intercept for all the other shots.

Parameter	Estimate	Std. Error	t-value	P	
Intercept	0.04323	0.32892	0.131	0.89548	
ShotSh21	0.07728	0.21926	0.352	0.72461	
ShotSh35	0.43901	0.22417	1.958	0.05067	
ShotSh54	0.52918	0.21323	2.482	0.01336	*
ShotSh7	0.75813	0.27199	2.787	0.00549	**
ShotSh80	-0.0996	0.23099	-0.431	0.66651	
BotSh	0.9499	0.01201	79.113	<2.00E-16	***

7.3.2 Height Predicted by Length

The ANCOVA comparison between shell height and shell length found no significant differences between the two models ($F = 0.3932$, $P = 0.8536$), implying that the regression gradients were not significantly different. However, when considering the parameters in Model 2 it was clear that the intercept for Station 54 (from NE Flinders (Commonwealth managed waters)) was significantly different from all other sample locations (Table 7.4). Given the large positive intercept adjustment parameter for station 54 it appears that the shell height for a given shell length will be slightly larger in the sampled region within Commonwealth waters.

Table 7.4. Summary of the output from the Model Height = Length + Shot. Intercept relates to shot 14, the parameters for each of the other shots are added to the Intercept for shot 14 to obtain the intercept for all the other shots.

Parameter	Estimate	Std. Error	t-value	P		Pred.Hgt
Intercept	7.0426	1.0481	6.720	4.36E-11	***	79.0
Shot 21	0.0723	0.3034	0.238	0.812		79.1
Shot 35	0.3862	0.3253	1.187	0.236		79.4
Shot 54	1.2970	0.3204	4.047	5.88E-05	***	80.3
Shot 7	-0.2484	0.3840	-0.647	0.518		78.7
Shot 80	-0.3999	0.3154	-1.268	0.205		78.6
Length	0.7994	0.0104	77.180	<2.00E-16	***	79.0

7.3.3 Shell Depth Predicted by Length

The comparison of shell depth with shell length identified highly significant differences between the two models, implying that some of the gradients differed significantly between stations (Table 7.5; Figs. 7.6 & 7.7). Stations 35 and 54 were significantly different from all other sample locations, with station 54 having the deepest shell valves for any given length (Figs. 7.6 & 7.7). As such, scallop shells at station 54 were deeper, or roomier, for a given shell length than elsewhere, which might have implications for the size of the scallop meats for a given size scallop.

Table 7.5. Summary of the output from Depth = Length + Shot + Shot*Length,

Parameter	Estimate	Std. Error	t-value	P	
Intercept	6.9540	1.5330	4.536	7.00E-06	***
Length	0.1496	0.0154	9.697	<2.00E-16	***
ShotSh21	2.1090	2.1400	0.986	0.32479	
ShotSh35	-4.3830	1.8490	-2.370	1.81E-02	*
ShotSh54	-4.8810	1.7910	-2.725	0.00662	**
ShotSh7	-1.3370	2.2100	-0.605	0.54552	
ShotSh80	-0.0604	2.2050	-0.027	0.97817	
Length:ShotSh21	-1.09E-02	2.12E-02	-0.514	0.60775	
Length:ShotSh35	5.55E-02	1.94E-02	2.857	0.00444	**
Length:ShotSh54	7.81E-02	1.86E-02	4.196	3.15E-05	***
Length:ShotSh7	7.61E-03	2.58E-02	0.295	0.7682	
Length:ShotSh80	8.79E-05	2.32E-02	0.004	0.99698	

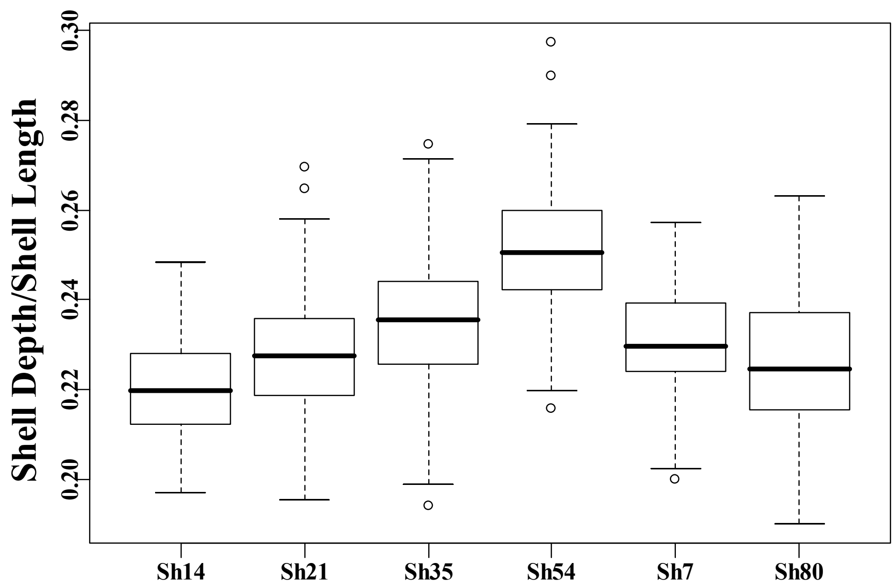

Figure 7.6. The ratio of shell depth against shell length for each shot.

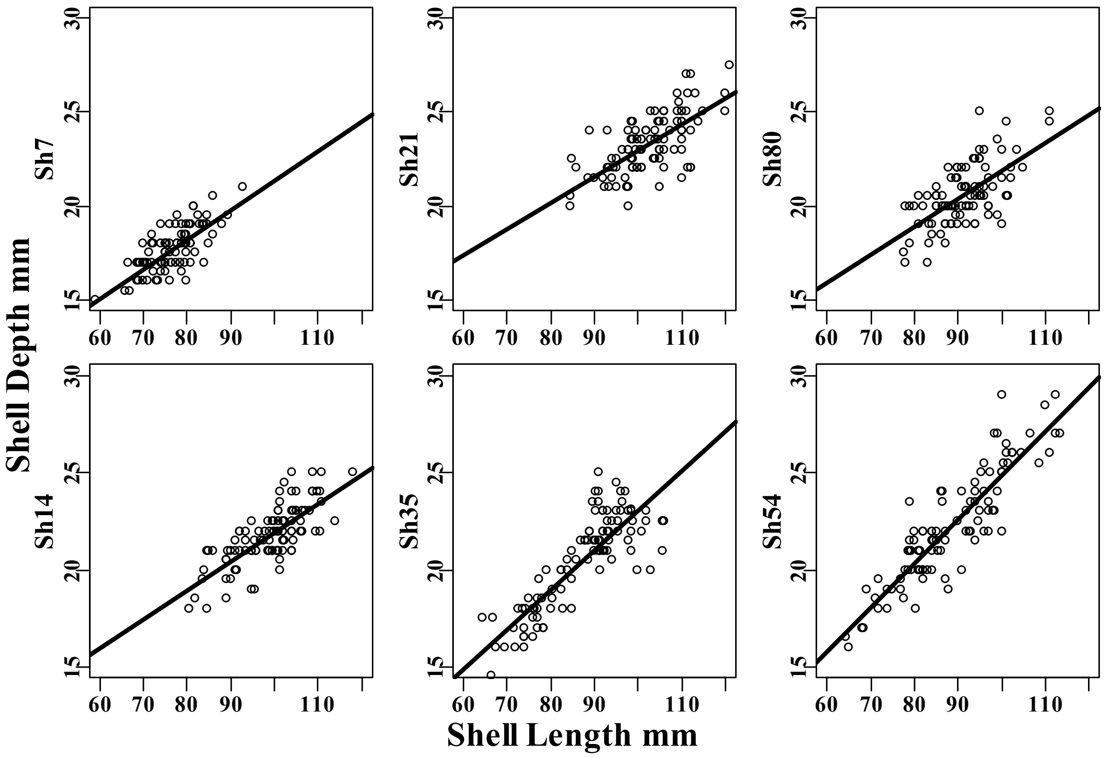

Figure 7.7. A comparison of the six regression lines from the six stations in the comparison of the relationship between shell depth and shell length. The similarity between stations 7, 14, 21, and 80 is clear, and the steeper gradient of station 35 is obvious with the steepest gradient being exhibited by station 54.

7.3.4 Scallop Shell Weight vs. Shell Length

The ANCOVA indicated there were no significant differences found between the gradients of the relationships for each station between total shell weight and shell length ($F = 1.1727$, $P = 0.3212$). When Model 2 was considered, however, significant differences were found between the intercepts of a number of the stations (Figure 7.8, Table 7.6).

Table 7.6. Summary of the output from Log(TotalWt) = Log(Length) + Shot, which indicated that the intercepts for Shots 14 and 35 are not significantly different but that all the others differ from Shot 14 (Figure 8.7 & Figure 8.8).

Parameter	Estimate	Std. Error	t-value	P	
Intercept	-6.9397	0.20615	-33.664	<2.00E-16	***
Shot 21	0.06854	0.01471	4.658	3.96E-06	***
Shot 35	0.02747	0.01573	1.746	0.0814	
Shot 54	0.25698	0.01552	16.558	<2.00E-16	***
Shot 7	-0.18747	0.01875	-9.996	<2.00E-16	***
Shot 80	-0.12386	0.0153	-8.094	3.43E-15	***
Log(Length)	2.34717	0.04483	52.359	<2.00E-16	***

Station 54 (in Commonwealth waters) was found to differ most strongly from the other stations (Figure 7.9). The implications are that the heaviest shell for a given length was found in Commonwealth waters while the lightest was found in the deep water site in Tasmania (station 7). Station 80 (in stratum T3, with the exceptionally fragile shells) was lighter than all the stations except station 7. However, the shells at station 7 were not fragile and the proportion of smashed shells obtained there while dredging remained low (less than 1%) while at station 80 in stratum T3 the proportion of smashed shells in 2003 was approximately 40% of all scallops. The fragility of the shells in stratum T3 was clearly not solely a function of weight of shell for a given size. Some other factor unrelated to simple morphometrics (maybe chemical composition, invasion of shell by parasites) is obviously causing abnormally frail shells.

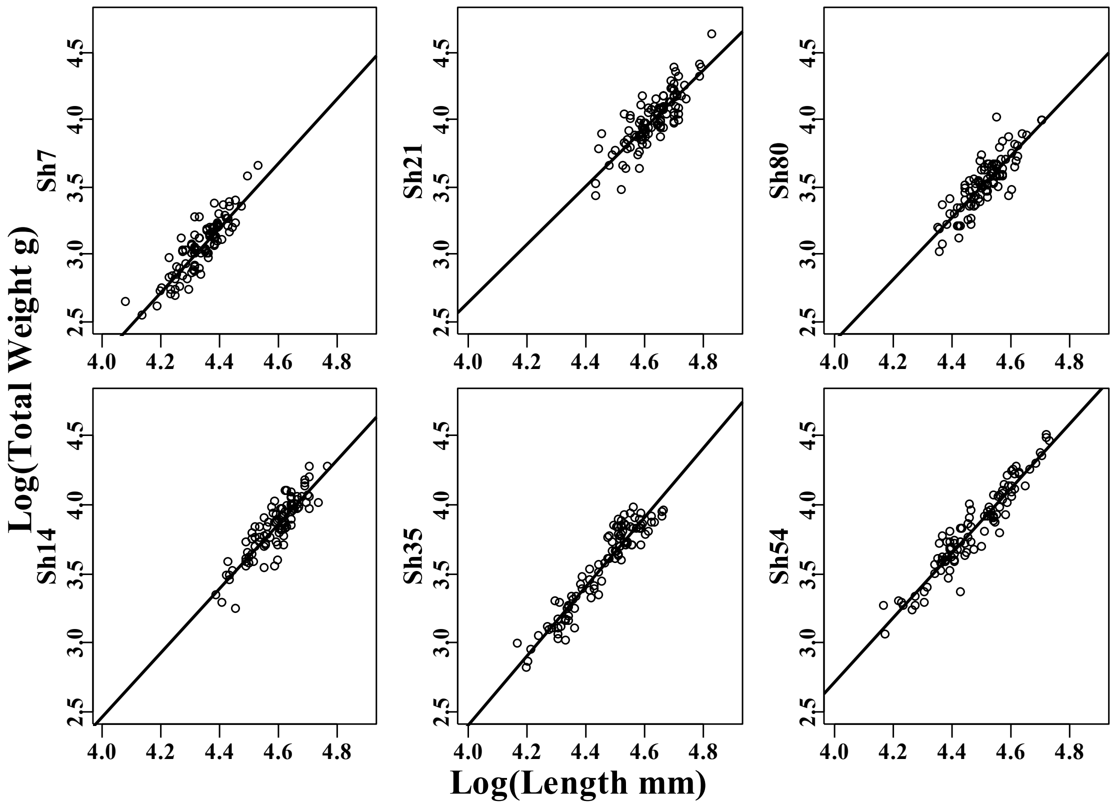

Figure 7.8. The individual regression lines between the log of total shell weight and shell length for each station. The gradients do not differ significantly between stations. Stations 14 and 35 do not differ significantly in terms of their intercepts but the intercepts of all the others do differ significantly.

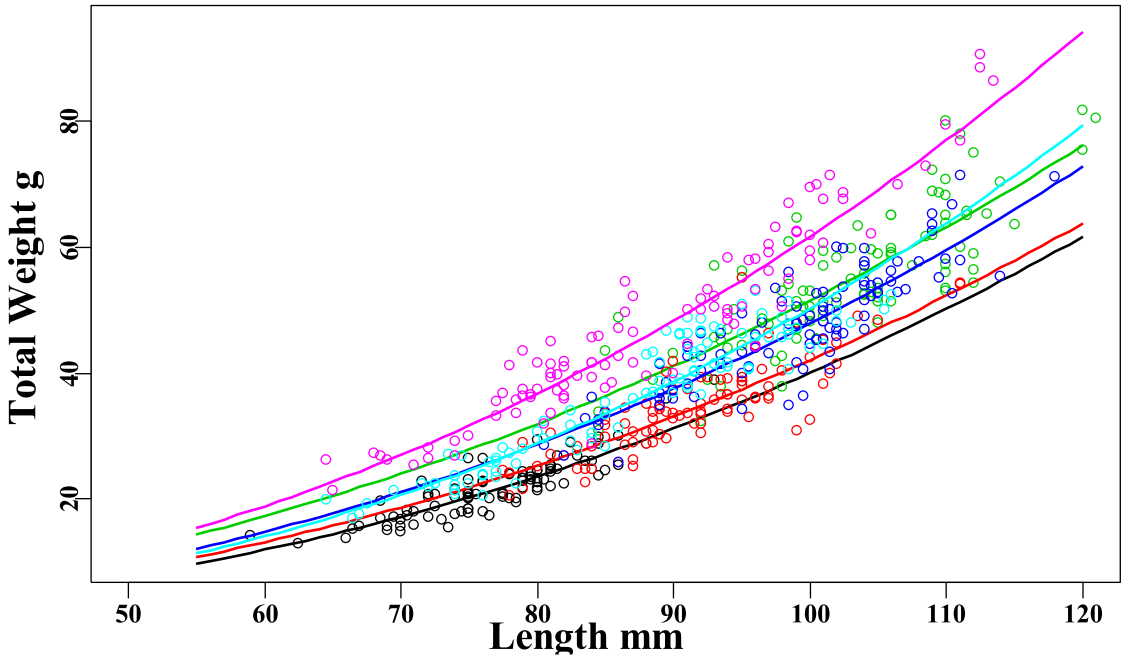

Figure 7.9. The total shell weight plotted against the shell length for each of the six stations. The ANCOVA indicates that the gradients of all six curves do not differ significantly. Starting at the lowest end of the curves the ordering of the stations is that Shot 7 is the lowest curve, followed by 80, then 35 and 14 (not significantly different), then shot 21 and finally shot 54.

7.3.5 Meat Weight as Predicted by Shell Length

The comparison of meat weight and shell length identified significant differences between the two models (F = 4.2184, and P = 0.00089), indicating that some of the gradients differed significantly from the base case gradient (for Shot 14). By considering the parameter estimates from Model 1 (Table 7.7) it can be seen that the gradient for station 7 has the least steepness of all stations while station 80 has the steepest relationship between shell length and meat weight (Figure 7.10; Figure 7.11).

Table 7.7. Summary of the output from Log(MeatWt) = Log(Length) + Shot + Shot*Log(Length),

Parameter	Estimate	Std.Error	t-value	P	
Intercept	-11.5809	1.1325	-10.226	<2e-16	***
Log(Length)	3.0918	0.2465	12.54	<2e-16	***
Shot 21	2.0523	1.5963	1.286	0.1991	
Shot 35	1.6666	1.3496	1.235	0.2174	
Shot 54	1.6384	1.3169	1.244	0.214	
Shot 7	3.697	1.5898	2.325	0.0204	*
Shot 80	-3.1294	1.6333	-1.916	0.0559	
Log(Length):Shot 21	-0.4314	0.3462	-1.246	0.2132	
Log(Length):Shot 35	-0.3758	0.2964	-1.268	0.2052	
Log(Length):Shot 54	-0.2941	0.2887	-1.019	0.3087	
Log(Length):Shot 7	-0.862	0.3563	-2.419	0.0159	*
Log(Length):Shot 80	0.697	0.3589	1.942	0.0527	

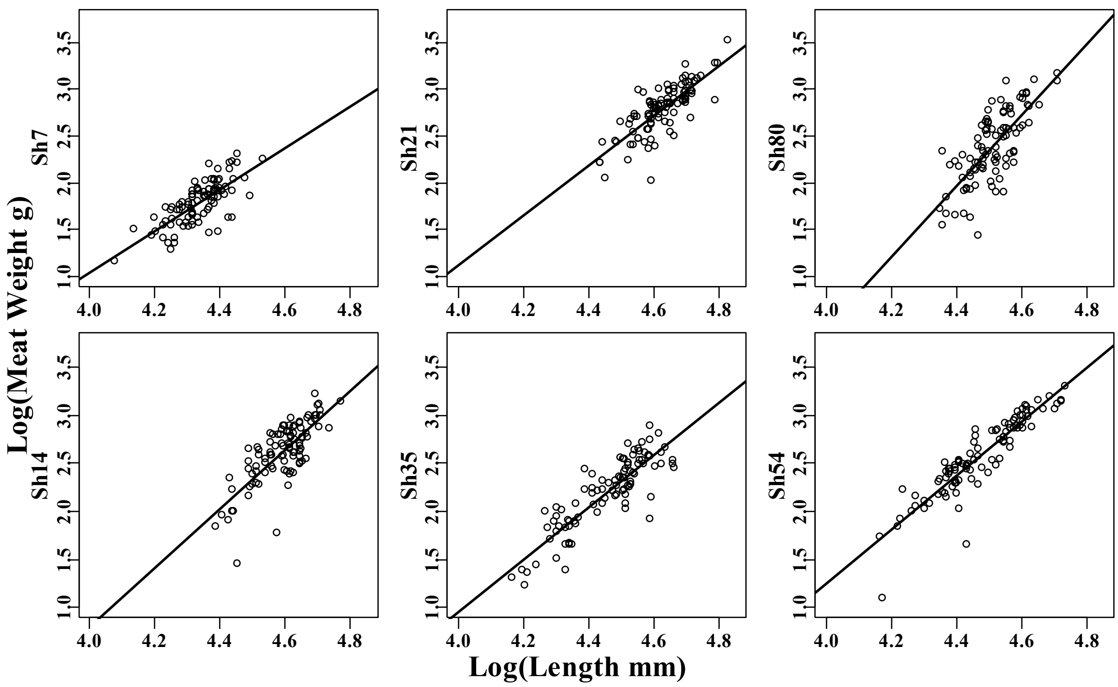

Figure 7.10. Separate regression lines for the six power relationships between meat weight and shell length for the six different stations. The gradient for station 7 is significantly less steep than that of other sample sites, while there is weak evidence that the gradient for station 80 is steeper than observed in other sites.

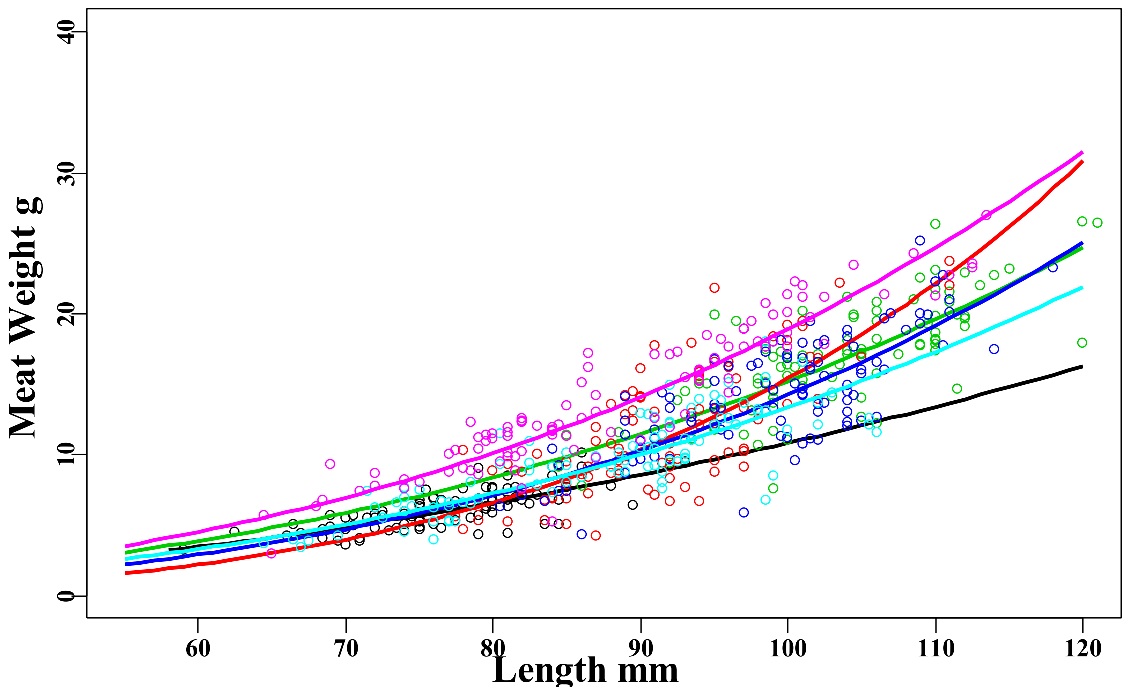

Figure 7.11. The meat weight plotted against the shell length for each of the six stations. The ANCOVA indicated that the gradient of station 7 (the lowest line on the right hand side – black) differed from the rest. With some evidence that the gradient of station 80 (the steepest curve – red) also differed from the rest. Predicted meat weights for different shell lengths are given in Table 8.8.

Table 7.8. The expected meat weights for each station for two different shell lengths.

Station	Length 80 mm	Length 90 mm
7	6.6	8.58
14	7.15	10.29
21	8.41	11.5
35	7.3	10.04
80	6.63	10.36
54	10.15	14.01

7.4 Discussion

7.4.1 Relative Growth and the Discard Rule

The relative growth of *Pecten fumatus* was found to differ between sample locations within the Commonwealth and Tasmanian scallop fisheries. This appears to be a general characteristic of scallops, with similar variation found for other pectinid species sampled over spatially discrete sites (e.g. *Pecten maximus*, Mason, 1957, *Chlamys opercularis*, Taylor & Venn, 1978). In particular, highly significant spatial differences were identified between shell depth and length, and meat weight and shell length. The observed variations imply there are spatial differences in the relative growth of scallops, a result which may have important implications for fisheries management with respect to management decision rules and Legal Minimum Sizes (LMS). Such a result is not unexpected, as many other studies worldwide have described variations in scallop growth over different spatial ranges.

At present, one of the decision rules used to decide whether a scallop bed is suitable for harvesting is the under-sized discard rate (or trashing rate) rule, which states that a scallop bed should not be fished if the discard rate of undersized scallops is greater than 20%. The origin of this decision rule stems from the notion that once a scallop bed is fished most scallops on the bed are either harvested or incidentally killed by the physical nature of dredging. As such, the discard rule is designed to avoid wasting juvenile or undersized animals. Another related management decision rule is the 'two spawnings criteria' which states that scallops should be allowed a minimum of two major spawning events before being harvested. Research conducted by CSIRO during the 1980's suggested that in order for scallops to have two major spawning events they would need to be 3+ years old. As McLoughlin (1994) stated: "While fecundity was found to be variable, there appeared a relationship of size (age) and egg production, with 3+ year class scallops shedding 3-5 times as many eggs as 1+ scallops. These 3+ scallops were 75-85 mm shell height." As observed in Table 7.4, a shell length of about 90 mm is required for a shell height of about 80 mm. As such, the LMS of scallops within both the Commonwealth and Tasmanian scallop fisheries is currently set at 90 mm shell length.

An important question raised by this study is whether the variation observed to occur in the relative growth of scallops across the geographical range studied is sufficient to make a size limit regulated for one area unsuitable in another? From the examination of the relationship between shell length and shell height it would appear that, from the point of view of relative growth, a LMS set in one place would also be acceptable in another. However, this would assume that the animals all grow at the same rate and therefore take the same amount of time (aged 3+) to reach the required size. If some areas have slower growing scallops then this relationship between shell length and age may not be adequate for determining the two major spawnings rule and appropriateness of opening a scallop bed to commercial fishing operations.

The variable relationship between shell length and shell depth suggests an alternative to using a simple measure of shell size to set a LMS. A commonly held belief among the scallop industry is that scallops of the same size from different areas can generate different meat yields. Martin *et al*. (1990) demonstrated differences in meat yields from standard scallops of 80 mm shell height from around Bass Strait, with the meat weights in some areas being double the meat weight of other areas. When the samples obtained in March 2004 were examined there was no obvious trend except that the scallops from the deep water bed (at 80 m) had the smallest meat weights for a given shell length. Even if these scallops ever reached the current legal size, the meat recovery would be less than that from other areas and depths and they may not be worth catching because of low meat yields. Station 80 had the steepest gradient relating meat weight to shell length. This may have been because there was some relationship between meat condition and latitude, although station 54 was at a lower latitude than station 80. The important thing to notice is that in March it is possible for an 80 mm shell length scallop in station 54 (in Commonwealth waters) to contain a meat weight that requires a scallop to be 90 mm in shell length in Tasmanian waters. If the important criterion is really size of meat (meat weight = meat plus roe) then, assuming the scallops are at least 3+, it would be acceptable from both the two major spawning events criterion and a suitable meat weight criterion to harvest scallops at 80 mm. The critical fact would be whether the scallops were at least 3+, which would be determined by how rapidly they grew in size.

Conclusions from this aspect of the study can only be tentative because in March very few of the scallops from anywhere were in prime condition (i.e. with roe in optimal condition). The scallop season tends to begin in May or June to allow the scallops to come into better condition before fishing begins. The design of decision rules should wait results from a consideration of growth rates and achieving the two major spawning events criterion. A review of the decision rule concerning the legal minimum size is a part of the more recent FRDC project 2005/027.

7.4.2 Shell fragility

The relationship between shell weight and shell length showed that the fragile shells identified in T3 were lighter when compared to other sample locations except for those from shot 7. In fact, shells from a deeper water location (Shot 7) had the lightest measured shells for a given shell length. This result suggests that scallops from T3 are only partly fragile because they are thinner (lighter) relative to other locations. Subsequently, other unknown factors must be contributing to the observed fragility. The most reasonable possibility is a nutrient deficiency within the sampled location at T3. Given the close proximity to the T2 location (1000's meters) this would not appear to be possible, however, the complexity of tidal and seasonal currents within the East Flinders Island region may allow differences in nutrient supply over small spatial scales.

8. SCALLOP BED DYNAMICS.

8.1 Introduction

Results from the June 2000 survey identified one small bed of scallops straddling the Commonwealth (C5a) and Tasmanian (T4) jurisdictional boarders to the east / northeast of Flinders Island. All remaining areas of the Commonwealth and Tasmanian fisheries were believed to contain very low abundances of scallops, insufficient to support a commercial fishery. It was subsequently assumed that scallop stocks within all areas, apart from in Strata C5a and T4 (see Chapter 6, Figure 6.2), were rebuilding from a very much reduced base. As such, new beds could have their year of settlement inferred from their size as long as they were detected within two or three years of settlement. Assuming new scallop beds formed, the dynamics of bed development could be followed by tracking different modes in the size distribution of scallops. In this way, recruitment events could be identified, growth rates estimated, and the development and dynamics of fishable scallop beds described.

In 2003, areas of the Commonwealth and Tasmanian managed scallop fisheries were opened to commercial dredge fishing, under each jurisdiction's spatial management arrangements (see Chapter 1). In the Commonwealth fishery the plan was to keep the small area of the known scallop bed, identified in 2000, closed while opening the remainder of the area (with similar arrangements for western Bass Strait). In Tasmanian waters, a spatial management system was put in place. This would open limited areas of known scallop beds while keeping most of the remaining coastline closed to fishing. As such, data collected from surveys conducted within commercially fished grounds could be used to compare the impact of fishing on scallop survival and recruitment, and potentially the effectiveness of the contrasting management strategies used in each fishery.

Four project objectives are to be addressed in this chapter:

1. Track modal growth in length frequency data and use this to characterize the growth of scallops under different conditions of location and density.
2. Characterize the development of scallop beds varying density, determining whether they are made up of single or mixed cohorts.
3. Characterize the dynamics of scallop bed formation in Commonwealth and Tasmanian waters since 2000, describing their location, the year of the recruitment events making up the bed, and the area of settlement.
4. Describe the management implications of scallop bed dynamics.

8.2 General Methods

The data used in this chapter was obtained from the nine fishery independent surveys conducted within Commonwealth and Tasmanian managed waters since 2000 (See Chapter 6). Data were collected using those dredge methods described in 6.2.1 and Chapter 3. It must be noted that these surveys covered a limited proportion of both the Bass Strait and Tasmanian east coast waters and, while giving good coverage of the major grounds that have historically supported scallop fisheries, there is limited or no data on scallop abundance from the larger area of each fishery.

8.2.1 Modal Analysis of Length Frequency Data: measuring scallop growth

During each survey the shell length (maximum diameter) of scallops collected in each dredge shot were measured. Where catches were low, all scallops in the catch were directly counted and measured. Where catches were large, preventing all of the scallops being counted and measured in the time available, the total number of scallops was determined by estimating the proportion of the total catch represented by a randomly selected fish bin of scallops, counting the scallops in the bin, and then scaling up to 100%. Shell length (measured at the widest part of the shell) of the entire catch, or the random sub-sample of 100 scallops, were measured to the nearest 0.5 mm. Occasionally, larger samples were taken to test whether the sample of 100 was large enough to adequately characterize the size distribution of larger catches.

Length frequency data could be analysed at different spatial scales: within single dredge tows (when the sample was large enough), within defined strata, and within combinations of strata. There are a number of published methods for fitting series of distributions to length frequency data to identify the cohort structure. One of the most general approaches was first described by MacDonald and Pitcher (1979). This maximum likelihood method can be used to fit an array of Probability Density Functions (PDFs) to different sets of length frequency data. The idea behind the strategy is relatively simple. The assumption is that the sample of lengths is representative of the population size structure so the relative frequencies of the different size classes represent the observed proportion of each size class. The fitting process involves selecting a PDF to represent the expected proportional distribution of each cohort across the size classes. For example, if there were two cohorts present in a sample then two normal distributions may be chosen, each with a mean size, a spread around that mean size (standard deviation), plus a measure of the proportion (π_c) that each cohort c makes up of the total size distribution. The maximum likelihood fitting process used multinomial likelihoods comparing the observed with the expected relative frequencies (Haddon, 2001). The expected numbers of scallops in each length or size class i, $g(L_i)$ was described by:

$$g(L_i) = \pi_1 f_1(L_i) + \pi_2 f_2(L_i) + ... + \pi_c f_c(L_i) \qquad (8.1)$$

where π_c is the scaling factor given to the PDF $f_c(L_i)$ representing the c^{th} cohort.

It eventuated that normal distributions fitted the available data well and all analyses used these.

When the average size of a size class i is denoted by L_i and the upper and lower limits denoted by L_i^{Upper} and L_i^{Lower} then the mean class width is denoted:

$$\bar{L}_i = \left(L_i^{Upper} + L_i^{Lower}\right)/2 \qquad (8.2)$$

The class width is denoted as:

$$CW = L_i^{Upper} - L_i^{Lower} \qquad (8.3)$$

The proportion of a given cohort with mean length $\bar{L}$ and standard deviation σ_i in each of the k size classes

$$k = \bar{L}_{Min} : \bar{L}_{Max} \tag{8.4}$$

is described by:

$$p_i = \int_{L_i=k-\frac{cw}{2}}^{L_i=k+\frac{cw}{2}} \frac{1}{\sqrt{2\pi}\sigma_i} e^{\frac{-\left(L_i-\bar{L}_k\right)}{2\sigma_i^2}} \tag{8.5}$$

The variation terms, σ, have a subscript suggesting that they could vary as a function of size-class but in the case of scallops this was not found to be necessary. An example of the use of these methods in an Excel workbook is provided in Haddon (2001). For each cohort based on the total number of observations n, and the expected proportions of each size class p_i, the observed numbers in each size class, x_i, can be fitted using multinomial log-likelihoods as follows:

$$LL\left\{x_i \mid n, p_1, p_2, \ldots, p_k\right\} = \sum_{i=1}^{k}\left[x_i Ln\left(p_i\right)\right] \tag{8.6}$$

By following size frequency distribution of the scallops from known areas through time, growth rates of scallops could be estimated. Furthermore, cohorts could have there settlement period deduced by back calculation and be subsequently attributed to age classes. As most surveys were conducted in March or April, the occasional signs of modes around 20 mm were assumed to be 0+ animals (approximately 4+ months old). By tracking the relative growth of the different modes discovered it was possible to estimate the overall growth rate of scallops, attribute expected ages, and infer when the beds recruited out of the plankton.

8.2.2 The impact of fishing on scallops

One of the assumptions behind the 20% trashing rule is that fishing a scallop bed until it is uneconomical to keep fishing will reduce scallops to very low densities and, kill off most undersized scallops through repeated handling and impact of dredges. Although the best methodology to test whether dredging has a major detrimental impact on undersized scallops would have been to make an arrangement to commercially fish a bed which did not meet the 20% trashing rule, this would have been difficult to arrange and probably un-economical to fish.

Instead, observations that attempted to compare areas (or scallop numbers and composition within areas) both before and after fishing were made. The key observation is whether scallops of any size are present after fishing, so included here are data from Eddystone Point, which was fished heavily in the 2003 season (with a removal of approximately 3,000 tonnes shell weight from the area) but for which we have no formal data on scallop density before the fishing. The decision to open this area came from a brief review of data from an informal Industry survey conducted prior to the 2003 season after the opening in T1S found primarily scallops in poor condition (even though 250 tonnes were taken there). Post fishing results from the Commonwealth fishery were also considered.

8.3 Results

8.3.1 Growth rates

Scallops measuring between 40 and 50 mm maximum shell diameter were interpreted to be 1+ cohort scallops (Table 8.1). In March 2002, an inferred 1+ cohort of scallops was identified within C2, while similar aged animals were identified within T1 (south and north) in March 2003.These scallops were believed to have settled in March 1999 (Table 8.1) In addition, there were six other locations and years where the 1+ mode was discernible, even though in the following year it was not always possible to clearly follow its progression (Table 8.2).

Initial growth of scallops from 1+ to 2+ age groups was found to be rapid, with the T1 scallops growing approximately 31 mm (Figure 8.1 and 8.2) and the C2 scallops 38 mm (Figure 8.5; when comparing Tasmanian with Commonwealth growth there is a need to refer ahead in the document). This result suggests that small scallops within the Commonwealth fishery grow quicker (over a 12 month period) compared to equivalent aged scallops from Tasmania. This conclusion is supported by the average sizes of 1+ scallops from the two regions, with 1+ scallops from NE Flinders, in the Commonwealth management area being on average 5 mm larger than 1+ scallops on the Tasmanian east coast (Table 8.2). It is possible this is not the result of faster growth but a result of differences in settlement times leading to the scallops in Commonwealth waters having longer to grow. However, as a general rule scallops come into conditions earlier in Tasmanian waters relative to in Commonwealth waters so the expectation might normally be that Tasmanian scallops have the opportunity to settle earlier than the Commonwealth scallops.

Not surprisingly, growth rates of older age classes of scallops found within both the Commonwealth and Tasmanian fisheries were reduced relative to the initial growth exhibited from 1+ to 2+. Within those strata to the east of Flinders Island (T1 to T4), a cohort of scallops believed to have settled in 1999 was 2+ during the 2002 survey. These scallops grew between 8.9 and 12.4 mm to reach 3+ scallops; grew between 3.75 and 7.48 mm to reach 4+ scallops; and grew between 3.1 and 4.72 mm to reach 5+ scallops (Figs 8.1 – 8.4). Within Commonwealth waters, a cohort of inferred 2+ animals identified in C2 and C3 during March 2003 grew approximately 18 mm to reach 3+ animals, which was considerably higher growth compared to similar aged animals within the Tasmanian fishery.

These results indicate that scallops in the East Flinders beds grew relatively slowly compared with rates observed at NE Flinders (also see Table 8.2). In addition, the scallops in bed C4X appeared to grow at rates more similar to those found in Tasmanian waters than those in Commonwealth waters (see 8.3.2). This indicates that growth rates could be a function of both location and scallop density; the two factors are confounded and difficult to separate.

Table 8.1. Mean values from identifiable modes in the length frequency of scallops from different strata progressing through several years. See Figure 6.2 for stratum locations.

Cohort	Stratum	2002	2003	2004	2005
Cohort 1999		Age 2+	3+	4+	5+
	T1S	80.26	90.36	95.60	98.70
	T1N	75.74	88.16	91.91	
	T2	71.64	80.60	88.08	92.03
	T3	72.75	84.95	89.49	94.22
	C2	83.15	101.83	102.41	106.72
	C3	80.70	98.48		
Cohort 2000		Age 1+	2+	3+	4+
	C2	49.62	88.08	84.64	90.27
Cohort 2001			Age 1+	2+	3+
	C2			68.52	75.80
	T1S		42.00	73.97	83.00
	T1N		44.25	74.84	87.00
	C4XMain			77.81	82.93
	C4XSouth			85.83	97.85

Table 8.2. All observations of 1+ modal cohorts within samples of scallop length frequency for various strata in various years. Strata locations are illustrated in Figure 6.2. The * superscript denotes those modes that were able to be followed through time (Table 8.4 and related Figs). November is the assumed approximate settlement month in each year. Commonwealth Strata mean = 48.61, Tasmanian mean = 43.03.

Stratum	Survey	Settlement	Mean Shell Length
C5a	Mar-01	Nov-99	51.42
C1	Mar-02	Nov-00	47.69
C2*	Mar-02	Nov-00	49.62
C1	Mar-03	Nov-01	45.12
C4	Mar-03	Nov-01	52.30
C5a	Mar-03	Nov-01	45.48
T1S*	Mar-03	Nov-01	42.00
T1N*	Mar-03	Nov-01	44.25
T4	Mar-03	Nov-01	42.85

Table 8.3. Mean sizes of particular cohorts in Tasmanian and Commonwealth waters across all strata and years. The difference in size appears relatively constant.

Inferred Age	1+	2+	3+
High Density	43.03	74.87	85.68
Relatively Low Density	48.61	80.68	91.38
Difference	5.58	5.81	5.7

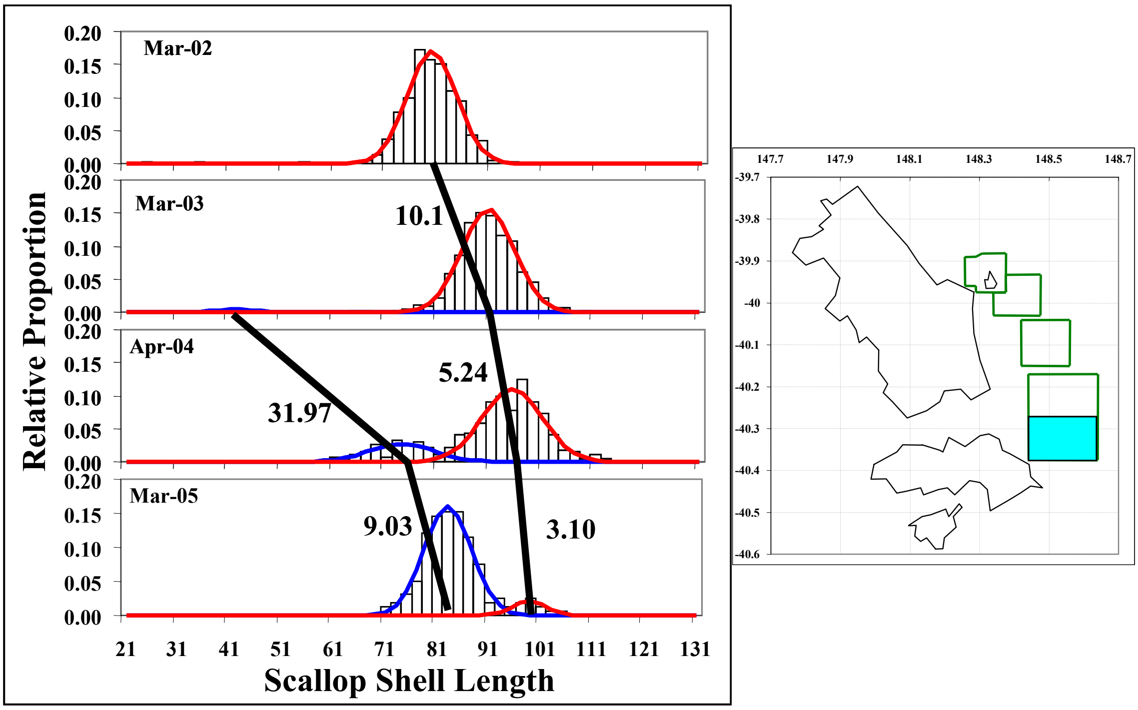

Figure 8.1. Length frequency distributions of scallops taken in stratum T1S in March 2002, March 2003, April 2004, and March 2005 with the fitted normal distributions defining the 2000 and 2002 cohorts. The thick black lines connect the estimated mean length for each cohort and the bold figures represent the growth increment in mm that has occurred over a year. Commercial fishing occurred between the 2003 and 2004 samples.

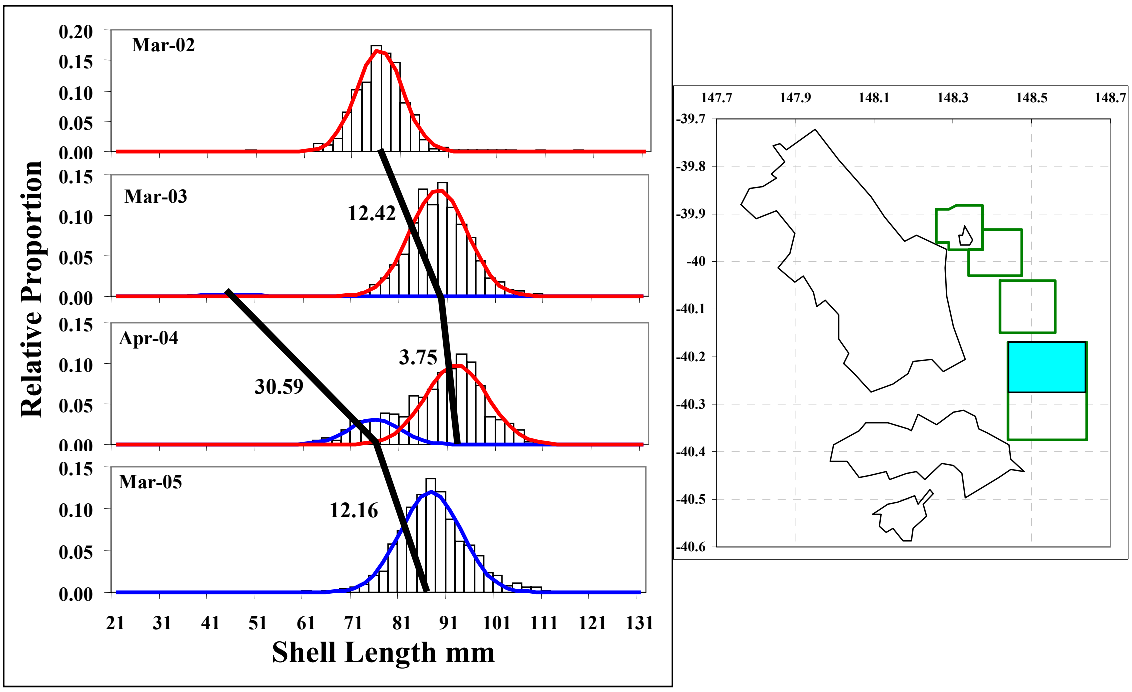

Figure 8.2. Length frequency distributions of scallops taken in stratum T1N in March 2002, March 2003, April 2004, and March 2005 with the fitted normal distributions defining the 2000 and 2002 cohorts. The thick black lines connect the estimated mean length for each cohort and the bold figures represent the growth increment in mm that has occurred over a year.

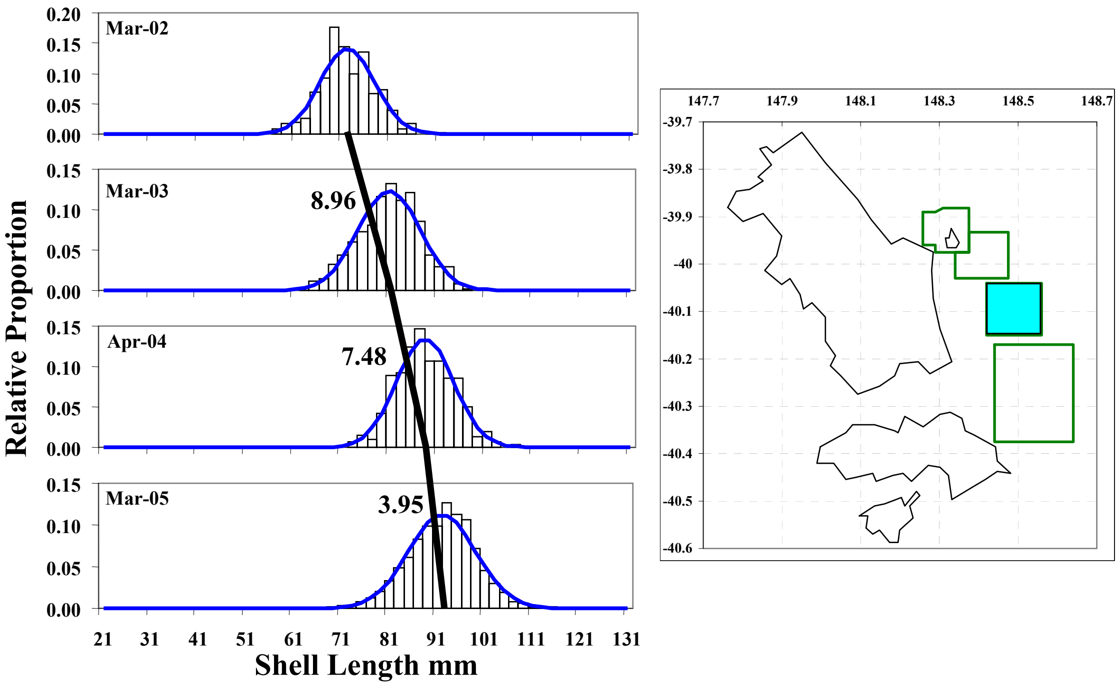

Figure 8.3. Length frequency distributions of scallops taken in stratum T2 in March 2002, March 2003, April 2004, and March 2005 (annual increments) with the fitted normal distribution defining the 2000 cohort. The thick black line connects the estimated mean length in each year and the bold figures represent the growth increment in mm.

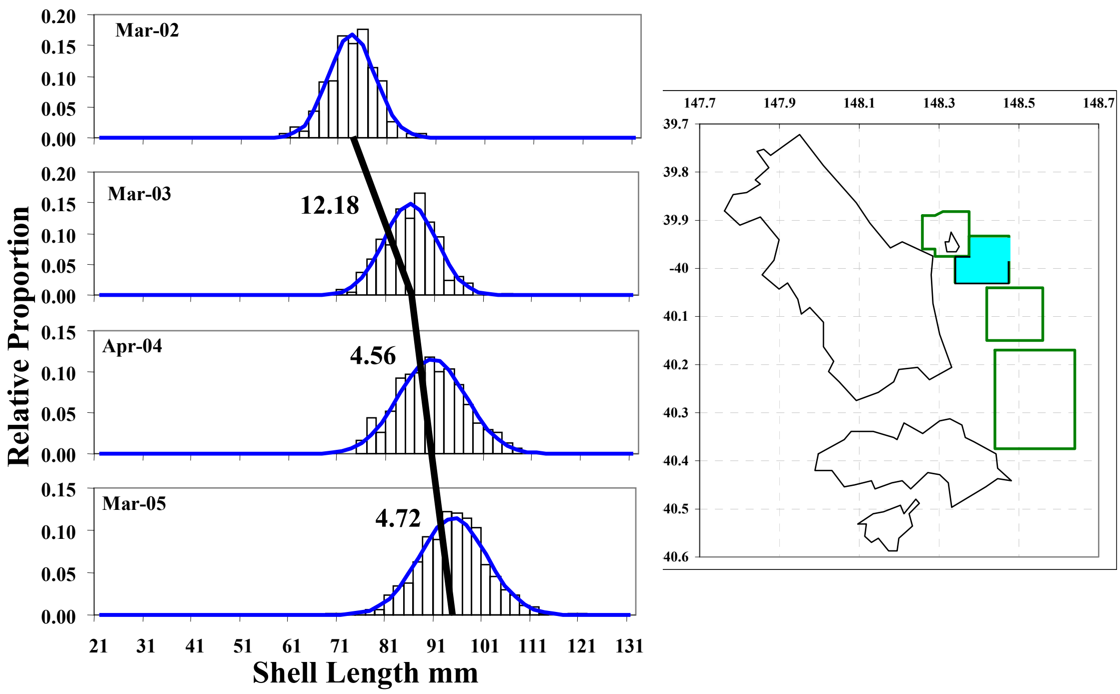

Figure 8.4. Length frequency distributions of scallops taken in stratum T3 in March 2002, March 2003, April 2004, and March 2005 (annual increments) with the fitted normal distribution defining the 2000 cohort. The thick black line connects the estimated mean length in each year and the bold figures represent the growth increment in mm.

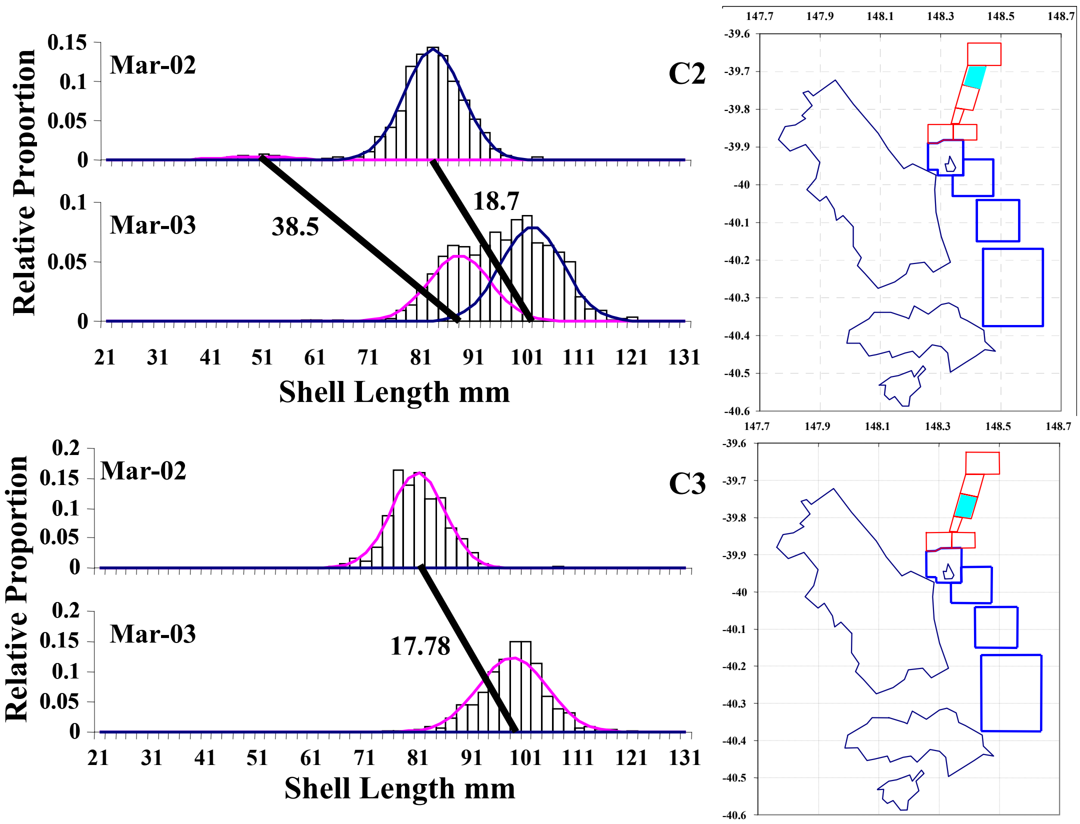

Figure 8.5. Length frequency distributions of scallops taken in strata C2 and C3 in March 2002 and March 2003 with the fitted normal distributions defining the 2000 cohort. The thick black lines connect the estimated mean length in each year and the bold figures represent the growth increment in mm. Fishing occurred in between the 2003, 2004 and 2005 samples.

8.3.2 Effect of Scallop Density on Growth

The dense scallop bed discovered in March 2004 (C4X) provides evidence for density dependent growth of scallops. After the March 2004 survey it was thought that the scallops in C4X consisted of two separate cohorts, the smallest thought to have settled in 2001 while the larger scallops (only found in some shots) were assumed to have settled in 2000 (Figure 8.6). After the more extensive survey of this region in 2005, it became clear that the larger, apparent older, cohort of scallops had grown more than the smaller, apparent younger cohort (Table 8.4). Such growth patterns appear to contradict the conclusions of the previous section, which showed that older (larger) scallops grow at slower rates than smaller (younger) scallops. However, C4X was found to contain different densities of scallops (see 8.3.3), with the less dense areas corresponding to the larger mode of scallops and higher growth rates, and the more dense area corresponding to the small mode of scallops and lower growth rates.

Further evidence for a relationship between scallop density and growth can be demonstrated by collating the various modal groups available and plotting initial size versus growth increment (Table 8.4; Figure 8.7). When the growth increments are plotted against the initial sizes, two rather different linear relations are found. These distinguish areas of relatively high density from areas of relatively low density (Figure 8.7). An ANCOVA on the two linear regressions indicated that the gradients were not significantly different ($F = 0.3701$, $P = 0.5534$) but the intercepts were very significantly different ($t = 10.1$, $P = < 1e\text{-}07$).

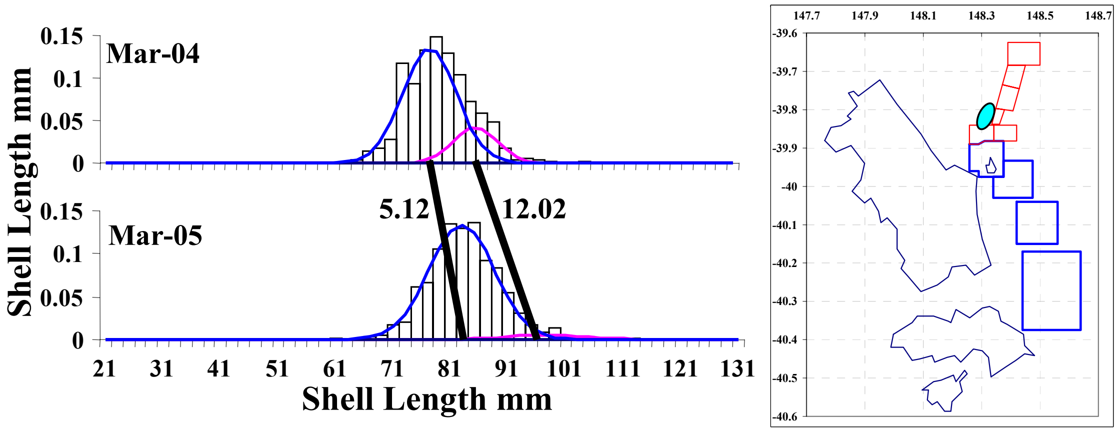

Figure 8.6. Length frequency distributions of scallops taken in stratum C4X in March 2004 and March 2005 with the fitted normal distribution defining the 2002 cohort. The thick black line connects the estimated mean length in each year and the bold figure represent the growth increment in mm. Data from other years were such that clear modes were undefined. So far, no commercial fishing has occurred on bed C4X. The bed structure appeared to change between surveys being more spread out in 2005 relative to 2004.

Table 8.4. Single step modal progressions observed in various strata in various years. These relate to 1+, 2+ and 3+ transitions. The growth increments in the Commonwealth waters appear to be greater than those in Tasmanian waters. Strata locations as in Figure 6.2. The density estimates are the average abundance of scallops per 1000 m^2. These values are only indicative as catchability appeared to vary between years.

Stratum	Years	Initial	Increment	Size Change	Density
T1S	02/03	79.39	11.01	79.39 – 90.40	436.35
T1S	03/04	90.40	5.16	90.40 – 95.07	359.95
T1S	04/05	95.01	3.69	95.01 – 98.70	175.235
T2	02/03	71.64	8.96	71.64 – 80.60	1990.35
T2	03/04	80.60	7.48	80.60 – 88.08	2914.45
T2	04/05	88.08	3.96	88.08 – 92.04	2229.85
T3	02/03	72.75	12.20	72.75 – 84.95	2110.75
T3	03/04	84.95	4.55	84.95 – 89.50	2528.85
T3	04/05	89.50	4.72	89.50 – 94.22	2044.3
C4XMain	04/05	77.8	5.12	77.8 - 82.9	1048.95
C4XMNorth	04/05	85.8	12.08	85.8 - 97.8	31.5
C1	04/05	83.18	17.41	83.18 - 100.6	105.9
C2	02/03	83.15	18.65	83.15 - 101.8	180.2
C2	03/04	88.08	14.32	88.08 - 102.4	173.2
C2	04/05	68.52	21.83	68.52 - 90.85	93.8
C2	03/04	59.99	24.65	59.99 - 84.65	173.2
C3	02/03	80.70	17.78	80.7 - 98.48	133.9

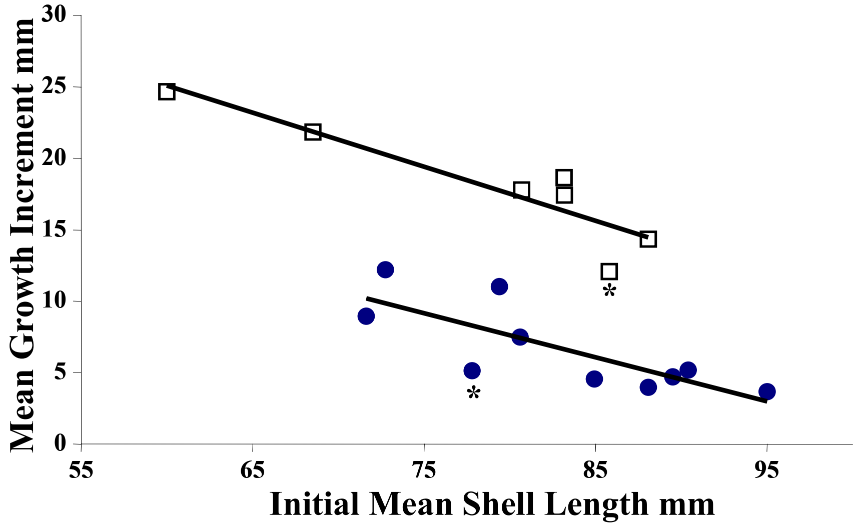

Figure 8.7. A plot of the mean growth increment of scallops from different areas, years, and densities, characterized by the mean shell length before growth. The filled circles relate to higher density areas while the open squares relate to relatively low density areas (Table 8.8). The two points marked with a * are from C4X. The lower point relates to the main high density patch of that bed, while the upper one is from a very low density part of the bed.

8.3.3 Patterns of Scallop Density and Size within a Bed

The density of scallops within C4X exhibited a distinct pattern which was approximately mimicked by the size distribution of scallops (Figure 8.8). Within C4X, the smallest scallops were found in the centre with the larger scallops to the periphery (Figure 8.9). Furthermore, there was a clear relationship between the abundance (implied density) of scallops taken in a dredge tow and the mean shell length of the sample of scallops obtained from each dredge tow (Figure 8.10).

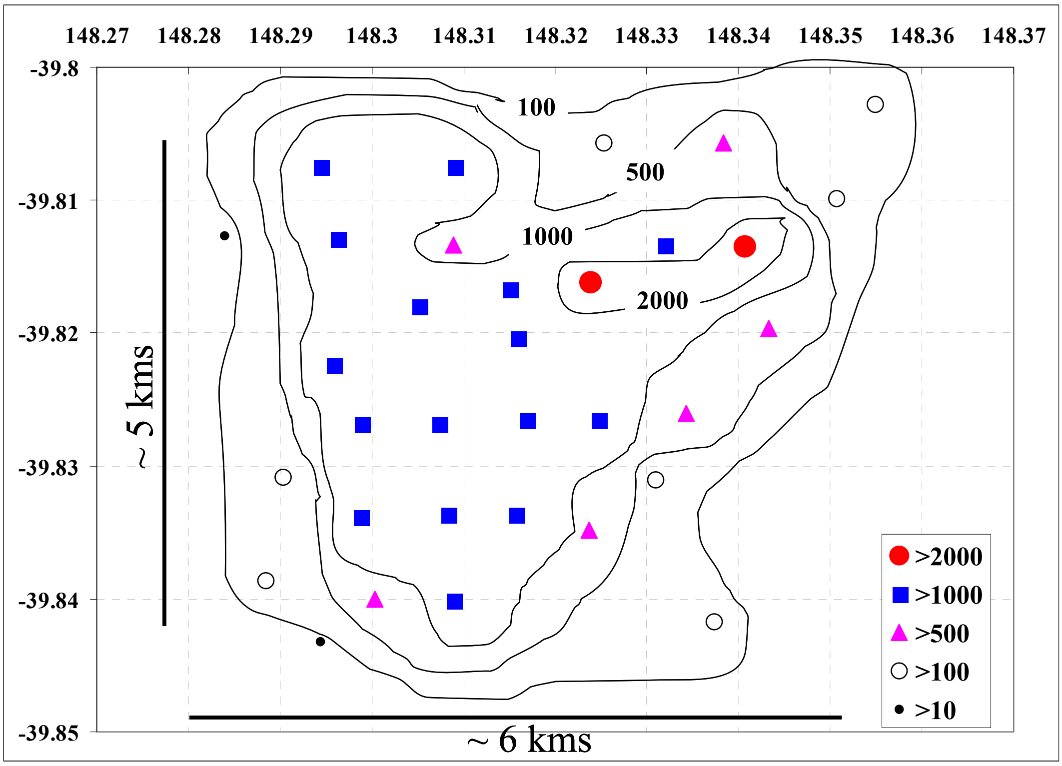

Figure 8.8. Schematic map of the different stations dredged in March 2005 within scallop bed C4X, indicating the relative density. It needs to be remembered that the average dredge shot extended between 300 – 400 metres so the contours are approximate.

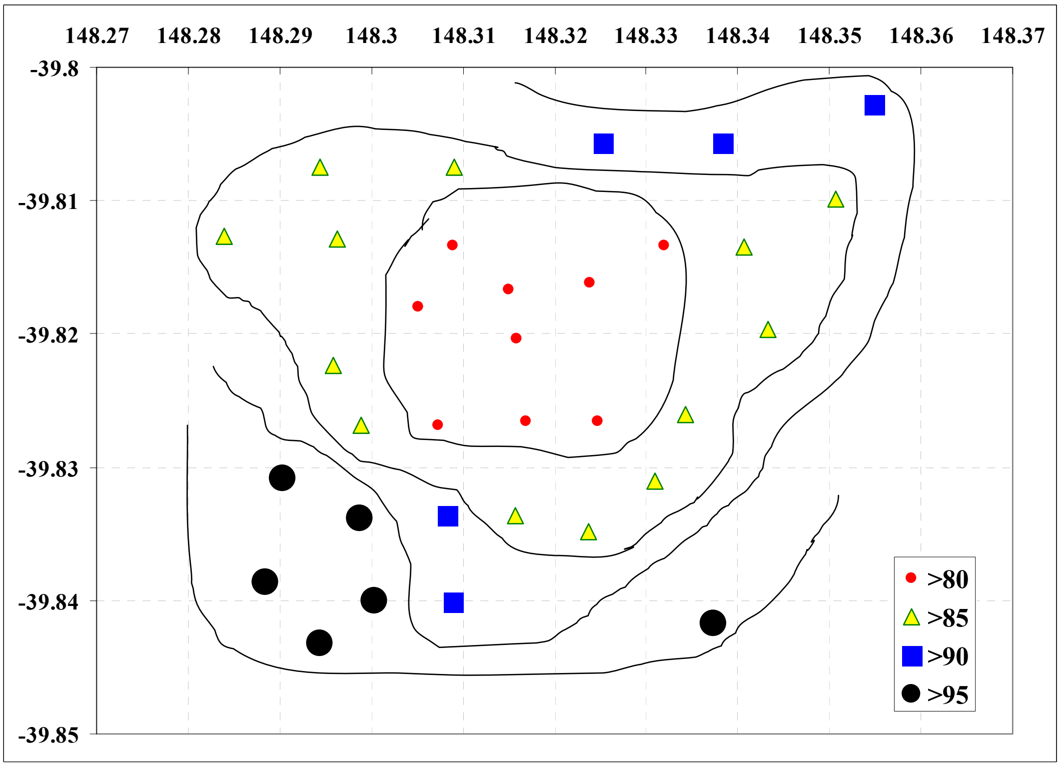

Figure 8.9. The distribution of relative sized scallops across scallop bed C4X. The smallest scallops in the middle of the bed and the biggest to the south and north.

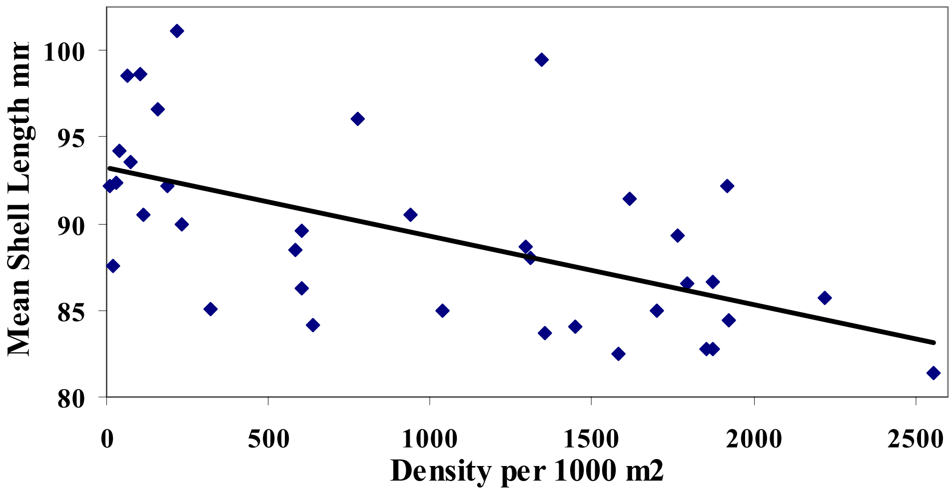

Figure 8.10. Plot of mean shell length of scallops in each dredge shot within scallop bed C4X against the estimated density taken in 1000 m^2. The regression line was highly significant Shell Length = 93.242 - 0.00396 Density (F = 18.07, P = 0.00015). The regression was noisy because the dredge samples covered distances of between 300 – 400 meters distance.

While the relationship between density and mean shell length is clear in C4X (Figure 8. 10), in Tasmanian beds the relationship is absent or far less marked (Figure 8.11). It is unknown whether this is because the Tasmanian beds have been uniformly dense from the time of settlement and do not appear to have spread out as those in C4X appeared to have. Certainly, the distribution of different density patches and of different sized scallops does not have the clear pattern observed in Commonwealth waters (Figure 8.12).

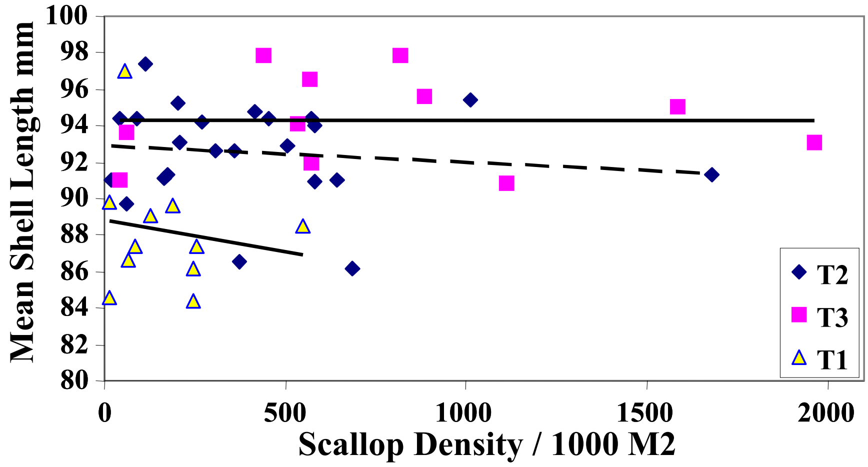

Figure 8.11. Plot of mean shell length in mm against scallop density per 1000 m^2 for strata T1N, T2, and T3. None of the regression lines are significantly different from horizontal.

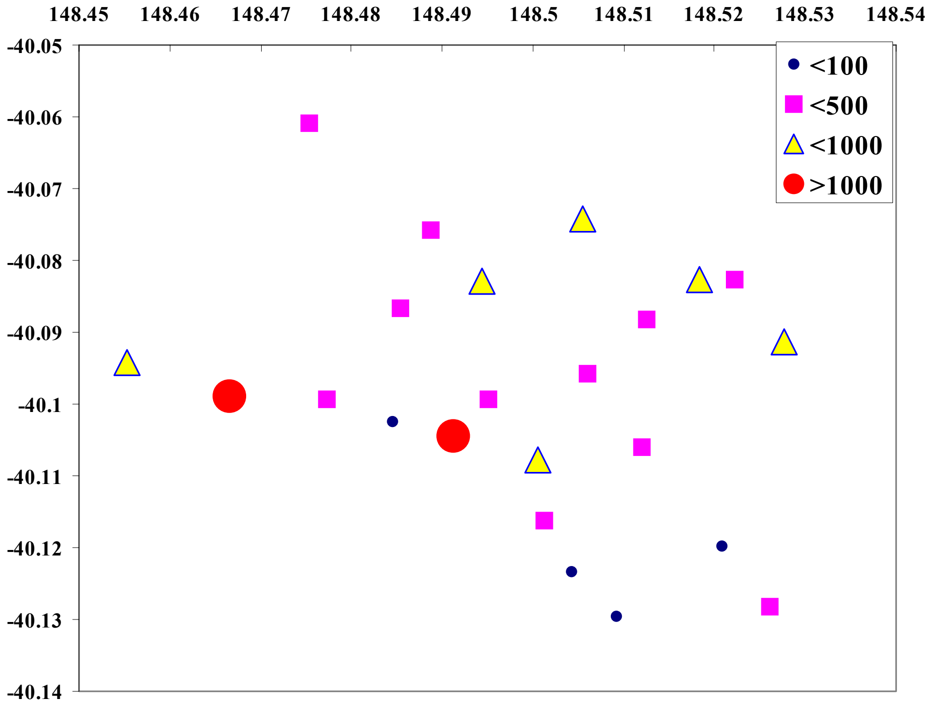

Figure 8.12. The distribution of different density of scallops in T2 in March 2005. There does not appear to be a centralized dense patch surrounded by less dense areas as in C4X.

8.3.4 The Impact of Fishing on Scallops

Figures 8.12 and 8.13 identify the location and relative intensity of fishing within the Tasmanian and Commonwealth fisheries during 2003. Although no pre / post fishing comparisons of scallop abundances is available, Figs. 8.13 to 8.15 clearly indicate that not all scallops die subsequently to commercial fishing. From Figure 8.15 it is also clear that 1+ and 2+ animals were present following fishing, albeit at very low densities. Clearly it is not the case that after commercial fishing, large starfish and other predators enter a scallop bed and remove any remainder.

In addition, commercial fishing occurred in 2003 and 2004 in strata C1, C2, and C3 in Commonwealth waters. In stratum C3 the numbers of scallops were greatly reduced in March 2004 (Figure 8.5) but while scallop numbers and density were reduced in C1 and C2 they did remain with 2+ animals making up an important fraction of the total (Figure 8.5). Commercial fishing does not always destroy all undersized scallops on a scallop bed.

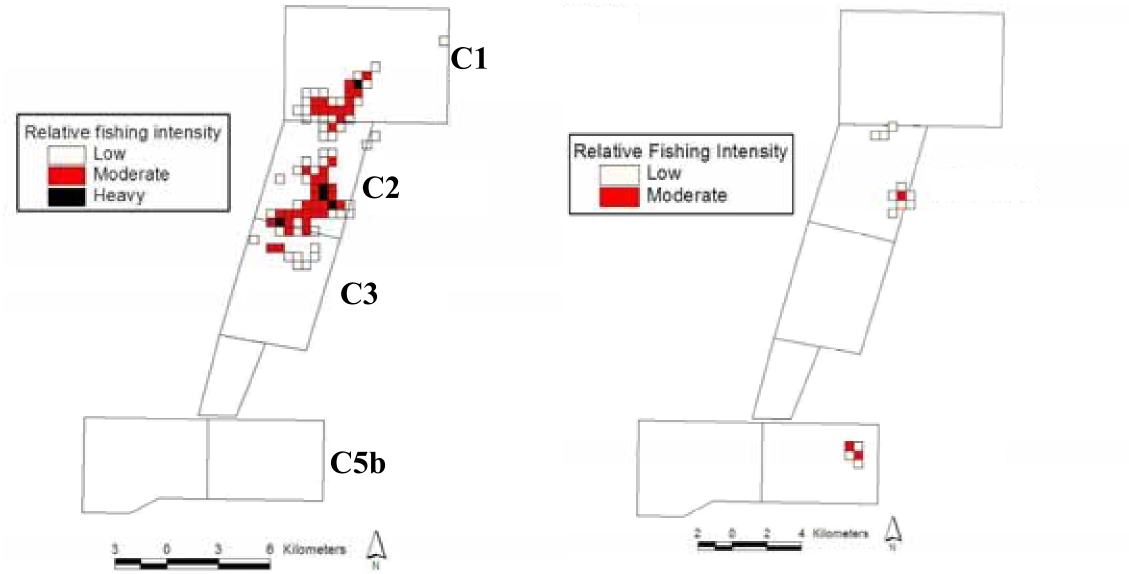

Figure 8.13: Extent of fishing, and areas of different fishing intensity for the 2003 (left panel) and 2004 Commonwealth fishery (right panel). This is a modified version of Fig 2.4 in Chapter 2.

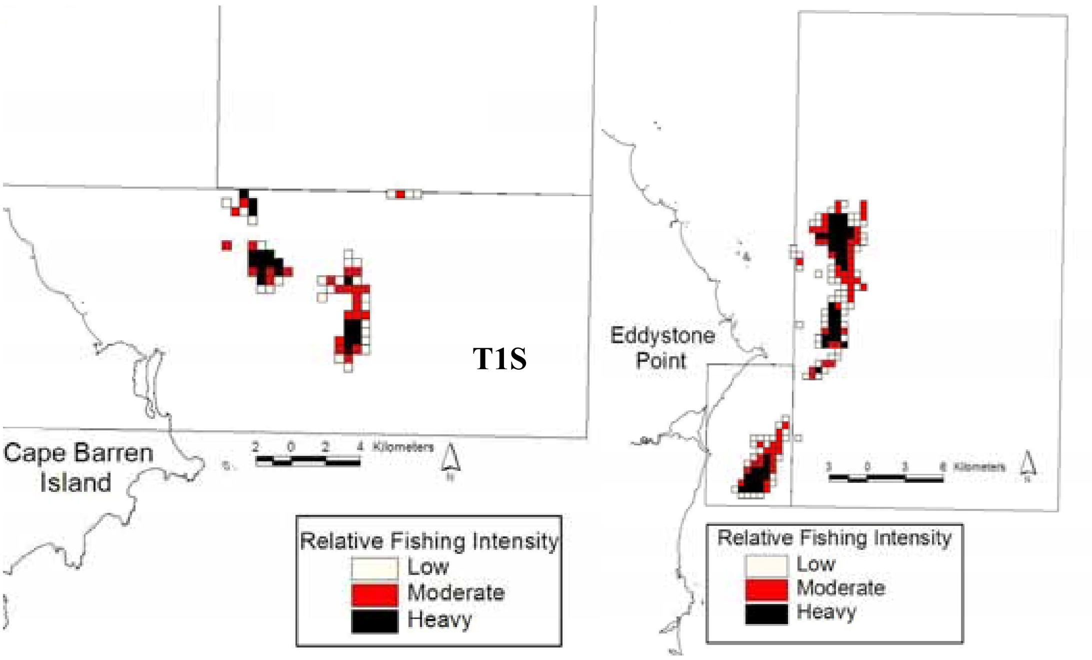

Figure 8.14: Extent of fishing during the 2003 Tasmanian scallop season in the area off Flinders Island in T1S (left panel) and Eddystone Point (right panel). This is a modified form of Figure 2.6 from chapter 2. In 2004 there was about 250 t of fishing at Eddystone Point which was quickly moved south as a result of reports the scallops at Eddystone Point were too small and in poor condition.

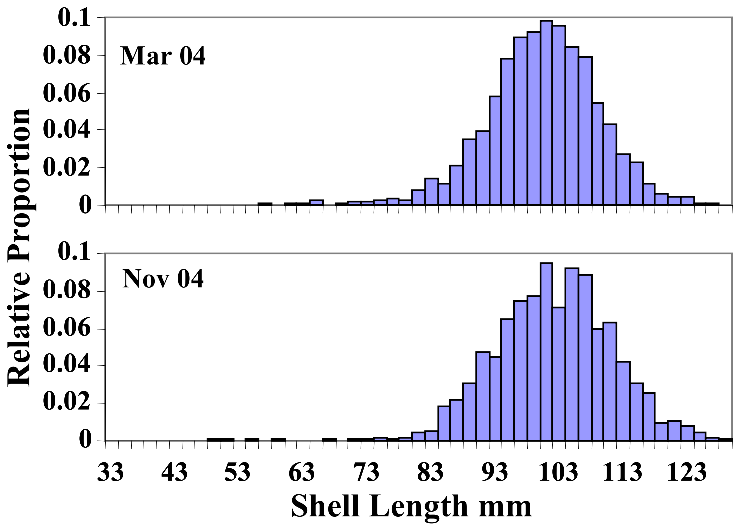

Figure 8.15. A comparison of the length frequency of commercial scallops found in the northern portion of the Eddystone Point scallop bed (see Figure 8.14). Densities in November were approximately 2/3rds those in March 2004.

8.4 Discussion

This discussion integrates the results from Chapters 6 – 8 in this report, which are those that directly address matters to do with scallops and their fishery. There were three project objectives to which these data can contribute:

1. Determine the relative impact of fishing on different size classes of scallops on those beds open to fishing, especially the rate of survival of undersized scallops.
2. Determine whether a relationship exists between juvenile settlement success in different areas and the relative fishing intensity, as defined by VMS data, experienced by those different areas.
3. Generate management options aimed at optimizing the use of area based management strategies for scallop fisheries.

Firstly, however, we need to consider the direct ageing versus modal progression techniques of determining scallop age / growth characteristics.

8.4.1 Ageing vs. Modal Progression

As the aim of this chapter was to follow cohorts through time, it might appear better to age scallops rather than use modal analysis of length frequency information. One widely used technique to age scallops is to count the rings visible on the curved section of scallop shells (Figure 8.16). Fairbridge (1953) and Mason (1957) argued such ageing of scallops was possible, although only by scraping away the surface ridges near the edge of the shell in scallops older than 4+ years old. However, such a technique could be considered subjective, with much uncertainty as to what should be included as a ring, and what should not (Figure 8.16). Furthermore, work conducted by CSIRO researchers in the 1980s indicated that the rings visible on an un-sectioned shell are most probably correlated with spawning events and other physiological shocks, and not necessarily age, so they are unlikely to estimate ages well. This problem is compounded by the finding that in a bed of scallops, only about 85% of the mature scallops spawn each year, while there is further evidence of multiple spawnings from an individual scallop within a 12 month period. Thus, using the apparent rings on the shells to "age" scallops would most likely lead to results which are confused and biased to an unknown extent (Gwyther & McShane, 1988).

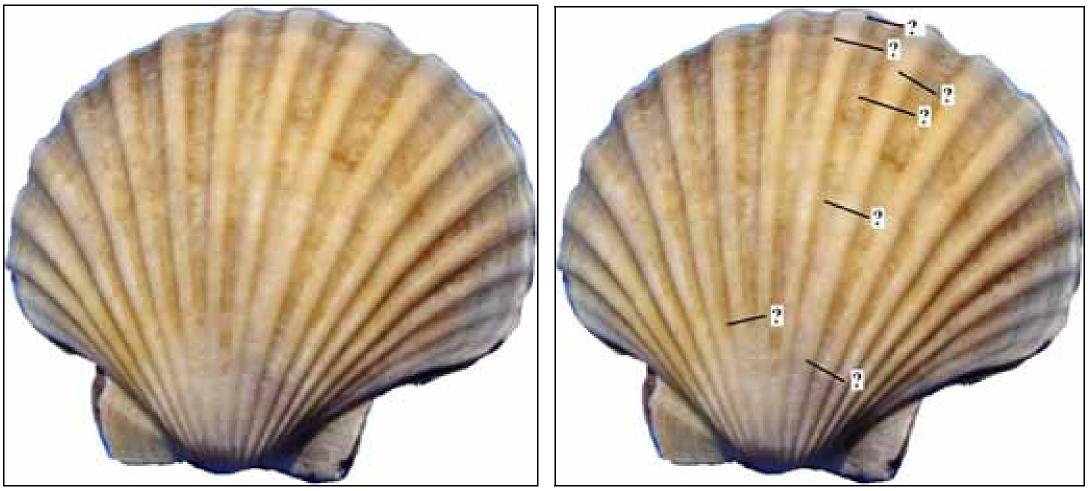

Figure 8.16. Possible interpretation of growth rings on a scallop shell. Such interpretation is can be considered subjective. This diagram also illustrates the problem of shell fading, which further increases the difficulty in determining rings with a degree of confidence.

8.4.2 The Impact of Commercial Fishing on Scallops

The most obvious, and least surprising, effect of commercial fishing on scallops is to significantly reduce their abundance from pre-fishing levels, especially for legal sized scallops. Although it was not possible to arrange to fish an area containing large numbers of undersized scallops, the evidence that became available, through the coincidence of pre-fishing survey observations, the locations of fishing, and subsequent designed surveys, were not consistent with the idea that all undersized scallops are killed during serious commercial fishing of a scallop bed. Video evidence indicated that immediately following dredging activity, fish such as leather-jackets, were attracted into the dredge track. It is presumed that they are attracted by the sediment disturbance that may bring edible species to the surface. However, in no hauls on areas where commercial fishing had occurred were higher than average numbers of starfish predators seen. This is not to say it does not happen but rather that it did not happen in our observations.

Perhaps more importantly, it was observed that once the scallop beds had developed and reached a size of about 70 – 75 mm shell length then further significant recruitment to such areas rarely occurred during the course of our study, however, other work has identified the existence of scallop beds containing a number of cohorts (Zacharin, 1994). This meant that most scallop beds were made up of a single cohort. There were more instances of beds having more than one cohort in the Commonwealth fishery than in the Tasmanian fishery (*e.g.* in C1, C2, C4, and C5a) and this was assumed to be a result of the lower densities of scallops found in all Commonwealth scallop beds except C4X (which exhibited one of the highest densities seen). There were occasions where the 20% trashing rule would have been influenced by the advent of greater than one cohort if the legal minimum size had been increased to 90 mm shell length, as in C1 and

C2 in 2004 (Haddon *et al*., 2004; these were the only previously fished strata in which significant numbers of scallops were left in Commonwealth waters). Length frequencies in the Tasmanian strata T2 and T3 were stable and predictable while strata T4 and T1, especially T1S, were much more variable suggesting that the scallops present may have been mobile. Even when the same stations were re-visited very different length frequency structures could be found between surveys. It is possible that the scallops were mobile in these areas and were shifting location by significant distances.

That commercial scallops can be mobile is supported by observations such as those seen in T1S and T4, but also in C4X, which appeared to increase in area and reduced in density between March 2004, November 2004, and March 2005. How the dynamics of scallop beds relate to the hydro-dynamics of the area in which they settle is still unknown. But some areas have extremely strong tidal flows making effective dredging a real skill. Under such conditions, scallops would only need to jet up into a current to be carried potentially significant distances.

8.4.3 Juvenile Settlement Success and Fishing Intensity.

The apparent lack of recruitment following the development of the dense beds of scallops sampled in this study (e.g. C4X) may suggest that spatial management can benefit from such scallop beds being fished to low densities once opened to fishing, however, there is no direct evidence of this. The scallop fleet includes boats of varying size, power and operating costs. For spatial management to match the needs of the fishery it needs to be remembered that the larger and more powerful vessels require a higher catch rate to remain economically profitable than smaller vessels. There may therefore be a temptation to maximize catch rates by only partially fishing out a given scallop bed before moving on to the next dense bed. However, if the pattern of recruitment observed through this study reflects some interaction between scallop density and subsequent settlement then leaving a significant density of scallops may lead to limited recruitment to a scallop bed. If this is the case, a better option may be to fish a scallop bed to low densities before either closing the fishery or moving to the next bed. Conversely, Rago and Smith (2004) suggest that conservation of high density scallop beds as a source of recruitment has greater advantages than being fished, so partially fishing a dense bed may in fact aid recruitment.

8.4.4 Management Implications

The Bass Strait scallop fishery was fortunate that excellent recruitment happened in 1999, followed by further recruitment in 2000 and 2001. The scallops responsible for generating larvae that sourced this recruitment were restricted to putative scallop beds to the south of Banks Strait and a single, relatively small scallop bed that bridged the Commonwealth and Tasmanian jurisdictions just north of Babel Island on the east coast of Flinders Island. Until the different jurisdictions either take on a cooperative and complementary management regime or reconsider the Offshore Constitutional Settlement to simplify the management arrangements, the need to treat what is almost certainly one stock (not including the Victorian stocks at this point) as if it were made up of two separate population units will continue to make the management and use of this resource sub-optimal. For example, there is a decision rule in the Commonwealth jurisdiction that requires closure of at least one scallop bed in the east (and in the west). Before that bed could be opened to fishing an equivalent biomass to that found in the 2000 survey would have to be found and closed in its stead. In the Commonwealth survey of 2000 the biomass estimate for the bed in stratum C5a was approximately 400 tonnes. However, it has become clear that this bed was merely an extension of a larger bed immediately adjacent to the jurisdictional boundary, in Tasmanian waters. In 2000, when this was being reported, this was not obvious because the Tasmanian survey had not been fully completed in time for the report to the Commonwealth. As shown in Figure 6.1, once the Tasmanian survey was completed it became clear that the scallop bed in Tasmanian waters was rather bigger than that in Commonwealth waters. It would appear that the biomass that led to the limited recovery of the Commonwealth fishery (though it may also have given rise to C4X) was perhaps 1200 to 1600 tonnes and not only 400 tonnes. This is only one example for where the multiplication of jurisdictions leads to confusion and, possibly, to inappropriate conclusions.

Spatial management is based upon the idea of leaving a spawning stock in place to provide the potential for recruitment in fished down areas. There are no guarantees that this will always provide for commercially viable scallop beds to be continuously fished but since the 1999 closure of the Commonwealth and Tasmanian fisheries it is a strategy that appears to have been effective. During the course of this study recruitment success in Tasmanian waters appears to have been greater than in Commonwealth waters with greater numbers of scallops settling south of Babel Island than to the north (though settlement in C4X gives some evidence of improved recruitment in the Commonwealth-managed area). Certainly the spatial strategy in Tasmanian waters has been more successful than that in Commonwealth waters in terms of total commercial catch. But this would have been the case even if much larger amounts of scallop settlement had occurred in the north. In the first open season in 2003 the effective TAC in Commonwealth waters was greater than 5,000 tonnes. In the event only about 1,450 tonnes were taken. But the effect of that fishing was to reduce available stocks so that from the same area plus C5b only about 150 tonnes were taken in 2004. The difficulty is that as most of the area is opened and only a small part secured then because of a legacy of a potential large scallop fleet existing, once a fishery occurs there is little to prevent the complete depletion of available stocks with little left for subsequent years. This strategy is almost guaranteed to lead to a boom and bust style of fishing where scallops constitute a bonus fishery that only occurs every few years. This would make maintaining markets, especially export markets, difficult, as well as retaining workers skilled at splitting scallops and processors that can handle the product. If the desired outcomes include a sustainable stock and a reliable fishery happening each year, then the spatial strategy of opening a small area and keeping the majority closed is much preferable to the alternative. It is true that the decision rules and information needed to determine which beds to open and when, have still to be worked out in detail in Tasmanian waters. Nevertheless, the approach used in Tasmania seems to have economic and social advantages when compared to that in use in Commonwealth and Victorian waters.

It has been shown to be possible to follow the growth and development of different cohorts on different scallop beds. This has demonstrated that growth rates differ in respect to location, density, and possibly depth. If the established management procedure of allowing two major spawnings before fishing a scallop bed is maintained then the differences in growth rates may have implications for setting the minimum legal size. The use of a minimum legal size has been in place since 1925 (Fairbridge, 1953). The idea is to avoid growth over-fishing by allowing the scallops to grow to a minimum size before harvesting. McLoughlin (1994) showed that by leaving scallops to have two major spawnings (by when they would be 3+ years old) the egg production would be 3 – 5 times that of a 2+ scallop. This was a further justification for leaving scallops to a minimum size of about 90 mm shell length (maximum diameter). This has always been a difficult regulation for which to obtain adequate enforcement and has instead relied on the cooperation of the Industry to stop fishing once more than 20% of the scallops caught had to be returned to the water (the 20% trashing rule). This may work well when scallops are abundant but the temptation to bend the rule and deplete stocks to critical levels certainly arises when they are scarce. For example, Young *et al*. (1989) state that: "In 1987, with the prospect of poor catches, and with widespread violation of the existing size limit, the minimum size for *P. fumatus* was reduced to 80 mm at the maximum diameter."

With the advent of detailed spatial management the use of legal minimum sizes may be transformed. In order to open particular scallop beds to fishing a set of decision rules are required to set criteria for which and when to open. Included in those decision rules should be details of whether the scallops have had a chance to undergo two or more major spawnings, the maintenance of high-density spawning reserves and procedures that lead to continuity of fishing operations. Given a means of discovering the size structure of the scallops in a prospective commercial scallop bed then once a decision has been made to open a bed there may be efficiencies to be gained from modifying the use of the minimum legal size regulation. The authors of this report (Haddon *et al.* 2005b) wrote a document for the ScallopRAG discussing the options and opportunities with regard the interaction between spatial management and the minimum legal size of scallops. It concluded that given detailed spatial management of the kind implemented in Tasmanian waters (but not in Commonwealth waters to this time) then once a scallop bed had been opened to commercial fishing there would be no need to retain the minimum legal size. The underlying assumption is that fewer than 20% of the bed would be undersized, or all scallops had spawned twice anyway. It was argued that the Industry might obtain some efficiency through not having to sort their catch nor would they have to worry about compliance issues if a small proportion of small scallops was landed. This would simplify both fishing and compliance issues, though it puts a greater onus on obtaining adequate data from the scallop beds to be opened. Further, under the Commonwealth's present decision rules requiring closure of at least one bed in east and west, and treating scallops in Commonwealth-managed waters as a separate stock, fishing for scallops in this area is likely to be intermittent at best and, in fact, unlikely to take place at all.

In addition, the different growth patterns around the Bass Strait fishery indicate that in a detailed spatially managed stock the deciding factor about size should be whether they have had at least two major spawnings. If this is the case then the scallops would not need to have a particular sized shell but rather would be best harvested when they are of a size suited to the export markets (a meat count of 60 – 70 per kilogram). This approach would benefit from further investigation.

9. UNDERWATER VIDEO SCALLOP SURVEYS.

9.1 Introduction

The effective implementation of small scale spatial management regimes within any scallop fishery requires a detailed knowledge of the available stocks across the entire spatial extent of the fishery. Although fishery-independent dredge surveys could provide the relevant information, such surveys would be prohibitively expensive if they covered the entire fishery. Consequently, an alternative low cost mechanism for surveying the entire known distribution of scallop populations is required.

The use of underwater video systems to survey scallop beds within the Tasmanian and Commonwealth scallop fisheries could be very informative in terms of identifying conditions and life on the seabed. One advantage of using video technology is the ability to process video footage post-survey. Although dredge samples could also be stored on board the survey vessel for post-processing, the large volumes caught within each sample tow would make the storage and transport of samples impracticable. However, the very low storage requirements for video tapes means that more time can be devoted to surveying a greater proportion of the fishery. That is the video transects can be longer and more numerous than individual dredges. This chapter aims to:

1) Describe the underwater video system used in this study;
2) Describe the main habitats observed in video footage collected during scallop surveys since March 2003;
3) Identify the main problems associated with the collection and analysis of video; and
4) Describe possible future directions for using video to quantitatively survey scallop beds within the Commonwealth and Tasmanian scallop fisheries.

9.2 The Underwater Video System

Three submersible video camera systems have been used during fisheries-independent surveys undertaken by TAFI to film scallop and other benthic habitats. Prior to November 2003, a Benthos Inc Model 4208 colour analog video camera system was used, which was superseded by a MorphVision MorphCam digital video system in November 2003, and finally from March 2004, a custom digital video system designed and built by SciElex Pty Ltd, a specialist in harsh environment electronics, was used. Only this last system will be described in this report. The custom built SciElex video system consisted of 3 main components; the video camera, control box, and towing mechanism. The video camera was a low-light, high resolution colour camera encased in a stainless steel water-proof casing rated to 300 meters depth. One hundred meters of polyurethane cable that incorporated cables for a video feed and a power supply was internally connected to the camera and housing. This cable was encased in ski-rope for added protection and strength. The cable connected the camera to a control box containing an integral power supply (battery and 12 volt), an output to its own LCD monitor display, and a further output to a digital video camcorder for recording of footage (Figure 9.1).

Figure 9.1. The underwater video control box is contained within a waterproof Pelican housing with the integral 5.6 inch monitor, and waterproof sockets for signal in, signal out, and power out.

When used in the field, the camera was mounted within a simple tow fish (Figure 9.2), which not only protected the camera, but also provided the weight required for deployment to the sea bed. The tow fish was secured to the boat using a rope, which enables the system to be lowered by hand or winch. A second operator would feed out the video cable. The height of the camera (tow fish) within the water column was controlled by hand using the safety rope.

Figure 9.2. The aluminium protective tow fish for the underwater video camera (the centrally located cylinder pointing down and forwards. The tow fish provided lateral stability for the camera in the water but so far no mechanism is available to remove vertical movements brought about by wave action. Note the cable leading to the camera is not used to lower or raise camera and tow fish. The white rope to the right of the image is used for that purpose.

Although the vessel's engine could be used to move the camera across the substrate, drift rates caused by the prevailing wind and swell were usually sufficient to allow desired spatial coverage and at desired speed. A maximum depth of 60 m was surveyed using this technique, however, depths down to approximately 100 m are possible using the system as it is currently constructed. It would be unusual to commercially fish at depths more than 60 m. The deepest stations fished during the series of surveys were at approximately 80 m depth. Scallops found at such depths were small with very slow growth (see Chapter 7).

9.3 Video observations of different habitat types

Although no quantitative video surveys were conducted in this study, general observations of video footage provided useful information about scallops and associated benthic habitats within the survey regions. The following sections describe the main habitats observed within the Commonwealth and Tasmanian survey areas. Links to actual video footage are available on the CD copy of this report.

9.3.1 Dense scallop bed

Footage location and date: Tasmanian waters

East Flinders (stratum T3)

March 2004

Description of video footage:

An area to the southeast of Babel Island provides a good example of a dense scallop bed. Footage from this region showed >10's of scallops within the field of vision at any one time. Individual scallops were clearly visible on the sea floor within very close proximity to other individuals. The majority of scallops observed were located within small indents in the substrate and had varying amounts of sediment covering the shell. Not every indent contained a clearly identifiable scallop, however, it could not be determined whether this was due to the scallop being completed buried or not being present.

Doughboy scallops were also easily identifiable as they were generally darker, however, their abundance was substantially lower relative to commercial scallops. Some individual doughboys were seen sitting with their shell parallel to the substrate, in much the same manner as commercial scallops, while others were attached by byssus threads, and were positioned in a more upright position within the water with the shell hinge closest to the substrate. An 11-arm seastar (*Coscinasterias muricate*) was observed at the 2 minute 20 second mark of the video. Track marks in the sediment, most likely from prosobranch gastropods (e.g. *Pleuroploca australasia*), were seen within some regions, however, the individuals responsible for such tracks were not obvious. The results from dredge tows conducted within this region identified several other benthic species of both molluscs and crustaceans, however, due to their cryptic nature (they bury themselves in the sediment) individuals were not obvious in the video footage.

At approximately three minutes into the footage, scrape marks left by the dredge from a sample tow conducted within the preceding hour of the video drop become obvious. A large number of scallops remain within the area covered by the dredge, providing evidence of the low catchability of such dredges under some conditions. Sand flathead were visible within the vicinity of the dredge tracks.

9.3.2 Dense doughboy and commercial scallop habitat

Footage location and date: Commonwealth waters

Stratum C4X

November 2004

Description of video footage:

Survey results from dredge tows conducted in the northeast of what is known as scallop bed C4X demonstrated the high abundances of commercial and doughboy scallops lived within the region. Video footage from this area showed that doughboy scallops occurred in distinct clumps of two or more individuals attached by byssus threads to the substrate with the shells exhibiting a general vertical aspect with the shell hinge downwards. Overall, the abundances of doughboy scallops were high, with small clumps within most locations, and some areas of much higher densities (more individuals per clump and more clumps per area). Commercial scallops could be seen positioned flat on the substrate, and partially covered in all areas. Abundances were exceptionally high in many places, with individuals literally side by side within all available space.

Dead shell, predominately scallop and cockle, could be seen in all regions. Other benthic species were difficult to distinguish, however, dredge survey samples conducted within this region showed relatively high numbers of dog and wavy cockles.

9.3.3 Barren ground

Footage location and date: Commonwealth waters

Stratum C5a

November 2003

Description of video footage:

The substrate within this region appeared to consist of coarse sand, with reasonable abundances of dead shell, predominately scallop, dog cockle and oyster. There was the occasional clump of sponge atop the sediment. Although this area appeared suitable for commercial scallops, only the occasional individual was observed, with dredge samples from this location also indicating low abundances of scallops and other benthic organisms.

9.3.4 Screwshell habitat

Footage location and date: Tasmanian waters,

Eddystone Point,

March 2004

Description of video footage:

Relatively large areas of New Zealand screwshell were located northeast of Eddystone Point. These areas were characterised by a patchwork of screwshell and sediment, with the screwshell generally occurring in a single layer on the sediment. Dredge shots showed the majority (approximately 80% within some areas) of these screwshell to be dead and occupied by hermit crabs. A few dead shells of other species, predominately scallop and oyster, were visible in both the screwshell and clean sediment regions.

Approximately two minutes 15 seconds into the footage, track marks from a dredge tow conducted within the preceding hour of the video drop become obvious. Within the proximity of the dredge track the abundance of screwshells decreases, presumably as a consequence of being caught in the dredge. A large number of fish, the most abundant species being leatherjackets (most likely Degens Leatherjacket, *Thamnaconus degeni*), the common stinkfish, *Foetorepus calauropomus*) and sand flathead, *Platycephalus bassensis*, have congregated within the region to scavenge on any organisms brought to the surface of the sediment or damaged by the dredge. The results from the sample tow that can be seen in the footage indicated very high abundances of screwshells. The dredge samples contained small numbers of fish by comparison with their relative abundance as observed on the video. However, the catchability of such mobile species in dredges would be very low. Very low abundances of scallops were recorded from the dredge sample tow (39 individuals) or video footage.

9.3.5 Soft bottom sponge habitat

Footage location and date: Commonwealth waters,

Stratum C5b,

March 2004

Description of video footage:

Large areas within Stratum C5b of the Central Bass Strait Commonwealth fishery were found to contain what could be termed soft sediment sponge habitat. Some areas within this region consisted predominately of soft sediment (coarse sand) and very sparse sponge (individuals) and sea whips. Interspersed within such habitat was more dense aggregations of sponges and sea whips (e.g. at 1 min; 4 min; and 6 min). The vast majority of sponge observed within all regions were classified as ‘bushy sponge’ (CSIRO reference). Dead shell, predominately scallop, dog cockle and oyster, was obvious within all regions, while doughboy scallops, attached to the sediment by byssus threads were regularly seen. Some fishes could be seen, however, accurate identification was not possible. Very occasionally a commercial scallop was seen within the patches of sediment.

9.4 Problems with Underwater Video Scallop Surveys

9.4.1 Collection of Video in the Field

The video equipment used in this study was easily assembled and simple to operate in the field. In general, the quality of video footage obtained allowed the visual characterisation of different habitat types, however, several physical parameters were found to have a large effect on the quality of footage obtained, and subsequent characterisation of benthic habitats.

The size of the swell within a location was found to have a major affect on the position of the camera above the substrate. When the swell was small (<1 m), the camera generally maintained a constant height above the sediment, however, when the swell size increased (>2.5 to 3 m) the height of the camera above the substrate would vary dramatically. In such conditions, the large movements of the camera away and towards the substrate would affect the auto-focus mechanism of the camera, making the identification and counting of individual scallops and other organisms difficult. Although the efficiency of dredges is also believed to decrease with increasing swell height (Stuart Richey pers. comm.), it is untested as to which methodology would provide the most accurate estimates of scallop abundance under such conditions. It is certain, however, that the video samples are sometimes completely unusable under sea conditions of high swell. Although this problem could be overcome by using a chain leader in the video tow line, which would act as a shock absorber (in the same way as anchor chain keeps load off an anchor in heavy sea and wind conditions),the procedure would probably interfere with the veracity / reality of underwater images).

The prevailing wind speed would greatly affect the speed at which the camera would move over the substrate. If wind speeds were low (< 10 knots), the camera would have a slow, constant speed over the substrate, making the identification of scallops and other epibenthic invertebrates relatively simple. However, when wind speeds increased (> 20 knots), the rate at which the camera moved over the substrate would often greatly compromise the ability to successfully identify and count scallops and other organisms. Although the boats engines could be used to counter the motion of the wind, there was some risk of damage / entanglement of the video equipment in the propeller or drive shaft of the vessel. The efficiency of dredges is believed to stay constant in high wind conditions (low swell).

Suspended particles in the water column were found to result from algal blooms or disturbance (usually large swells) of the benthic environment in the preceding days. Under such conditions, visibility was greatly reduced such that the range and clarity of video footage was greatly decreased. This made the identification and counting of scallops difficult. Poor water visibility has no effect on the efficiency of dredges.

Several other problems were found to affect the survey of scallops using video, but would not affect the results of dredge surveys. At depth, the video would lose its ability to differentiate colours, the result of the rapid filtration of the different spectra of light in water. Colour footage could be restored by using external lights attached to the tow-fish, however, this would have required more powerful batteries and associated cables. Furthermore, the video systems used in the surveys conducted in this study did not have the capacity to estimate the size of objects within the field of view. Consequently, there was no ability to quantitatively determine the size frequency of scallop populations from video footage. This latter problem could have been corrected by using an array of lasers to provide a 3-dimensional scaling grid (see section 9.5 of this Chapter), however, once again this would have required a larger machine and a greater funding commitment.

9.4.2 Post-Survey Analysis of Video

Although no quantitative analysis of the video footage collected during the course of this study was attempted, problems associated with the post-survey quantitative analysis of such footage have been well documented.

At present it is necessary for human observers to manually annotate video footage collected during surveys. Dredge (1989) attempted to use video recordings to determine trawl induced mortality of juvenile Saucer scallops, *Amusium japonicum*, in Queensland, concluding that results were inconclusive, mainly due to significant variation in counts of scallop abundance between video film observers. Furthermore, video processing is very labour intensive and is likely to cause a bottleneck between the collection and analysis of footage. Several examples of such problems can be found in the literature. For example, Franklin et al. (1980) used underwater television to survey *P. maximus* and *Chlamys opercularis* off the southern coast of England and reported that tape review was difficult and fatiguing; and Giguère and Brulotte (1994) compared video and dredge techniques for sampling seas scallops *Placopecten magellenicus* in the

Gulf of St. Lawrence and concluded that video sampling produced better estimates of scallop density than dredge sampling, but they noted that time demands for video review were unreasonably high.

Rosenkranz et al. (2004), in their video stock assessment surveys for weathervane scallops *Patinopecten caurinus*, which are a similar size to *Pecten fumatus,* in the eastern Gulf of Alaska, overcame some of these reviewing problems by towing a sled equipped with a miniature digital video camcorder at speeds that could be reviewed at normal playback speed, with a high probability of correctly identifying scallops as they passed through the field of view. As such, they found that 15 minute sample tows (maximum time for review before fatigue) averaged 674 m long and took approximately 15 minutes to review to obtain scallop counts.

Video systems, which do not have the capacity for a live feed of footage to a display module run the risk of survey time and data being lost due to poor underwater visibility and various technical problems, because they will not be identified at the time of survey.

9.5 Future Directions in Video Surveys

9.5.1 Ability to Measure Scallops

The most obvious requirement for future video surveys of scallop stocks is the ability to estimate the size of scallops observed in video footage, especially considering that one of the main decision rules for opening areas of the Commonwealth and Tasmanian scallop fisheries revolves around the population size structure of scallops (20% trashing rate rule).

The mounting of lasers on the tow fish would allow the determination of scallop length. In its most simple form, the mounting of two lasers would provide reference points within the field of view of the video footage, which in turn would allow the measuring of scallops within the 2–dimensional plane. If the view from the video is not perfectly vertical then a third laser reference point (three vertices of a box) would allow the determination of the height of objects or their respective distance from the video camera. These estimates can be further improved by adding a fourth laser at a known angle to the other three lasers, which can be used to double check the angle of the camera and distance from objects. Such laser technology is commonly used in marine research to quantify the size of objects from a single perspective.

Underwater stereo-video systems are also being used worldwide for conducting transects of the benthos and determining the size of a range of marine animals. Such systems consist of two video cameras mounted side by side, such that the slight perspective difference between the two camera views allows measurement using the principles of photogrammetry. TAFI have recently conducted some preliminary work using stereo-video systems for the survey of scallops, however, preliminary results are not yet available as the processing of such video has proven difficult.

9.5.2 Automated Video Analysis

Although the use of lasers and stereo-video technology allow users to determine the size of objects within the field of view of video footage, the manual annotation of video footage collected during surveys is both time consuming and labour intensive (see section 11.4.2 of this chapter). This has led several research organisations to develop applications relating to the automated analysis of underwater video footage.

A recent research project being conducted through the School of Computing, University of Tasmania, is titled ‘Artificial Intelligence Techniques for Marine Image Analysis’. This research aims to automate the analysis of video footage of scallop beds, with the ultimate aim of providing counts of scallops and estimates of length frequencies from raw video footage. Such a system would eliminate the manual viewing and measuring of scallops on video footage, and has the potential to greatly increase knowledge of scallop stocks within the Tasmanian and Commonwealth fisheries.

10. ACOUSTIC SURVEYS OF SCALLOP BEDS AND EXAMINING THE IMPACT OF DREDGING.

10.1 Introduction

The use of single and multi beam acoustic technology can provide information about the spatial distribution of habitats across broad regions of seafloor and has been used to identify scallop beds (Hutin *et al.* 2005; Kostylev *et al.* 2003; Pickrill and Todd 2003) and detect the effects of dredging and trawling on the seafloor (Weinberg and Bartholomä 2005; Humborstad *et al.* 2004; Friedlander 1999).

There are several potential benefits in using acoustic technology to identify commercial scallop, *Pecten fumatus*, beds / habitat in the Commonwealth and Tasmanian scallop fisheries and to examine the impact of dredge fishing within these two jurisdictions. Firstly, the use of acoustics is a non-destructive alternative to dredge surveys, which have a direct impact on both the target species and other benthic habitats within the survey region. Furthermore, methodologies incorporating acoustic technology have the potential to allow larger areas of the sea floor to be surveyed within the same time frame and budget of dredge surveys. This latter advantage is especially important given that knowledge of scallop stocks over the entire spatial range of the Commonwealth and Tasmanian scallop fisheries is presently limited, but is an essential requirement for the effective implementation of small scale spatial management regimes.

This chapter will present the preliminary results of single-beam acoustic surveys conducted within scallop habitat of the Commonwealth Central Bass Strait scallop fishery in 2003 and 2004. The main questions of interest being addressed were 'can single beam acoustic sounders be used as a quick, low cost survey tool for identifying scallop beds / scallop habitat?' and 'can this tool be used to detect the impact of commercial scallop dredge fishing on the benthos?' In addition, the potential use of swath acoustic technology in detecting scallop habitat was explored.

10.2 Methods

10.2.1 Study Site

The study site was situated in Commonwealth Central Bass Strait waters within the area described previously as C5b, which is approximately 15 km north east of Babel Island (see Chapter 7, Figure 7.2 and Figure 10.1) and is in the eastern part of stratum C5b. The study site covered an area of approximately 2.5 by 3 km, with depths ranging from 36 m to 44 m, and supported a range of soft sediment habitats, in particular scallop, sponge, dead shell, and sand (see Chapter 9). No scallop fishing had occurred in the study site between 1999 and 2003 due to fishery closures. However, data collected during scientific dredge surveys conducted in March and November 2003 (see Haddon and Semmens 2003) indicated that scallops in the area were predominately legal size, and as such, there was a high possibility that the region would be opened to commercial dredge fishing operations during 2004. As such, this site provided an opportunity to determine if acoustic surveys could be used to identify and characterise scallop habitats and detect the impact of commercial scallop dredge fishing on the benthos, by allowing for both pre (December 2003) and Post-fishing surveys (October 2004), following the recommencement of fishing in the Commonwealth in May 1st 2004.

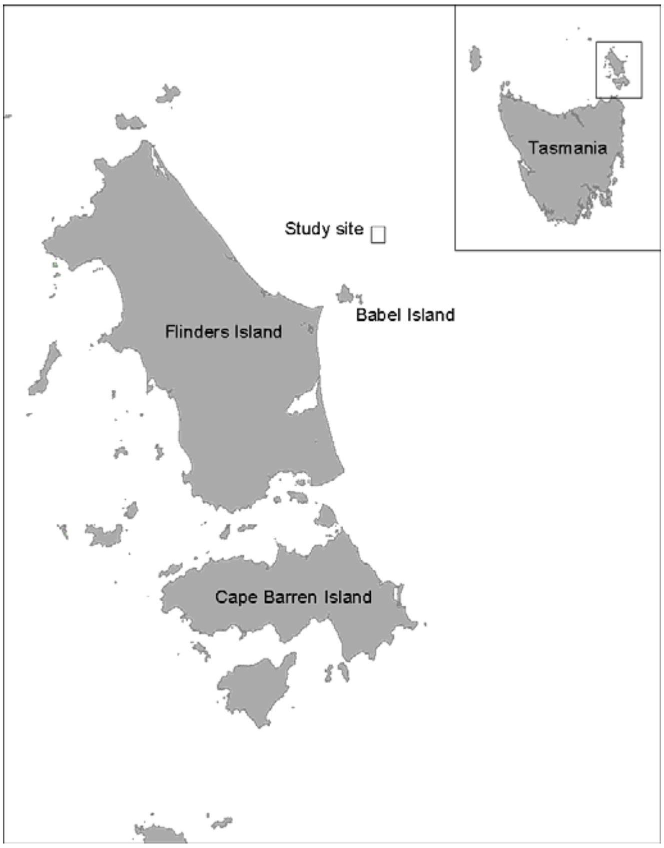

Figure 10.1. The location of study site off the north east of Flinders Island, Tasmania.

10.2.2 Detection of Known Scallop Habitat

Coordinates (latitude and longitude) of each individual ‘poll’ from VMS data (see Chapter 2) taken from the 2004 Commonwealth Central Bass Strait scallop fishery were plotted using the software package ArcView GIS 3.2a for Windows. VMS ‘hits’ falling outside the area of this particular study site were eliminated from the data set used in this analysis. In addition, VMS ‘polls’ recorded from boats within the study area but moving at speeds greater than 8 knots (measured or calculated speed) were classified as travelling boats and were also eliminated from the dataset. This speed is higher than that used for dredging and provided a natural break in the available data, thus preventing dredging vessels demonstrating short term changes in speed from being classified as travelling vessels (see Chapter 2).

A grid creator extension in ArcView 3.2a was used to place a 100m x 100m grid over the entire extent of the study area. This grid size was chosen as it was the smallest scale that could be used to reflect fishing activity as a continuous polygon within the fished region. A ‘point count’ script was used to perform a count of the total number of VMS hits falling within each individual 100 m x 100 m cell. These counts were then classified into three categories of inferred fishing activity: no fishing activity, low fishing activity and high fishing activity. The different fishing activity categories implied the cells contained different relative numbers of VMS hits. Because of the confidentiality and security agreements between TAFI and AFMA / DPIWE, no explicit quantification of the number of hits making up each category can be given, however,

Table 10.1 gives an indication of the abundance of VMS hits within each category, relative to the lower bound number of hits (= 1) in the minimal fishing activity category.

Table 10.1. Relative abundance of VMS hits in the different fishing activity categories. No indication of absolute intensities can be given for confidentiality reasons.

Activity Category	Relative Lower Bound	Max. Relative Upper Bound
High Fishing	> 3.0	<9.0
Low Fishing	>1.0	< 3.0
No Fishing	<1.0	

The main assumption of this methodology was that areas containing higher VMS counts correspond to areas of increased fishing activity. Furthermore, areas of higher fishing activity were assumed to overlay areas containing higher abundances of scallops, while areas of no fishing activity were assumed to overlay areas of scallops of such low densities to be of no commercial interest. Dredge and video data supported these assumptions.

10.2.3 Single beam acoustic survey design

The study site was surveyed using single beam acoustics in December 2003. The Fisheries Research Vessel *Challenger* was fitted with a Simrad ES60 single beam sounder with a 120 kHz 10^{o} transducer pole mounted on the starboard side of the vessel approximately 1.5 m below the surface of the water. The echo sounder was set to run at 500 W and 1.024 ms pulse length, with a signal frequency of 1 ping per second. The raw data from the echo sounder, including the entire first and second echoes, were logged through the BI500 port option of the Simrad ES60 software (Version 1.5.0.73) to a laptop computer. A Differential GPS was connected to the laptop to allow position information to be logged with the raw echogram. During the survey, the echo data was visually checked for excessive noise and / or interference and aeration under the transducer. If poor data were received, sampling was delayed until conditions improved.

The vessel was driven at approximately 6 kts along a series of parallel transects. Transects were conducted at 500 m spacing in the north / south direction and 250 m spacing in the east / west direction, which resulted in a grid pattern across the study site. The navigation software OceanVision was used to plot position and maintain course.

The study site was open to commercial dredge fishing, from May 1st 2004 to December 21st 2004 as part of the Commonwealth Central Bass Strait fishery's management process. As VMS data indicated that all fishing within the study site had ceased by the end of September 2004, the FRV Challenger repeated the 2003 pre-fishing survey design in October 2004, as a post-commercial fishing survey. The equipment used in both surveys were identical, and the grid tracks sampled during 2003 were repeated in 2004, with over 53% of points sampled within 20 m of the previous year and 86% within 50 m.

10.2.4 Single beam acoustic data analysis

For both the 2003 and 2004 data, the Java utility software es60adjust.jar (CSIRO Marine Research Laboratories) was used to correct the inbuilt triangle wave error of ± 0.5 dB inherent to the Simrad ES60 single beam echo sounder. The corrected raw ES60 acoustic data was then imported into the acoustic processing software Echoview 3.30 (SonarData) for further analysis. This software allowed a calculation of acoustic indices from the raw echo data using an approach similar to that of Kloser *et al.* (2001).

The first and second echo-returns from the transducer (see Figure 10.2) were used to define two indices based on a RoxAnn type approach to seabed classification, which are equivalent to the E1 and the E2 parameters. The E1 parameter is derived from an integration of the tail of the first acoustic bottom return (Figure 10.2) and the E2 parameter is derived from an integration of the complete second acoustic bottom return (Siwabessy *et al.* 1999). The rationale of this is that the energy in the tail of the first acoustic bottom return (E1) arises from the roughness of the seabed and that the entire second acoustic bottom return (E2) arises from the acoustic impedance mismatch of the seabed and water column. This E2 parameter is customarily taken to be a proxy for the 'hardness' of the seabed (Siwabessy *et al.* 1999).

The calculation of the E1 and E2 indices were based on defined regions of the echogram and were modified from those of Kloser *et al.* (2001), as described below, to maximise the discrimination power of these two indices given the echo sounder settings and depth range. The E1 was calculated as an integration of the average echo s_A (Nautical area scattering coefficient) in a region between two user defined lines. These lines are based on the sounder detected bottom and set at off-axis angles of 15 and 30 degrees plus a 1 pulse offset (+0.48m). The E2 value was calculated as an integration of the average echo s_A between a line set at two times water depth and a second line at 2.3 times water depth. The s_A data (Nautical area scattering coefficient) was converted to S_A (Nautical area scattering strength) using the formula:

$S_A=10\log_{10}(s_A)$

This gave the data the units dB re m^2 n.mile^{-2}.

An interpolation technique known as kriging was used to convert the raw E1 and E2 point data for each survey (2003 and 2004) to a continuous surface coverage. The variogram function of the software program Surfer8 (*Golden Software*) was used to visualise the spatial trends in the data within a 2d graphical format. A spherical model with nugget, best described the trends in the data and was used as the model in the kreiging process. The raw 2003 and 2004 datasets were interpolated using this model with a 5m grid cell. This grid size was chosen, as the average spacing between raw acoustic values was 5 meters and as such, the kriging technique would be interpolating at the scale of the raw data set. Subsequently, four maps were created, which represented the 2003 E1 and E2 parameters and the 2004 E1 and E2.

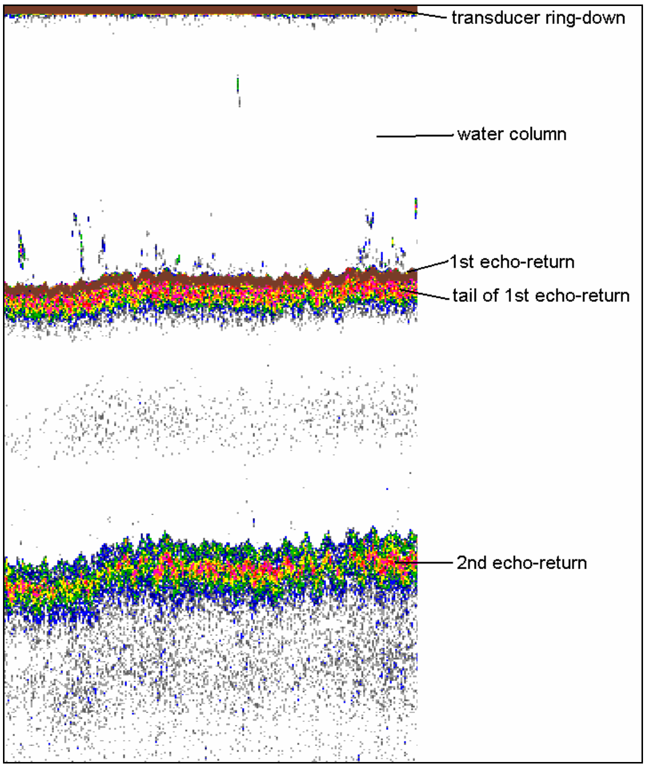

Figure 10.2. Acoustic output from Simrad ES60 120 kHz single beam echo sounder, set at 500 W and 1.024 ms pulse length.

10.2.5 Detecting Scallop Habitat using Single-Beam Acoustics

To identify which areas of the study site contained scallop habitat, areas in which VMS data showed fishing had occurred were overlayed on the 2003 E1 and E2 graphical datasets collected prior to commercial fishing operations. Individual E1 and E2 acoustic ping values for a sub-sample of the entire study site were assigned a category based on the spatial overlap with inferred fishing activity. The categories used were high fishing, low fishing and no fishing. This reduced dataset was then plotted as a scatter plot. If the acoustic signal (E1 / E2 combined) was unique within scallop habitat, it was anticipated that the E1 / E2 values would group together within a different region of the scatter plot.

10.2.6 Detecting the Impact of Scallop Dredging using Single-Beam Acoustics

Differences in the 2003 E1 / E2 and 2004 E1 / E2 raw data grids were compared using the ‘grid math’ function of Surfer8. This function calculates a difference grid between two input grids. Areas of VMS inferred fishing activity were overlayed on these difference maps in an attempt to determine the potential use of single beam acoustics in determining the impact of fishing on soft bottom habitats. No statistic analyses were conducted as visual observations provided sufficient evidence for the potential use of this technique in identifying the impact of fishing on soft bottom benthic habitats within the Commonwealth fishery.

10.2.7 Bathymetry

Depth measurements from the Simrad ES60 were used to construct a bathymetric model. The sounder detected bottom was exported using Echoview3.30 and corrected for the transducer depth in the water column. These depths were then corrected for tidal variation based on predicted tide information and using the formula:

$$D_i = D[h_1+(h_2-h_1)*(\cos(\pi*((t-t_1)/(t_2-t_1)+1))+1)/2]$$

Where D_i is corrected depth and D is measured depth, $h_{1,2}$ correspond to the heights of the high and low tides, $t_{1,2}$ are the times of the high and low tides with t being the current time.

All depth measures were then corrected to Mean Sea Level based on the available standard port measurements from the Australian National Tide Tables. The bathymetric model was constructed using the TIN (Triangular Irregular Network) feature in *ArcView3.2*. One meter depth contours were generated from this TIN model and manually smoothed to remove model artefacts.

10.2.8 Side Scan Sonar

In March 2005 the study site was surveyed using a GeoAcoustics 114 khz side scan sonar. The side scan was deployed from the FRV *Challenger* on 100 m of cable and flown approximately 20 m from the seafloor at 7 kts. The side scan was towed in a north / south direction, with a 200 m transect spacing and the range of the swath set at 200 m. The raw side scan data was processed by Fugro System, and supplied as a 1 m resolution georeferenced BIL file (binary image library file) of acoustic backscatter intensity. This file was imported into a GIS platform and areas of known fishing activity, as identified by VMS, were overlayed in an attempt to visualise known scallop habitat from other soft bottom habitats. Although the use of the side scan sonar to survey the study site was opportunistic rather than being part of the initial single beam acoustic survey design, it did allow a basic determination for the potential to use acoustic swath technology to identify scallop habitat, and to compare the benefits of swath acoustic technology compared to single beam acoustic technology.

10.3 Results

10.3.1 Identifying Levels of Fishing Activity

VMS inferred fishing activity identified strong spatial trends across the study site, with most activity occurring on the eastern (left) side of the study site (Figure 10.3). The majority of the study site had no significant (detectable) levels of fishing activity.

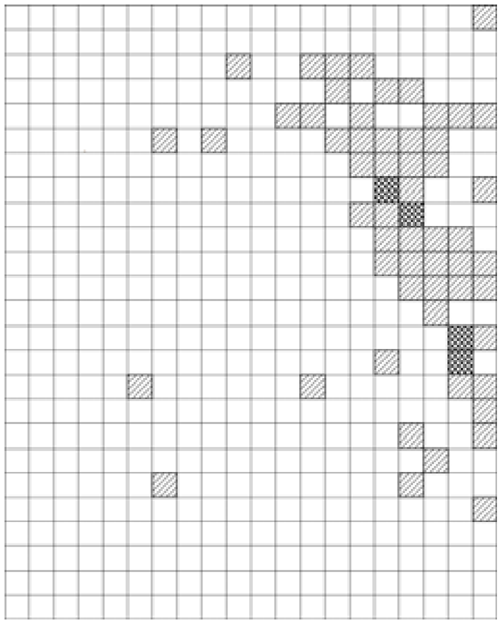

Figure 10.3. Fishing activity across the study site for the 2004 Commonwealth scallop season as inferred from VMS data and based on a 100 m grid cell. The cross-hatched grid cells represent maximum fishing activity, the diagonal hatched grid cells minimal fishing activity, and empty grid cells no fishing activity.

10.3.2 Single beam acoustics – detecting scallop habitat

In general, the northeast corner of the study site (top left) had the lowest recordings of E1 and E2 values, however, several bands of low E1 and E2 were found to run in a NNW – SSE direction near the middle of the study site (Figure 10.4 and 10.5). These areas represent substrates that are acoustically softer relative to the other sampled areas. The southwest corner of the study site contained the highest E1 values, however, this difference was less pronounced for the E2 values (Figure 10.4 and10.5). This area is acoustically rough relative to the remainder of the study site.

When VMS inferred fishing activity is overlayed on the E1 and E2 diagrams, most fishing activity was concentrated along the gradient between the acoustically harder and rougher central part of the study site and the acoustically softer and smoother northeast corner (Figure 10.4b and 10.5b). This area, however, did not show a unique combination of acoustic E1 and E2 values, with similar areas being found within areas overlaying fishing activity, and areas overlaying no fishing activity (Figure 10.6).

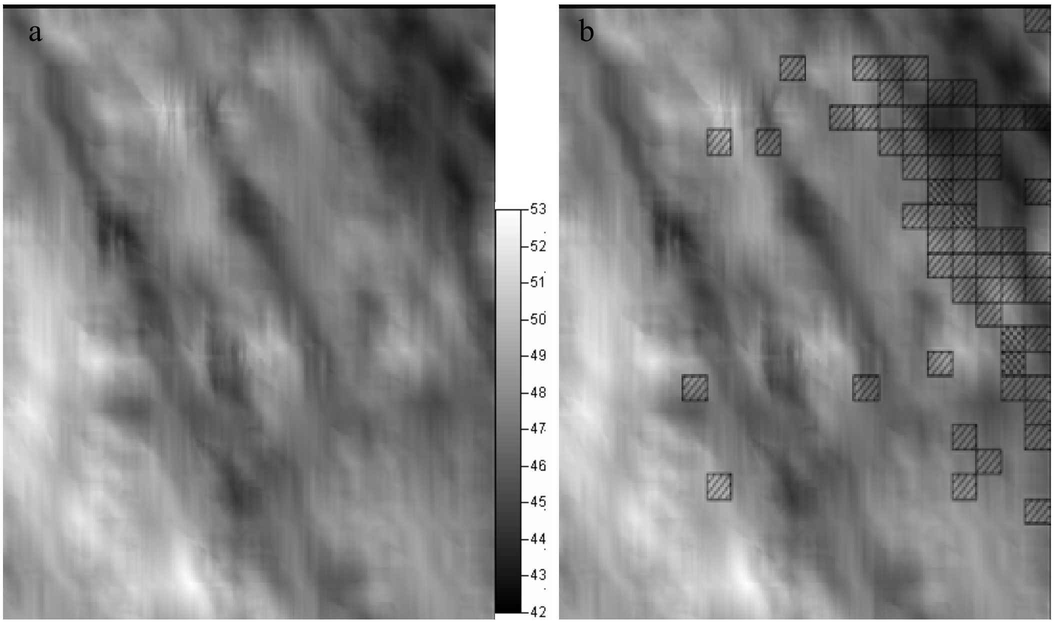

Figure 10.4: Map indicating the interpolated surfaces of the 2003 E1 acoustic index **(a)** and E1 acoustic index with inferred fishing activity overlayed **(b)**. Cross hatch grids indicate maximum fishing activity, diagonal hatched grids minimal fishing activity and all other areas no fishing activity.

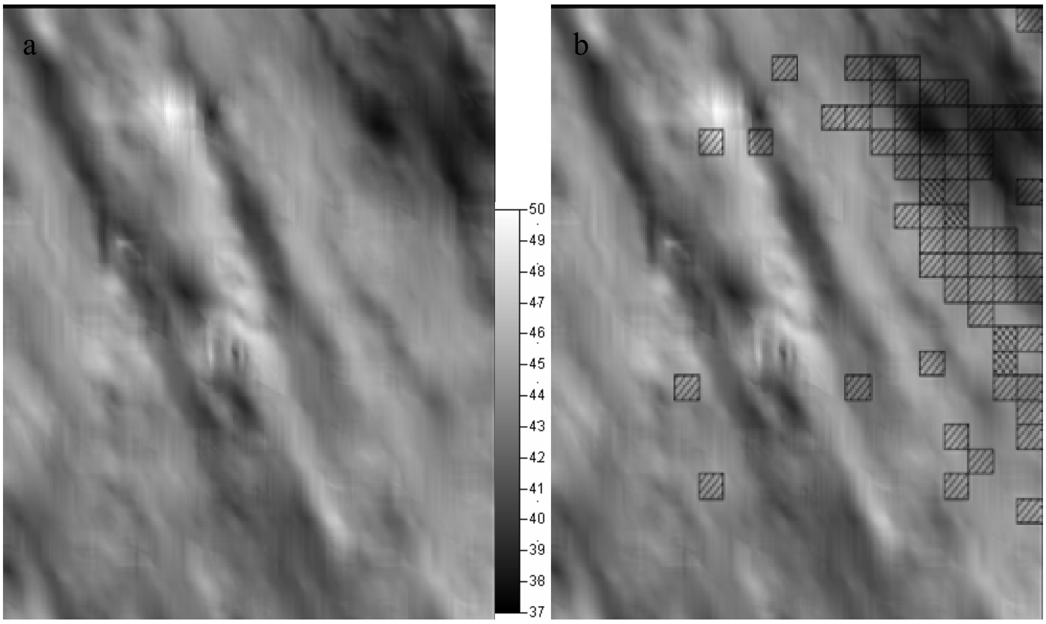

Figure 10.5: Map indicating the interpolated surfaces of the 2003 E2 acoustic index **(a)** and E1 acoustic index with inferred fishing activity overlayed **(b)**. Cross hatch grids indicate maximum fishing activity, diagonal hatched grids minimal fishing activity and all other areas no fishing activity.

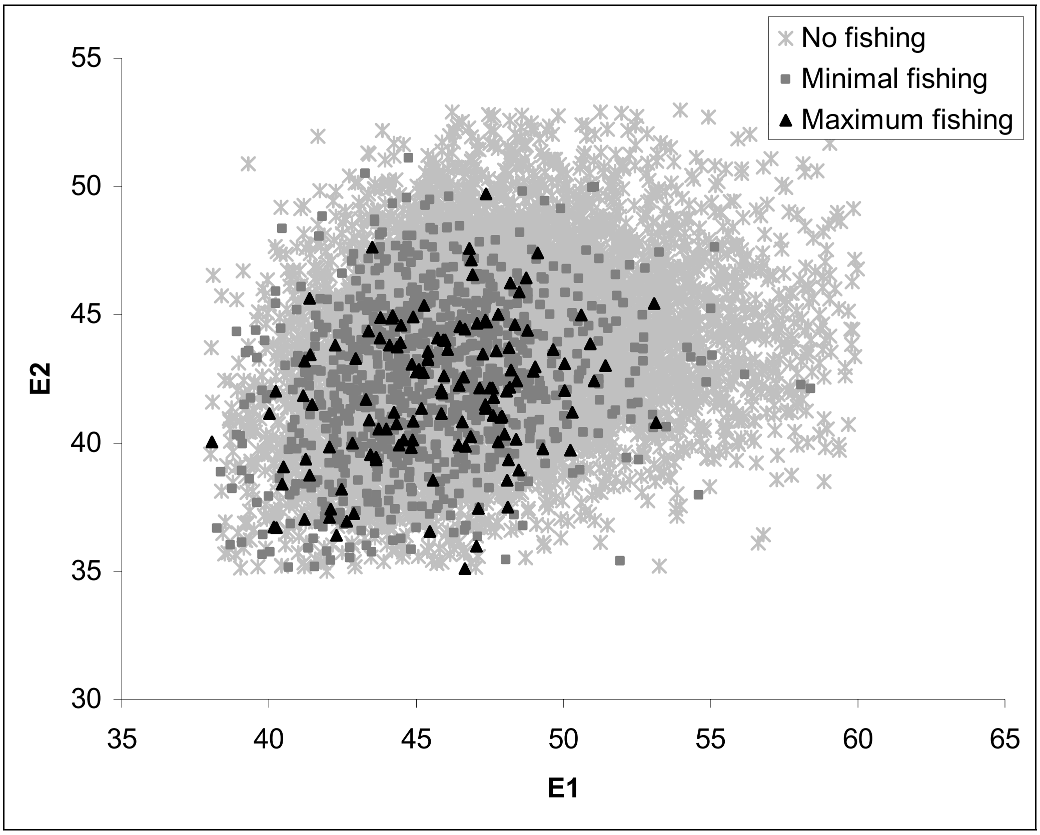

Figure 10.6: Scatter plot of the categorised E1 / E2 index combinations for 2003 data.

10.3.3 Single beam acoustics – detecting the impact of scallop dredging

E1 comparison

The comparison map for changes in the E1 values from 2003 and 2004 data showed that the majority of the study site (59%) recorded less than ± 1.5 dB of change. However, extensive areas did have an increase of up to 5 dB in E1 values and a small area to the southwest corner (lower left) had up to a -4 dB decrease in E1 values (Figure 10.7), but these were not areas covered by fishing. As such, there does not appear to be a correlation between changes in E1 acoustic index changes and inferred fishing activity.

E2 comparison

The majority of the study site showed less than ± 1.5 dB change in E2 acoustic index values (59%). Approximately 38% of the study site recorded a decline of up to -7 dB, while remaining areas recorded an increase in E2 of up to +4 dB (Figure 10.8). All changes were spread throughout the entire survey area, and do not appear to correlate closely with fishing activity (Figure 10.8).

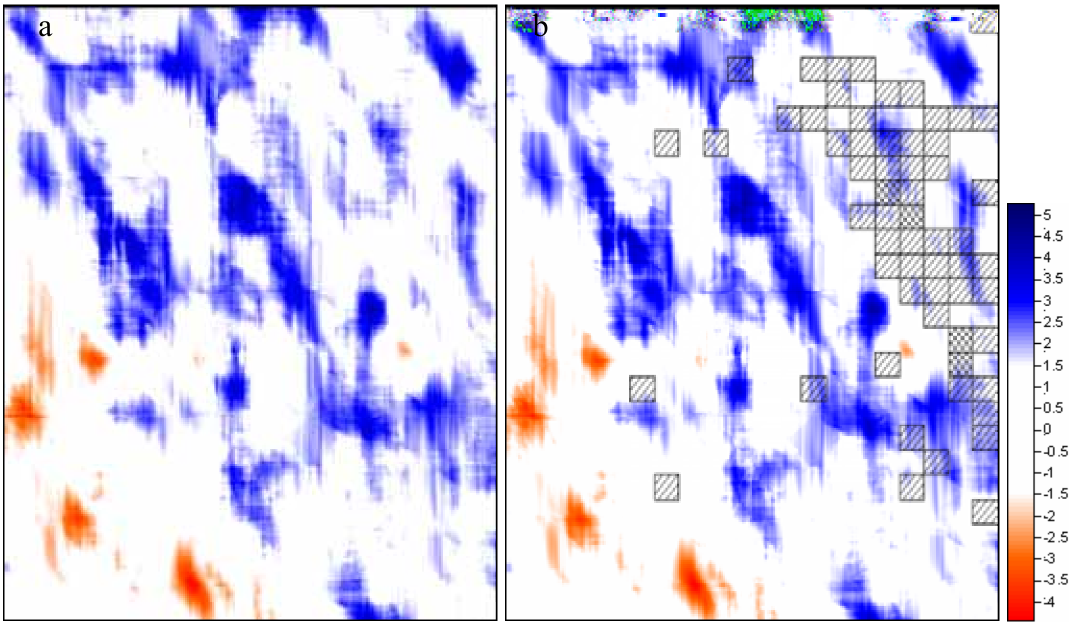

Figure 10.7: Map showing change of acoustic index E1 for the study site between the December 2003 and October 2004 surveys (**a**) and with inferred fishing activity using 100m grids overlayed (**b**). Cross hatch grids indicate maximum fishing activity, diagonal hatched grids minimal fishing activity and all other areas no fishing activity.

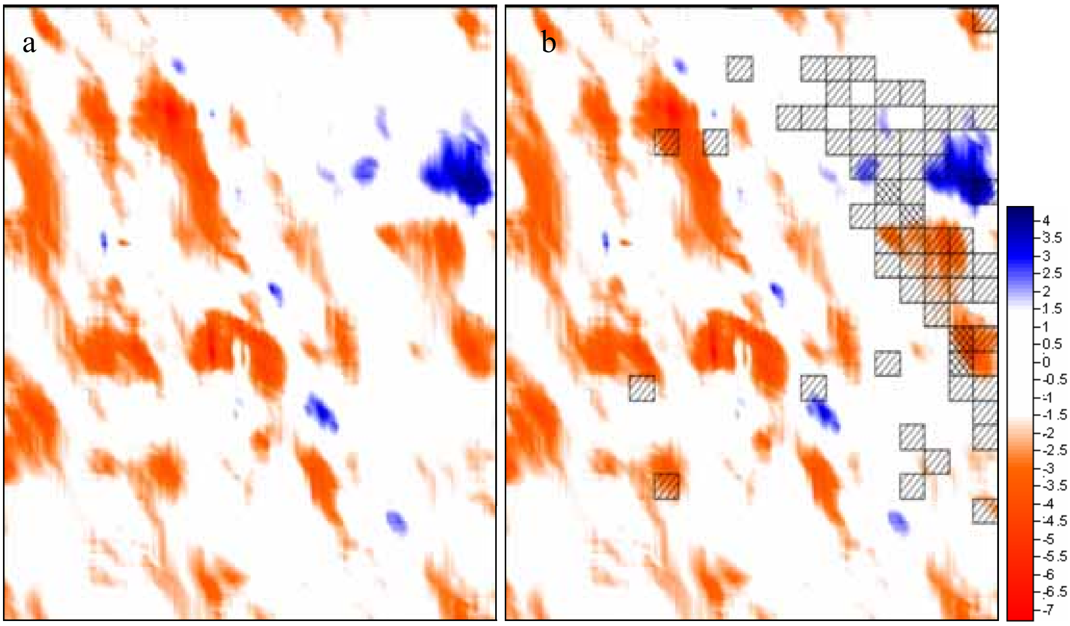

Figure 10.8: Map showing change of acoustic index E2 for the study site between the December 2003 and October 2004 surveys (**a**) and with inferred fishing activity using 100m grids overlayed (**b**). Cross hatch grids indicate maximum fishing activity, diagonal hatched grids minimal fishing activity and all other areas no fishing activity.

10.3.4 Bathymetry

The bathymetry of the study site was characterised by a gently sloping seafloor. The depth ranged from 37m on the southwest corner, to a maximum depth of 44m in the northeast part of the study site (Figure 10.9). No significant bathymetric features were noted in the study site, however, most fishing activity occurred around the 42 m / 43 m contour near the northeast corner of the study site (Figure 10.9).

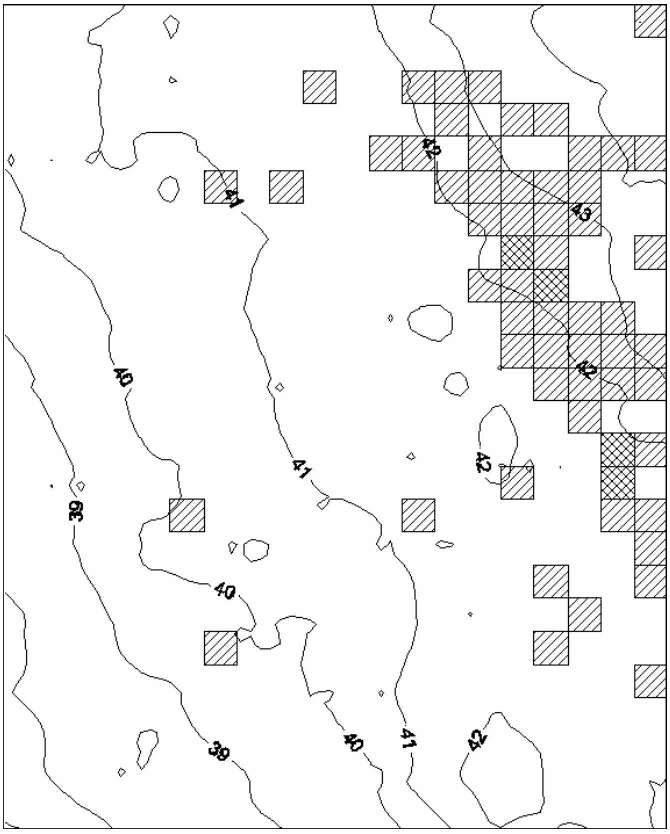

Figure 10.9. Bathymetry of the study site based on interpolation of the single beam acoustics with areas of fishing activity overlayed.

10.3.5 Side scan sonar

The side scan sonar image identified distinct structuring in the backscatter pattern within the northeast corner of the study site (Figure 10.10). Similar patterns of backscatter were also seen running in a NNW-SSE direction. Both these features were apparent on the single beam, E1 / E2 data (Figure 10.10). Areas of fishing activity were found to concentrate along the boundary of the northeast area (Figure 10.10).

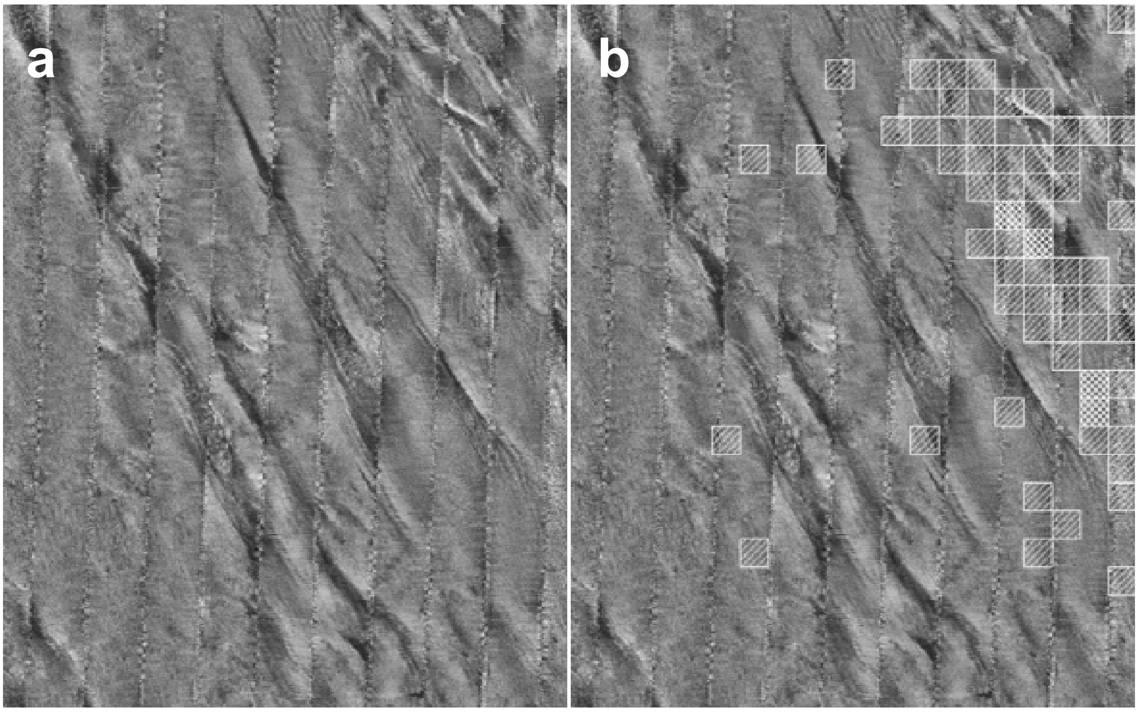

Figure 10.10. Geo-referenced side scan sonar image of the study site from March 2005 (a) and with the 100m fishing activity grid overlayed (b), The cross hatched grid cells represent maximum fishing activity, the diagonal grid cells minimal fishing activity, and all remaining areas (no grids) no fishing activity.

10.4 Discussion

10.4.1 Detecting Scallop Habitat using Single Beam Acoustics

Results from the single beam acoustic survey showed that VMS inferred scallop habitat within the study site did not display a unique signature based on the two simple acoustic indices (E1 and E2) used in this study. The swath map created by the side scan sonar identified a similar pattern of acoustic bottom types within the study area, however, fishing activity did not appear to correspond to an obvious single acoustic bottom type for either technique.

Substrate type greatly influences where a species may or may not occur, however, other environmental factors can also influence where a species occurs. Video and dredge survey results from the Commonwealth and Tasmanian-managed scallop fisheries suggest that areas containing suitable substrates for scallops (coarse sand) do not necessarily contain scallops or a scallop bed. Similarly, Kostylev *et al.* (2001) found that scallop and three other types of habitat could occur within the 'gravel lag with thin sand' substrate type. By incorporating a detailed habitat mapping approach, which used geological and biological data to ground-truth the multi-beam data, Kostylev *et al.* were able to distinguish different habitats, which occurred within the same substrate type.

Although a comprehensive habitat mapping approach, which would ground-truth acoustic signals with sediment and video data, may allow the determination and location of scallop beds within the Commonwealth and Tasmanian-managed scallop fisheries, such a process would substantially increase the time and costs associated with data collection and analysis. For example, sediment grabs and video footage would need to be collected during the survey itself and post-survey time devoted to sediment particle size analyses, and video analysis. Furthermore, comprehensive habitat mapping approaches require specific expertise for sampling, equipment and analysis techniques.

In conclusion, the apparent inability of simple acoustic approaches to detect scallop beds from a background of other acoustically similar soft sediment habitat types make the use of single beam and swath acoustics unattractive as a quick, low cost alternative to dredge surveys. The time and expertise required to properly identify habitats and map their spatial distribution also make dredge surveys a more appropriate method for locating commercially exploitable scallop beds within the Commonwealth and Tasmanian fisheries. However, comprehensive acoustic mapping of target areas could provide invaluable information about the location of scallop beds, and their distribution in relation to other soft bottom habitats, which in turn would increase our knowledge of scallop biology and ecology.

10.4.2 Is bathymetry the answer?

Within the surveyed region of the Commonwealth fishery, scallops appear to have settled along the 42 m / 43 m contour. Water depth may have several important influences over the successful settlement of scallops, and subsequent formation of a scallop bed within a region. Firstly, depth will influence water currents, which in turn impact the successful dispersal and settlement of scallop larvae. Furthermore, the survival of settled larvae is most likely reliant on the habitat within which they have settled. Although the combination of physical and environmental parameters required to promote successful settlement of scallops within an area are unknown, it appears that favourable settlement conditions within the study site occurred along the 42 / 43 m depth contour but not in adjacent shallower or deeper regions containing similar soft sediment habitat types at the time the bed of scallops fished in 2004 settled from the plankton. Having said this, it must be emphasized that scallop beds were found across a range of depths during this study, with good beds of scallops found in < 10 m within southern areas of Tasmania, and to a maximum of approximately 80 m east of Eddystone Point. The advent of the scallop bed in C5b along the 42 – 43 m contour lines may simply indicate that a single large larval cloud was involved in the generation of the scallop bed and the currents at the time channelled the settling larvae into this depth range.

10.4.3 Detecting the Impact of Dredge Fishing

Comparisons of the acoustic difference maps comparing 2003 and 2004 single beam acoustic data failed to identify any trends in the rate of change in E1 and E2 acoustic indices and occurrence of fishing activity, with increases, decreases and no changes in values observed within all fishing activity categories. Previous studies looking at the short term impact of intensive trawling on the benthos have identified increases in E1 values and decreases in E2 values within more impacted sites (Humborstad *et al.* 2004). Other studies, however, have identified variations in E1 and E2 values over two surveys in the absence of fishing disturbance (Greenstreet *et al.* 1997). Such variations have been attributed to differences in the survey coverage, potential changes in the transducer attitude and seasonal changes in the acoustic properties of the sediment. Environmental conditions at the time of survey can also affect single beam acoustic surveys (Cholwek *et al.* 2000; Kloser *et al.* 2001). Collins and Galloway (1998) showed that acoustic diversity could be related to sediment particle size and the presence or absence of shell debris. The presence of distinct benthic communities has also been shown to influence the acoustic response of the seabed through bioturbation or the presence of superficial organisms (Cadell 1998; Pinn and Robertson 1998; Freitas *et al.* 2003a; Freitas *et al.* 2003b).

Such temporal variations in equipment and environmental conditions could potentially result in the observed temporal changes in acoustic indices identified in this study. Large swells preceding the October 2004 survey, resulting in the movement of substrates both vertically and horizontally within the survey region (personal observations). Furthermore, the residual 2 to 3 meter swell present during the survey caused a greater degree of vessel pitch and roll, relative to the November 2003 survey, which may affected the measured single beam acoustic indices. The small spatial scale that different habitats potentially occur over within the study site (< 100's m) and fishing behaviour within such an array of habitats (see Chapters 2 and 14) may influence the ability to acoustically detect changes to the benthos due to fishing disturbance. As previously mentioned, the same acoustic tracks were covered for both surveys, ± 10's of meters. There is potential for such error between replicate acoustic tracks to result in the sampling of different substrates within the same spatial area of the survey grid, especially given the known complex nature of habitats within the survey region. Such variation in sampling could easily account for changes in acoustic index values pre and post commercial fishing. Furthermore, the level of fishing imposed on the study site may not have been at levels that would adversely impact the benthos / substrate, and as such, no trends were observed. Other possible influences, which need to be considered include the dynamic nature of the environment within the survey region, with high tidal currents and impact of large seas. Such influences may result in rapid changes in the distribution of habitats, and as such, the techniques used in this study may have identified natural changes in the environment.

10.5 Conclusions

Single beam acoustic surveys do not appear to have any time or cost associated savings, relative to dredge surveys, in locating scallop beds within the Commonwealth-managed scallop fishery area. Furthermore, such techniques failed to detect any observable impacts or differences attributable to fishing on E1 and E2 acoustic values within the study site. However, further development of the technology and methodology may have the potential to complement traditional dredging techniques, and increase our knowledge of the biology and ecology of commercial scallops in the future.

11. FISHERY DEPENDENT SURVEYS.

11.1 Introduction

Chapters 9 and 10 explored the potential use of video technologies and acoustic sounders to conduct fishery-independent surveys of scallop beds. Such methodologies were identified as having the potential to allow a cost-effective fishery-independent survey of scallop beds, as a greater area of the fishery could be explored for the same costs, relative to fishery-independent dredge surveys. Although preliminary results from both methodologies showed some promise in identifying scallop habitat and abundance, problems associated with the survey techniques and post-survey processing of data made reliable identification and determination of scallops and their abundances difficult. While each method may have potential applications in future scallop surveys, limitations with the current technology mean these approaches do not appear to be the most effective means of collecting data on scallop distribution and abundance.

Consequently, some means of direct broad spatial scale surveying scallop habitat is still required in order to implement effective spatial management regimes. One possible means for acquiring such information would be to devise some means of encouraging Industry members to collect the information necessary to generate the management advice for their own fishery.

The main aim of this chapter was to:

1) briefly explore the methodologies of a trial industry survey conducted in Tasmanian waters during 2003;
2) provide a brief summary of the survey results and identify the problems associated with the survey techniques and data collected; and
3) discuss the future use of Industry in scallop surveys (FRDC project 2005/027, “Facilitating industry self-management for spatially managed stocks: a scallop case study”)

11.2 Exploratory Permit Fishing, 2003

11.2.1 Expression of Interest and Allocation of Permits

After a three year closure starting in 2000, a small area of the Tasmanian scallop fishery reopened to commercial fishing in June 2003. At the time of this reopening, the only knowledge of scallop stocks within the fishery came from fishery-independent surveys conducted by TAFI in waters east and west of Flinders Island, and in Banks Strait. In an attempt by the Tasmanian Scallop Fishery Advisory Committee to determine if there were scallops beds in other regions of the fishery, the Tasmanian Department of Primary Industry, Water and Environment (DPIWE) called for expressions of interest from commercial scallop fishers to conduct exploratory fishing operations within closed areas of the fishery under special permits.

In June 2003, a total of 23 permits were issued to commercial scallop license holders. The key requirements of these permits were 1) catch could be retained from fished areas, however, 2) this was considered as a compensation for exploratory fishing (grid searches) within the $^{1}/_{8}{}^{th}$ degree scallop fishery management blocks allocated to each fisher, 3) a maximum quota of scallops could be caught during the surveys and 4) data sheets (fishing log and catch log) had to be completed for every tow conducted, and survey procedures (i.e. grid searches within allocated areas) must be followed for every tow (see Appendix 11.2). The permits were active initially from the 17th June 2003 to the 13th July 2003, however, the permit period was extended to August 2003 to allow further exploratory fishing to occur.

At the completion of the permit exploratory fishing period, only 9 permit holders had undertaken surveys and submitted their data to DPIWE.

11.2.2 Methodologies: Data Entry and Analysis

The TAFI scallop research team had agreed to assist DPIWE with the analysis and reporting of this fishery dependent survey data. Datasheets submitted to DPIWE were sent on to TAFI, and data was entered initially into an Excel spreadsheet. The two main objectives for the analysis of this data were 1) to identify the relative abundance of scallops within specific surveyed locations and, 2) to determine the size structure of scallops within different surveyed regions (length frequency analysis).

The minimum data requirement, allowing the determination of location and abundance of scallops, were a start latitude and longitude and an estimate of the total catch from each sample tow. In order to standardise the catches of scallops in different areas (for presentation purposes), an estimate of the number of scallops caught per 1000 m sample tow was determined, a calculation which required tow speed and shot duration. Not all data sheets provided all the necessary data, but for those that did the location and relative abundance of scallops caught in sample tows was mapped using the GIS program Arcview 3.2a for Windows.

In order to determine the size structure of scallops within a given area, some indication of the location of the sample tow (preferably a latitude and longitude), an estimate of the total catch, and a measure of the maximum diameter of a set of randomly selected scallops from the catch (preferably 50) was required. The size distribution of measured scallops was then scaled to the estimate of the total catch. For presentation purposes, the properties of the size distributions of scallops from each area were plotted as length frequency histograms. Two mm size classes were used (to reduce noise) using all available data.

Data presented within this report will not always use a reference to coastlines / locations in order to not disclose those persons who conducted surveys.

11.2.3 Results: an Overview

The location and abundance of scallops caught per 1000 m dredge tow are shown in Figure 11.1. Within many surveyed areas, there appears to be a trend for data to be collected when in areas of high scallop abundance, but to provide less data from areas assumed to have lower or zero abundance. This was potentially a consequence of fishers being able to retain catch taken during the survey and not appreciating that knowledge of where scallops are not available also has value for spatial management.

Length frequency plots were able to be generated for each discrete area surveyed (Figure 11.2), however, compared to the total number of sample tows conducted and total number of scallops caught, relatively few scallops were measured. Furthermore, there were many sample tows where no scallops were measured so the estimates of scallop size are greatly influenced by only a few locations; though these locations may have been the densest areas of scallops.

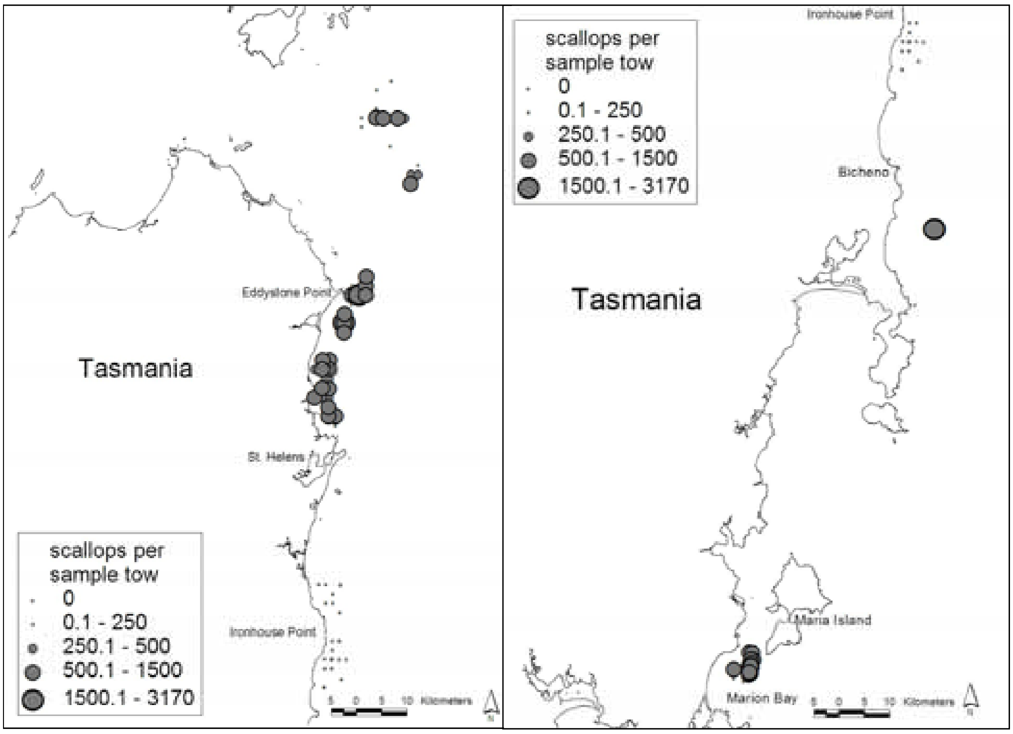

Figure 11.1. Abundance distribution results from data collected from the 2003 permits. Note that the size of the circles do not illustrate the size of a patch of scallops but the number of scallops caught standardised to the number per 1000 m dredge tow.

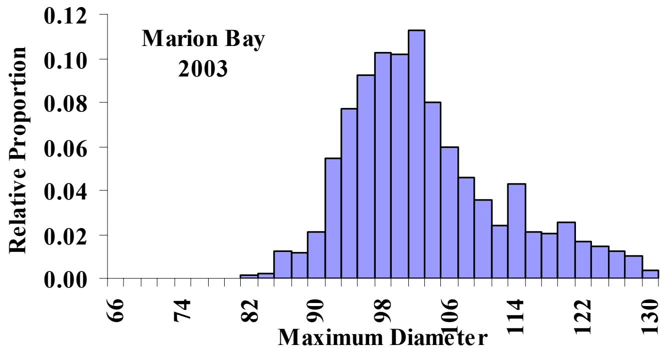

Figure 11.2. Length frequency distribution from one of the survey vessels in the 2003 fishery conducted permit survey.

11.2.4 Usability of Data in Analysis / Presentation

Data collected by commercial fishers during the 2003 exploratory permit season could be broadly categorised into three groups with respect to the amount of data recorded and their possible use in data presentation and usefulness as a data source for aiding the management of the Tasmanian scallop fishery.

11.2.5 Complete Data / Survey Technique

Of the total data acquired, only a small amount (approximately 20%) could be categorised as complete data collection and survey techniques. Such data required data sheets to be completed fully, without ambiguity. Furthermore, sample dredge tows needed to be conducted in a grid-like manner across the extent of the survey area (fishing locality block), and a sufficient number of scallops measured from each tow, or at least a high proportion of sample tows.

Data submitted in a complete form was generally easy to interpret and enter into the database, and gave a clear indication of the available scallop stocks and their size distribution within a region (Figure 11.3). A very important factor in this figure is the presence of data for low / no scallop abundance areas, a consequence of the grid-like search conducted within the majority of the survey region. Areas not surveyed were either land masses, or were in depths and habitat types not suited to scallops.

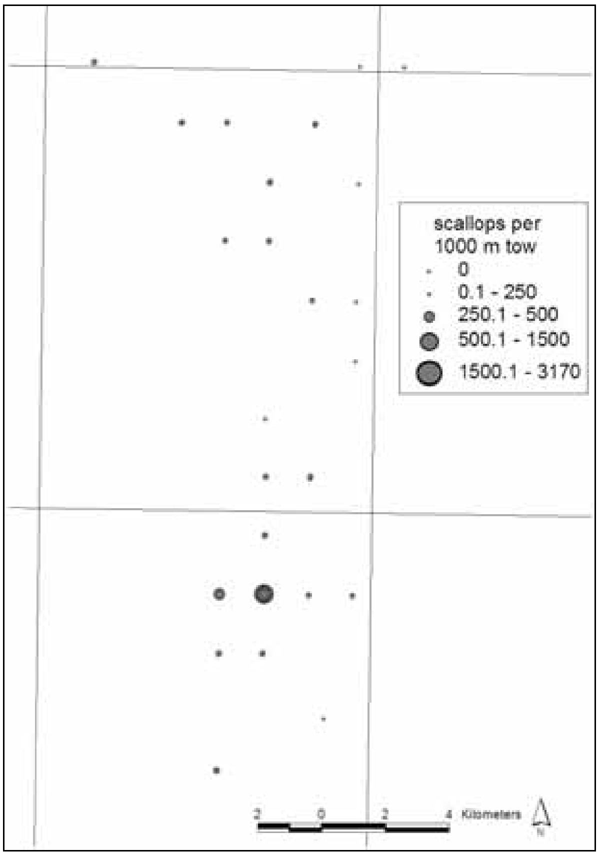

Figure 11.3. Spatial distribution and abundance of scallops from complete data sets submitted after the 2003 permit survey season. The lines on the map indicate different fishing locality blocks.

11.2.6 Partially Complete Data / Survey Technique

The main reason for categorizing some data contributions as partially complete data / survey technique was that there were missing or uninterpretable information on data sheets. The types of missing data and their consequences were varied (Table 11.1), and accounted for approximately 55% of received data.

Partially complete survey techniques limited the knowledge of scallop stocks within many surveyed regions. In particular, although data sheets were generally complete, the data provided was often clumped into small areas of high scallop abundance and not randomly spaced in a grid like fashion throughout the entire locality block surveyed (Figure 11.4). Such clumping of survey data may have been the consequence of unsuitable habitat / hard ground within the unsurveyed areas, however, no justifications or reasons for the non-grid like sampling pattern were recorded on the datasheets. It is also possible that no scallops were found elsewhere but zero catches were not recorded.

Table 11.1: Types of missing data and the consequence of this missing data.

Data field missing	Consequence
Latitude / Longitude	Specific location of scallop abundance / population structure data unknown.
Tow speed	Unable to calculate the number of scallops per 1000 m tow.
Shot duration	Unable to calculate the number of scallops per 1000 m tow.
Total catch	Unable to determine the abundance of scallops within a survey area.
< 20 scallops measured	Low confidence in population structure within an area when scaling up to total catch.
No scallops measured	Unable to determine the population structure of scallops within an area.
No sample tow number	Unable to match location data with catch / scallop size data.
Uninterpretable data	Any of the above consequences depending on the data that could not be interpreted.

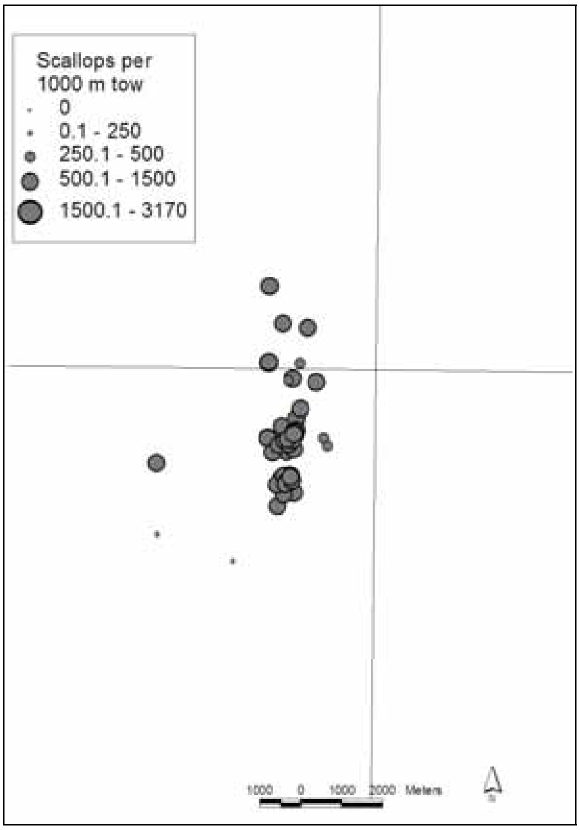

Figure 11.4. Spatial distribution and abundance of scallops from partially complete data sets submitted after the 2003 permit survey season. The lines on the map indicate different fishing locality blocks. The clumping of samples within dense areas is obvious. Whether other stations were occupied but no scallops were found is unknown/uncertain.

11.2.7 Incomplete Data / Survey Technique

Being categorized as incomplete data / survey technique was generally the result of missing or uninterpretable data from two or more of the required data fields (Table 11.1), in particular the total catch of scallops and the shell length measurements from these scallops. Data was also deemed incomplete if the units of measurement were unknown. For example, a total catch of 15 could imply 15 scallops, or 15 kg of scallops (=150 scallops), or 15 bins of scallops (= between 4500 and 6000 scallops depending on their size). Many datasheets also contained general comments for a grouping of sample tows, i.e. '25 drags in this area, lots of small scallops'. It was difficult to present such data adequately or accurately and so to gain full knowledge of the abundance and size of scallops from such areas would require further surveying.

Such incomplete data led to minimal knowledge of scallop stocks within some areas. For example, complete data from a survey region allows the determination of scallop abundance and length frequencies (Figure 11.5), while incomplete data can identify the location of all sample tows conducted within the area but neglects to inform with respect to abundance or size (Figure 11.6). Consequently, although the entire survey region was covered, usable data is only available for a small portion of sample tows.

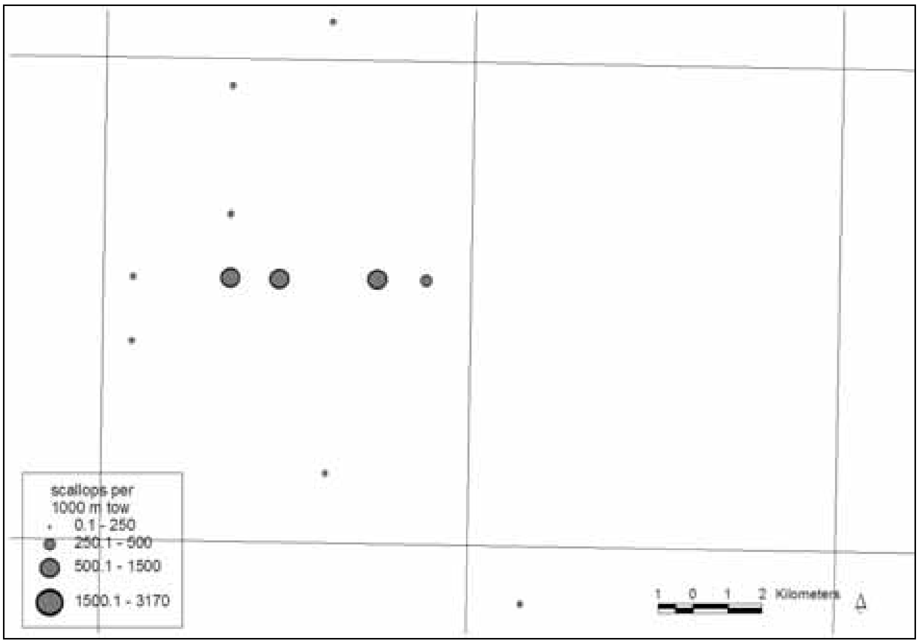

Figure 11.5. Location of sample tows with usable (complete / partially complete) data. Only part of a sampling grid is visible. This leaves a high degree of uncertainty about the remaining area.

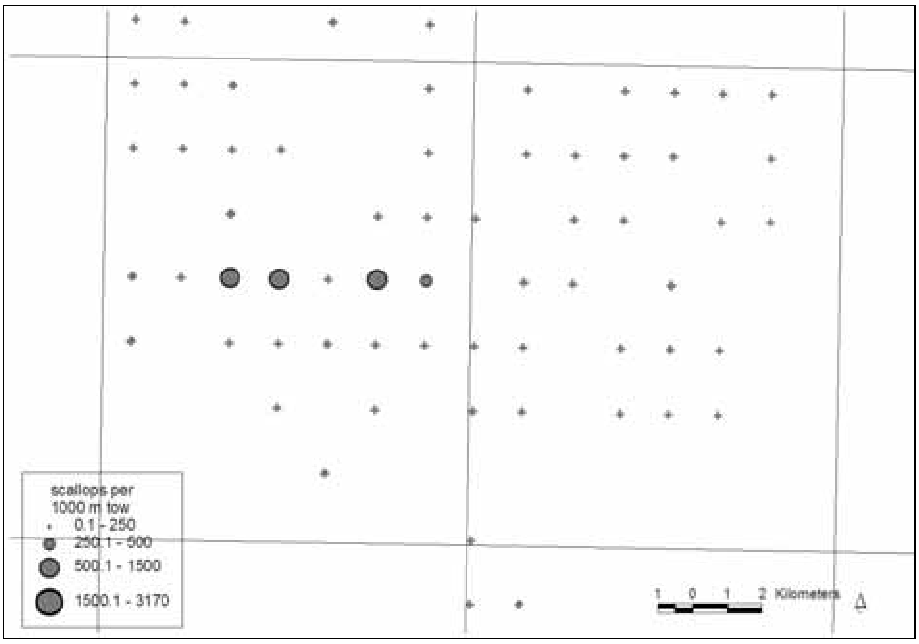

Figure 11.6. Example of incomplete data from permit fishing data sheets showing both the usable data, and location of all sample tows conducted within the area. Those sample tows within incomplete (unusable) data area marked with a cross.

11.3 Designing Credible, Industry Based Surveys (FRDC 2005/027)

The effective implementation of the spatial management strategy used in the Tasmanian scallop fishery, where only a small area within the fishery is open and the remaining area closed, requires detailed information about the size structure, relative abundance, and location of scallop beds across the entire range of the fishery. The underlying problem is, however, that fishery independent surveys would be prohibitively expensive. The question remains: how is it possible to obtain the necessary information while maintaining economic efficiency in the current cost-recovery management environment? The results of the trial Industry permit survey presented in this chapter showed that Industry, under the scope of permit fishing, has the potential to provide such information at minimal cost. However, many operational problems were identified in this first trial. Solutions to such practical problems will be found through explanation and training. However, even more importantly, for such Industry-led surveys to be able to withstand critical public scrutiny, ways of adding credibility and authority need to be found.

The successful submission of the project titled ‘Facilitating industry self-management for spatially managed stocks: a scallop case study’, by Haddon and Semmens was a logical progression from the results of not only the trial Industry survey presented in this chapter, but also the overall conclusions of the current research of this report (FRDC 2003/017). The vision of thes new project (FRDC 2005/027) is of a sustainable and annual Commonwealth and Tasmanian scallop fishery managed at a small spatial scale based on the necessary stock assessment advice provided by Industry itself. The information underlying the advice would be gathered in the absence of formal independent observers. Such a vision relies on Industry becoming a vital and directly contributing component of the management processes. This requires the development of protocols to ensure the growth in participation and expertise for industry-run sampling, which will in turn overcome those problems identified in this chapter. This vision has still to be developed in detail, but reflects the needs and wishes of the scallop Industry for better economic returns to fishers, while striving towards the long-term sustainability of the fishery through a more rational and organized harvest of the resource.

The specific objectives of the research are:

1. Develop a generalised, credible regime of Industry observations to provide the necessary assessment information required to manage a spatially structured fishery.
2. Develop and trial a workable design for a pre-season permit fishery in the Tasmanian and Commonwealth scallop fisheries to provide the information necessary to characterise the stock status in each spatial region of the entire fishery (Size distribution, condition, and possibly abundance).
3. Develop and trial a workable design for within season volunteer Industry survey observations within the Tasmanian and Commonwealth fishery for within season monitoring, comparison with pre-season survey, and more detailed characterisation of the available resource.
4. Develop mechanisms whereby Industry take (foster) ownership over the details of survey design and the organisation and funding of such operations, along with how best to generate management advice that is perceived by Industry as unbiased, acceptable to all, and providing maximum return for product landed.
5. Aid the development of a clear vision for the future of the Bass Strait scallop fishery and how it can use spatial management to its own benefit.

This project (FRDC 2005/027) is scheduled to start in mid-2005, and has a three year completion date.

12. SCALLOP FISHERY REGULATIONS AND SPATIAL MANAGEMENT.

12.1 Introduction

The re-opening of the Commonwealth and Tasmanian scallop fisheries in 2003 saw the implementation of two contrasting spatial management strategies. The Commonwealth's Australian Fisheries Management Authority (AFMA) took the approach of closing (protecting) a relatively small area of scallops provisionally defined as an area that can be effectively protected, with reproductive potential at least equivalent to the scallop bed east of Flinders Island that was closed to fishing in 2000, which was estimated as 407 ± 338 tonnes shell weight (AFMA 2002; Semmens *et al.*, 2000; though see Chapter 6). In other words, two scallop beds must be located within the fishery before it can be opened. The Tasmanian fisheries management organisation, DPIWE, used a spatial management strategy of closing the majority of the area available too the fishery, while opening relatively small, discrete areas containing known scallops beds for commercial fishing. Meanwhile, the Victorian fishery, managed by the Victorian Department of Primary Industries, maintained status quo in their management approach, with all areas being open, but with the potential for seasonal closures in response to declining scallop condition or size. Concurrent with these new spatial management approaches to scallop stocks were other management regulations relating to seasonal opening periods, legal size limits, gear limitations, and limited entry, which had been developed over the preceding 30 to 40 years of the fisheries' histories.

This Chapter aims to contrast the effectiveness and highlight the implications of the differing Tasmanian and Commonwealth approaches to spatial management, with respect to the long term sustainability, productivity and other implications for the scallop fishery. The Victorian fishery was not considered in detail because their implementation of spatial management remains limited and our direct observations were restricted to Commonwealth and Tasmanian waters. Firstly, an overview of the main findings of the research reported in this document will be presented. Then the main management rules and regulations implemented throughout the history of each fishery will be described. This history will detail the reasons why each regulation was implemented, the effectiveness (benefits) of each regulation, and how each regulation now fits into a spatial management strategy with scallop stocks. Finally, the advantages and disadvantages of each spatial management approach will be addressed, which will lead to a vision for the management of the Bass Strait scallop stock.

12.2 The Main Biological and Ecological Conclusions

12.2.1 The Spectrum of 'Good' to 'Marginal' Beds

The results of the present study have identified several ecologically and biologically significant aspects of scallops, scallop beds and the impact of dredge fishing on the benthic communities, which have direct relevance to spatial management strategies, and ultimately the long term sustainability and continuity of the scallop resource. Coastal and 'offshore' Scallop beds within the Tasmanian and Commonwealth scallop fisheries can be categorized across a spectrum of forms, from 'good' scallop beds to 'marginal' or 'poor' scallop beds. A 'good' scallop bed was broadly categorised as a relatively small (1000's of meters x 1000's of meters), discrete area of abundant scallops, often made up of a single cohort. Such beds generally occurred within high energy / high turnover areas, as evidenced by tidal or storm waves in the sediment and the rapid deletion of dredge track marks from the sediment (which could occur within 15 – 30 minutes of the dredge run in the most dynamic areas). A 'good' scallop bed was generally characterised by a dominance of commercial scallops and low abundance and diversity of other benthic species, although dominance of other bivalves, such as doughboys and oysters, was observed within some high scallop abundance areas. At the other end of the spectrum, a 'marginal' scallop bed was broadly categorised as an area of varying size, (10's of meters to 1000's of meters) which contained relatively sparse scallops, which was often be made up of more than one cohort. Such beds were found to occur within high to low energy / turnover areas and generally contained a greater variety of species (higher species richness) and high species dominance of discard species. However, some 'marginal' scallop beds were also found on barren ground and contained very few other species (low diversity and dominance) and so were merely low density scallop areas. Given a successful recruitment, marginal scallop habitat may develop into good scallop beds.

Commercial scallop fishers may alter their fishing behaviour, depending on the type of scallop bed they are fishing. The clean nature and high abundance of scallops within a discrete 'good' scallop bed can allow a scallop fleet to fish within close proximity to each other, or even allow several boats to work together along the same drag. Catch rates in such areas begin at relatively high levels, and the dominance of scallops means there is minimal sorting required by the crew (assuming the scallops are of a good size). The low occurrence of other discard species results in minimal impact to benthic communities, and what impact does occur is isolated to a relatively small area due to the discrete nature of 'good' scallop beds. This was well illustrated by the plots of VMS activity in Chapter 2. Within 'marginal' scallop beds, fishers generally conduct what could be termed a 'scratchy' approach to fishing. Dredging occurs over habitat, which can be dominated by a range of other benthic species, including screwshells, oysters, doughboy scallops and dead shell. Catch rates are relatively low, sorting time increased, and the time required to catch a given amount of scallops is relatively high. Such fishing behaviour, even though it tends to remain in relatively discrete areas (see Chapter 2) has the potential to have a larger impact on benthic communities that contain a higher diversity of species relative to 'good' beds.

12.2.2 Growth Rates, Longevity and Management

The growth of scallops was also shown to vary spatially, with different scallop beds having different relationships between shell length, height, depth, and meat weights (Chapter 7). Such differences will have a major influence on scallop meat recoveries (meat counts per kilogram) even when both scallop populations are in the same condition.

Scallop growth, age and longevity are all known to vary spatially, and were also greatly affected by factors such as the location of the scallop bed, the density of surrounding scallops and water depth. As an example, commercially fished scallop beds in some areas along the east coast of Tasmania were inferred to contain predominately 7 – 9 year old scallops (Phil Lamb pers. comm.), while there was one instance of a scallop bed (T2) east of Flinders Island, which contained predominately 5 year old scallops, that showed signs of die-off along the edges of the bed in March 2005. By July 2005, many more scallops had died throughout this bed. This latter case is thought to be relatively unusual and it is unknown whether it relates to the peculiar hydrographical conditions of the area east of Flinders Island or perhaps to the negative effects of infection by parasitic organisms such as trematodes.

12.2.3 Recruitment Events

There is evidence from this project that new cohorts of scallops (<60 mm) can settle amongst existing adults (eg Area 5X, Haddon and Semmens, 2001, Area C1, Haddon and Semmens, 2002, C4 & C5, Haddon and Semmens, 2003), however, it cannot be determined if the beds have self-seeded, or if larval scallops have been transported from other beds. In the second case, it is also undetermined how far the larvae can travel to re-seed scallop beds, however, given that they settle approximately 30 days after fertilization (Young *et al.*, 1989), it is plausible that they could be carried long distances in the prevailing currents. There is some evidence that 'new' scallop beds (*i.e.* those beds that have occurred in areas previously devoid of scallops) recur in areas where they historically occurred (*e.g.* C1-4, Haddon and Semmens, 2002).

Large recruitment events occurring over a very wide geographical range, such as the one that occurred in late 1999, have been recorded recurrently in scallop populations (eg Serchuk, Wood, Posgay & Brown, 1979), but recruitment can also occur over a more restricted region (Chapters 6 and 8). Once dense scallop beds become established further recruitment to the same areas may be limited until the scallops are fished out or die off, as this study showed little recruitment in these beds. However, our observations only demonstrate that further recruitment did not happen, not that it cannot happen.

12.2.4 Fishing Disturbance and Scallops

It was also found that fishing a scallop bed certainly had the ability to deplete the commercial scallops but that it did not necessarily destroy all remaining scallops on the bed irrespective of their size. The density of scallops remaining in stratum T1S following fishing was very low and recruitment occurred there in subsequent years. However, at Eddystone Point, significant numbers of large scallops remained following fishing and to date no successful recruitment is known to have occurred within this region.

12.3 History of Management Regulations.

12.3.1 Offshore Constitutional Settlement (OCS)

History of the OCS

The following section provides a brief background on the OCS arrangements between the Victorian, Tasmanian and Commonwealth Governments, as summarised from the review paper, 'A review of the Offshore Constitutional Settlement Arrangements of Bass Strait scallops' (Anon, 2004), which was jointly written by the Victorian Department of Primary Industry (DPI) (Fisheries), the Tasmanian Department of Primary Industry, Water and Environment (DPIWE), the Australian Fisheries Management Authority (AFMA), Industry members of the Victorian Co-management Council, the Tasmanian Scallop Fishery Advisory Committee (Scallop FAC) and the AFMA Scallop Management Advisory Committee (Scallop MAC) in July 2004.

During the early history of the southeast Australian commercial scallop fisheries, Victoria and Tasmania had their own scallop fisheries, and issued scallop licences for their respective 3 nm territorial waters. As such, each State had control over the management regulations within their jurisdiction. State licensed scallop fishers were also eligible for a scallop endorsement (a '121 endorsement') on their Commonwealth

Fishing Boat Licence. By the early 1980's, the discovery of productive fishing grounds in Commonwealth waters near Flinders Island and the fish-down of beds along the Tasmanian east coast had resulted in the transfer of fishing effort for most Victorian and Tasmanian boats into Commonwealth waters. Catch rates rapidly increased, but the fishery was largely unregulated and there were many stories of poor fishing practices and wasted product. By the mid 1980's catch rates had declined and the fishery had essentially collapsed. As stated in Young *et al.* (1989, p.15): "The last major bed in Bass Strait was fished out during the 1986 season, leaving the industry with few prospects for the remainder of the decade and a legacy of excess fishing capacity that will ensure the rapid depletion of any new beds that may be found in the future."

In 1984, the Federal Government established a joint industry-government working group called the Bass Strait Scallop Fishery Task Force, whose main role was to provide advice on the long term management arrangements of the Bass Strait scallop fishery. At this time, the position of the Australian Fisheries Service (now AFMA) was that it would be preferable for the Commonwealth to hand over control of scallop fishing to the States under an OCS arrangement. It was argued that one less management agency would lead to more efficient management and administration, and lower costs. Although the two State Governments agreed in principle, the differing histories and management objectives for each respective fishery made it difficult to reach agreement on common management arrangements for the Commonwealth fishery.

In 1986 the OCS agreement was finalised, and three scallop fishing zones were recognised; a 20 nm zone adjacent to each State, to be managed by the respective States, and a Commonwealth managed Central zone (see Figure 2.2 in Chapter 2). This agreement was seen as a first stage in handing over responsibility for management of the Commonwealth Bass Strait scallop fishery to Victoria and Tasmania.

Soon after the 1986 OCS agreement was finalised, the Bass Strait Scallop Consultative Committee (BSSCC) was established. This had the aim of providing advice on the management of the Central scallop zone to the Commonwealth Minister, and to progress development of mutually agreeable joint management arrangements between Victoria and Tasmania that would allow the Commonwealth to withdraw from management of the Central Bass Strait fishery. However, differing views between Victorian and Tasmanian industries and management agencies on how to best to manage and allocate the resource meant little progress was made, and the three jurisdictions were maintained.

A further attempt to hand over responsibility of the Commonwealth controlled scallop zone to the Victorian and Tasmanian Governments was made in 1995. Despite extensive consultation between the respective Ministers, no agreement was reached, the reason given being 'historic differences between Victoria and Tasmania'. The two main differences related to minimum sizes and the rationale behind the opening and closing of the season.

The most recent attempt to change the management arrangements for scallops in Bass Strait occurred in 2004. Again, no consensus between Victorian and Tasmanian industry and management organisations was reached, and the three management jurisdictions established in 1986 were maintained.

Benefits of a change in the OCS arrangements

Although considered to be one stock of scallops, the southeast commercial scallop fishery continues to be managed by three separate organisations. Consequently, decisions relating to the scallops of Bass Strait must be dealt with in triplicate. For example, those operators with entitlements in all three fisheries must have three separate fishing licences, deal with three separate government managers, pay three sets of access fees and levies, and support three research programs and three consultative committees. Furthermore, there are three compliance programs and, given the recent need to gain approval for export of native wildlife from the Department of Environment and Heritage (DEH) three separate, complex and expensive strategic assessments are required. Furthermore, given the apparent fact that all three fisheries fish a single stock, decisions made under one jurisdiction have the potential to influence the scallop stocks within an adjacent jurisdiction.

If management were to be handed over to one or two management agencies, then more efficient management and administration, and lower costs for the fishery are expected to result. The review paper, ‘A review of the Offshore Constitutional Settlement Arrangements of Bass Strait scallops’ (Anon, 2004), states the potential benefits of changing to a more streamlined OCS arrangement as including:

- Improved economic benefits (fewer resources used to generate the same income from the scallop resource);
- The total cost of licensing across the entire scallop fishery is reduced, possibly resulting in lower costs for some fishers (and for individuals that are in all three current fisheries);
- Increased scope for quota trading between operators across the entire fishery, which will allow a reduction in latent effort and the number of operators in the fishery;
- Increased scope for at least part of the fishery to be open each year (while still meeting the objectives of ecologically sustainable development etc);
- Potentially more efficient (less costly and more effective) enforcement;
- Reduced costs for industry and government (management and compliance);
- An improved business environment and platform for business development;
- An easier mechanism for dealing with issues generated by DEH (e.g. export approval, strategic assessment), the National Oceans Office (e.g. the South-east Regional Marine Plan) and marketing of product (by industry); and
- Simpler processes for responding to fisheries management issues.

As such, the main advantages in moving towards a more streamline management system for scallops in Bass Strait relate to economics.

Future OCS arrangements and spatial management: improving scallop stocks

As a response to the OCS options paper, the authors of this report submitted a discussion paper entitled ‘Discussion of OCS Options for the Bass Strait Scallop Fishery’ to all interested parties (Haddon *et al.,* 2004b). The main aim of this paper was to provide an external, non-partisan view of the OCS options available to the Bass Strait scallop fishery from the point of view of optimising the sustainability of the stock, obtaining a fishery each year as often as possible, and minimising the impact on the benthic biota. This was an attempt to use the preliminary results of this current project to provide information to the stakeholders in the fishery that might assist them in their discussions and decisions.

The main conclusion of this discussion paper (Haddon *et al.,* 2004b) was that, with respect to the sustainability of the scallop resource and the chance of having a fishery each year, any spatial management arrangement that uses a “most areas closed, small areas open” in a rotational manner is to be preferred over alternative harvest strategies, as such a strategy has far more benefits than other current options (see later section). One of the most important considerations for future OCS arrangements, however, is the management of one complete stock of scallops. At present, the three managerial organisations manage their jurisdiction as if they each contain an isolated stock, when in reality they are most probably one stock; although this still needs to be determined using genetic techniques. Subsequently, decisions made within one jurisdiction may impact the success of decisions made within another jurisdiction. Changes to the current OCS arrangements may allow for the management of Bass Strait scallops as one stock, which would have potential benefits for all fisheries depending on the management arrangements adopted.

12.3.2 Limited entry fishery / non-transferable licences

History of participation limiting regulations – Tasmanian fishery

There were no regulations controlling entry to the Tasmanian scallop fishery prior to 1986, and licenses were issued unrestrictedly. With the discovery of new scallop stocks near Flinders Island during the early 1980's, there was a rapid expansion of the scallop fleet, with an estimated trebling of effort in the fishery in the two years from 1981 – 1983 (Zacharin 1988). Industry members tell stories of licences being given out at fishing ports or even on the fishing grounds from patrol vessels to 'anyone passing by' with a licence fee. By 1983, there were 231 vessels and by 1986, 285 vessels participating in the Tasmanian scallop fishery (Zacharin 1988). It was soon recognised that fishing effort needed to be controlled to prevent the waste of product and promote more effective management of the fishery. With the implementation of the OCS agreement in 1986, fishers had to demonstrate past involvement in the fishery to qualify for future access. As a result, 187 non-transferable scallop licences were issued for Tasmanian State waters in 1987.

No new Tasmanian scallop licences have been issued since 1987, and from 1987 to 1991, all licences were made non-transferable, meaning that the transfer of a fishing licence package with a scallop entitlement caused the loss of the scallop entitlement. In 1992 scallop licences became transferable; however, all licensees had to pay a $2000 scallop research levy to remain in the fishery. By 1992 the number of vessels with a scallop entitlement for Tasmanian waters had decreased to 120.

The total allowable catch of scallops was divided among the various licences and the amalgamation of a number of licences on single vessels (to increase each fishers share of the total take) led to a further restructuring of the fishery. By 2005, the number of Tasmanian scallop licences had reduced to 92, with only 18 boats activating their licences during this year.

History of participation limiting regulations – Commonwealth fishery

With the rapid increase in fishing effort during the early 1980's, fishers who proposed to fish for scallops in Commonwealth waters were required to apply for, and were generally granted, a Commonwealth Fishing Boat Licence (CFBL). From 1984, boats were also required to have a specific non-transferable endorsement on their CFBL to be allowed to fish within a defined area of the Commonwealth Central Bass Strait fishery. These endorsements were only granted to those fishers who held a Tasmanian or Victorian State licence and had a history of scallop fishing in (or generally around) 1983 under a CFBL.

With the implementation of the OCS agreement in 1986, a total of 237 operators, generally those who had gained an endorsement in 1984, although there was some modification of the eligibility criteria in the interim, gained access to the Commonwealth fishery. Interim management arrangements included limited entry to the fishery.

In 1991, the Bass Strait Scallop Consultative Committee (BSSCC) was formed, and in consultation with the Australian Fisheries Service, the Bass Strait Scallop Preliminary Management Plan was developed. Management restrictions included no further entry to the Fishery (at 165 licences), and restrictions on the transferability of licences.

By July 2004 there were 135 current permits held for the Commonwealth Central Scallop Zone, by 74 permit holders.

In 2005, the Commonwealth fishery moved from a licence fishery to a Statutory Fishing Rights (SFR's) fishery. As of the 1st January 2005 there were 154 SFR's issued in the Commonwealth fishery (which is the same number of fishing permits held on the 1st March 2001, the eligibility date for the grant of SFR's under the plan) held by 103 SRF holders.

Benefits of participation regulations and implications for spatial management strategies

The implementation of non-transferable licences within the Commonwealth and Tasmanian fishery was initially developed to decrease the fishing effort within each fishery and reduce the amount of wastage that was occurring. Despite some restructuring during the 1980's and 1990's, which saw a decline in the number of vessels participating in the fishery, fishing effort remained too high, and successive successful recruitments of scallop stocks continued to be overfished and collapse into the late 1990's.

With the implementation of spatial management, the number of boats participating within each jurisdiction of the Bass Strait scallop fishery will have a varying impact depending on the type of spatial management regulations implemented. In general, other management regulations, such as quotas, TAC's and seasonal closures, combined with periodic recruitment success and spatial management regimes, will have the most influence on the sustainability and annual nature of the scallop fishery. Under a most closed, little open regime of management, the number of boats participating within the fishery will have an impact on a discrete area of scallops, while the remainder of the fishery is protected from the impact of fishing. However, under a most open, little closed spatial management regime, the greater the number of boats, the greater the potential impact over the larger area of the fishery. Reducing the number of boats may have other positive effects, such as; greater economic efficiency as the total catch is shared between fewer players, consensus on management regulations and decisions, ability for the fisheries to develop, agree on, and sign onto their own fishery policies, and the overall control of product quality.

12.3.3 Quota units, Total Allowable Catches (TAC) and Trip / Period Quotas

History of quota units, TAC's, and trip / period limits - Tasmanian fishery

With the implementation of the OCS agreement in 1986, all Tasmanian scallop licences were granted a unit-per-trip quota, calculated according to the length of the fisher's vessel. This possession quota was implemented in an attempt to rationalise the harvest rate, as between 1981 to 1984, much wastage occurred, with reports of scallops rotting on wharfs because fish processors could not handle the large volumes being landed. Trip quotas were an attempt to ensure that the markets were not flooded with product so that the price paid remained profitable and wastage was minimized. As such, trip quotas were implemented for economic, not conservation purposes.

In the 1990's fishers were permitted to catch a certain volume of scallops, measured as a standard bag, per fishing trip and over a specified time, with the number of bags issued dependent on the number of units on their licence. These non-transferable 'bag' quotas were used primarily as a marketing tool to try and facilitate an orderly flow of quality product into the processing sector and to try and prevent a 'gold rush' event as was seen in the previous decades. However, catch limits were not set on a biological basis, as there was insufficient fisheries data, but were instead based on maintaining economically viable fishing trips for participating vessels.

In an attempt to encourage restructuring in the fishery, transferable units were introduced in 2000. Furthermore, to offset the risk of an increase in the annual catch, associated with the activation of inactive units and licences, the quota unit value was reduced, which effectively reduced the bag quota unit value based on volume (equating to around 950kg) to a weight based value 'kilogram scallop unit' of 500 kg. This reduced the total potential catch from 10,400 t (if all units were activated and used) to a more conservative level of 5,350 t. In addition, a trigger point was incorporated into the 2000 policy document, which would result in a review of the management plan if the catching capacity of the active licences exceeded the long term average catch for the fishery, namely 4,200 t.

Following fishery-independent surveys in 2002, a high level of interest in the fishery developed as it appeared highly likely that the fishery would re-open in 2003, after several years of closure. As a result of this interest, it was expected that most scallop licences would be activated and most scallop units would be seasonally transferred, which created the strong potential for the trigger point of 4,200 tons being reached when the fishery opened in 2003. In response to this situation, the Tasmanian Scallop Fishery Advisory Committee, took a pro-active approach and the scallop unit value was reduced to 400 kg per unit prior to the commencement of the fishery opening in June 2003. With 10,730 scallop units attached to scallop licences at the time, the change reduced the maximum potential catch from 5,350 t to 4,292 t.

During the 2004 season, trip and period quota limits were also implemented in an attempt to control the volume of scallops reaching the local markets as the season progressed. This was deemed desirable as no viable export markets were then active; in the 2005 season these restrictions were removed as being an unnecessary restriction on the marketing of the product.

In 2005, a new management plan was introduced which allowed the Minister to set and alter the quota unit value, up or down, from 400 kg by public notice. This alteration in unit value would effectively set the total allowable catch (TAC) for any particular year, which was to be based on the best available stock information at that time. With no evidence of recruitment during the 2004 season, the TAC for 2005 was reduced to 350 kg per unit, or an effective TAC of 3,721.6 t. After the March 2005 survey found that parts of the scallop beds in T2 and T3 were dieing, it was decided that the Industry should be given the chance of catching at least some of the stock remaining on those beds. An extra-ordinary change within the scallop season was made to the TAC providing each unit holder with an extra 100 kg of catch, increasing the TAC by 1,199 tonnes to 4, 920 tonnes, though the expectation is that not all of this will be caught before the scallops lose condition.

History of quota units, TAC's, and trip / period limits - Commonwealth fishery

With the implementation of the Bass Strait Scallop Preliminary Management Plan in 1991, the Commonwealth fishery had a catch limit of 100 bags (equivalent to approximately 6.5 tonnes shell weight) per fortnight placed on each permit. In 1995, this catch limit was changed to 200 bags every four weeks, with a 150 bag trip limit, and in 1996 the catch limit was increased to compensate for a shortening of the fishing season.

During the 2003 and 2004 Commonwealth fishing seasons, a total of 5,000 t was set as the TAC, through a temporal series of smaller TAC allocations. In 2005, the Commonwealth fishery moved to a Statutory Fishing Right's (SFR's) system, with each boat having 3,500 quota SFR's issued for each species of scallop, with management regulations allowing a TAC to be determined on economics rather than biomass.

The role of TAC's in spatial management

The main strategy behind setting TAC's is to attempt to provide sustainability and continuity of the resource, while still providing good financial returns to fishers. As such TAC's should ultimately be set on a biological basis, which allows reproduction / recruitment into the fishery to match the output through natural mortality and catches. During the 1980's and 1990's this strategy was not achieved, as the TAC was set on an economic, not a biological basis. A shift in management saw the allocated TAC based on the historical average annual catch levels, however, this historical average overlapped those periods where the TAC was set on an economic basis. Under both strategies, the level of fishing never allowed stocks to rebuild, and available stocks rapidly declined to levels associated with a collapse several times during the 1980's and 1990's within both the Commonwealth and Tasmanian fisheries.

The implementation of a new management plan in the Tasmanian fishery in 2005 allowed the Minister to set and alter the quota unit value, up or down, from 400 kg by public notice, with the TAC to be set for any particular year based on the best available stock information at the time. The difficulty with this approach is the current lack of knowledge of scallop stocks throughout the entire extent of the fishery, which, during 2005, led to differences in opinion between fishers, scientists and Tasmanian management organisations as to what level the TAC should be set.

The role of trip limits / period limits in spatial management strategies

Trip / period limits also have the potential to control the amount of product being landed within a set time period. Trip / period quotas have proven to be an effective management tool controlling the amount of scallop caught and landed within a spatial management approach to scallop stocks (*i.e.* 2004 in the Tasmanian fishery). However, a greater degree of responsibility within both the fishing and processing sectors has now effectively taken over control of the amount of product landed and fishers are mostly only catching scallops for which they already have a buyer (processor). This agreement between the fishing and processing sectors of industry has, in effect, made trip / period limits a redundant regulation within the current Tasmanian and Commonwealth scallop fisheries structure.

12.3.4 Seasonal closures

History of seasonal closures – Tasmanian fishery

Before the 1980's, the commercial scallop fishery was a seasonal fishery, occurring between May / June to September / October (Zacharin, 1988). With the rapid increase in scallop catches and participation during the early 1980's, the scallop fleet began fishing all year round as management regulations were not in place to prevent this from happening (Zacharin, 1988). Some time during the late 1980's, regulations were implemented, making the scallop fishery seasonal, with the fishery opening around the middle of June each year, depending on the condition of the scallops. In 1987 the fishery opened on 14th June and was closed on the 1st September as the catch rates of scallops had decreased. In more recent years, the annual season has occurred from around mid-June to mid November / December.

History of seasonal closures – Commonwealth fishery

A similar history of seasonal closures occurred within the Commonwealth fishery, with vessels fishing 12 months of the year during the early 1980's. Seasonal closures were implemented some time after this, with Zacharin (1994) stating that the Bass Strait fishery opens on the 1st of April each year and closes in late December. Within recent years, similar open seasons have operated.

Benefits of seasonal closures and relevance in spatial management regimes

The main purpose of seasonal closures is to protect newly settled spat, with research conducted in Bass Strait indicating that larvae settle over the period October to February with a peak in November (Young *et al.*, 1999). Furthermore, it has been shown that the survival of spat seeded on the seafloor was enhanced if they were not disturbed by trawling (Bull 1991). A further benefit of seasonal closures is that fishing is limited to the periods when scallops are usually in their best condition (i.e. gonads are fully developed). Consequently, closing the fishery over summer not only reduces the potential detrimental disturbance to newly settled spat, but also prevents the exploitation of the stock at a time when scallop condition is likely to be poor (potentially leading to a poor yield-per-recruit and possibly damaging the established markets if only poor quality product is available). Consequently, seasonal closures remain a highly relevant management regulation within spatial management regimes.

12.3.5 Legal Minimum Sizes, the 20% trashing (discard) rate rule and two spawnings rule

History of legal minimum sizes – Tasmanian fishery

Size restrictions have been in place in Tasmanian waters since 1925, when the legal minimum size (LMS) for *P. fumatus* was 88.9 mm (3.5 inches) across the largest diameter (shell length) (Fairbridge, 1953). In 1935, the LMS was increased to 88.9 mm (Fairbridge, 1953) across the smallest shell diameter (shell height), however, there was a shift back to 90 mm across the largest shell dimensions sometime before 1987. In 1987, with the prospect of poor catches, and with widespread compliance breaches related to size limits, the LMS of commercial scallops was reduced to 80 mm at the maximum diameter (Young *et al.*, 1989). The legal size was not returned to the initial 90 mm at the widest diameter until 2003, in accordance with the two major spawnings rule (see later section).

History of legal minimum sizes – Commonwealth fishery

Since the 1980's, the minimum legal size for commercial scallops within the Commonwealth fishery has been set at 80 mm across the widest diameter (Zacharin 1994). However, in 2005, this minimum legal size was increased to 90 mm across the widest diameter, in accordance with the two major spawnings rule (see later section).

Why the increase in minimum size to 90 mm: Shell height vs. shell length

Studies conducted by CSIRO during the 1980's showed a relationship between size (age) and egg production, with 3+ year class scallops shedding 3 – 5 times as many eggs as 1+ scallops, and as such it was important to allow scallops to reach this 3+ year class. The key point was that 3+ scallops were 75 – 85 mm in shell height, however, the legal minimum size was maintained at 80 mm maximum shell diameter, which only correlates to a shell height of approximately 70 mm. This confusion between scallop height and scallop width may have been instigated by a scallop management article written during the 1990's, which talked about 80 mm maximum diameter allowing at least two major spawnings (see Zacharin 1994).

In 2001 the Commonwealth ScallopFAG and ScallopMAC had four main arguments for retaining 80 mm shell length as a minimum size, rather than 80 mm shell height (from the Fishery Assessment Report, May 2002).

1) A minimum size limit of 80 mm shell length had previously operated within the fishery and so this was the size limit with which industry were used to working with.
2) Growth rates and egg production are very variable throughout Bass Strait. Ideally different size limits could be set for different areas of the fishery, but realistically this is not a practicable option because enforcement costs would be prohibitive.
3) The current size limit is one at which, depending on area, some scallops are likely to have undergone two spawnings whereas others may not have done so. If only a small proportion of scallops within a particular area has reached a shell length of 80 mm, the 20% discard rule (see next section) will prevent these scallops being exploited at the risk of increasing mortality rates in the rest of the population.
4) With the introduction of the decision rule requiring that there are always some beds of scallops that remain unfished in order to provided broodstock there is now a mechanism additional to the 'two-spawning' criterion to help promote the recovery of the fishery.

Despite these arguments, by 2005 both the Commonwealth and Tasmanian scallop fisheries had moved to a minimum size limit of 90 mm maximum shell length, in accordance with the two spawnings rule.

20% trashing rate rule and two spawnings criteria

During the early 1990's, fishermen and managers recognised that future harvesting strategies of scallops needed to be based on current biological knowledge of the species (in regard to reproductive maturity and growth rates), fleet dynamics and the need for economic efficiency. In 1991 a new management plan for scallops in Bass Strait was drafted by the Bass Strait Consultative Committee (BSSCC). The two main management strategies implemented were the 20% trashing rate rule and the two major spawnings criteria.

The 20% trashing rate rule was designed as a yield optimisation strategy, through limiting the capture, and minimising incidental mortality to small scallops (Zacharin 1994). The trashing rate is the proportion of small scallops discarded over a fishing ground during commercial operations. If more than 20% of the catch landed on the sorting tray is being returned to the water, fishermen are required to cease fishing in the area until scallop size increases. In more recent years, areas containing >20% undersize scallops (determined through fishery independent surveys) have been afforded protection through closures. The two major spawnings criteria is a parallel management requirement to the 20% trashing rate rule designed to allow scallops two major spawnings prior to their being fished, without regard to size.

Benefits of size regulations and relevance to spatial management regimes

There is a well established belief that two major spawnings from adults, prior to their being fished, are considered essential if sufficient reproductive output from the fishery is to occur, hence delaying catching scallops until they have reached 75-85 mm shell height (85 – 95 mm maximum diameter) and are in the 3+ year class has obvious advantages for the stock (see previous section on 3+ year class scallops). The fishery's history suggests that this belief, when considered in isolation, does not stand up to scrutiny. To aid in the discussion of the minimum legal size within the Commonwealth fishery the authors of this present report prepared a paper for the Commonwealth Scallop Resource Assessment Group (Scallop RAG) (Haddon *et al*. 2005b) that considered the interaction between the requirement of a minimum legal size and strict spatial management.

Protection of juvenile scallop beds (< 20% scallops < 90 mm shell length) is essential for increasing the chances for long term sustainability and continuity of the scallop resource. As such, a management regime which imposes maximum protection of such areas of scallops should be favoured. It should be obvious that "little open, most closed" best provides this protection, especially to previously unknown scallop beds containing undersize and newly settled scallops that are found by fishers during the course of the season. Such a management system will maximise the potential for having a sufficient bulk and density of scallop spawners to consistently supply recruits when environmental conditions are compatible with larval transport, settlement and survival.

This strategy is being implemented in Tasmanian waters and has implications for how legal minimum sizes could be used. Within such a spatial strategy of management the decision on what area to open incorporates the 20% discard and two spawnings rules. However, once an area is chosen for opening the requirement for fishers to sort their catch and return undersized (< 90 mm shell length) scallops to the water is still enforced. It could be argued that after an area is opened under the Tasmanian style of spatial management *i.e.* 'most closed, little open', it is legitimate to permit the fishers to land scallops of all sizes and thereby make the fishing operation more efficient (Haddon *et al*., 2005b). This would in effect turn the size limit into a decision rule for use only in determining whether an area is suitable for opening (*i.e.* the 20% trashing rule). However, the potential for illegal catches of undersize scallops from outside the legally open areas remains a possibility where a strategy of 'most open, little closed' is in place (as currently in the Commonwealth), and as such the continuation of the legal minimum size limit subsequently still holds value for protecting scallop stocks outside open areas. Furthermore, scallops of above the 90 mm size are more often than not the size that the processing sector of the industry requires, as they produce scallops of high value (exportable) quality.

A potentially more beneficial management decision rule to be used for determine of which beds should be opened, would be to have scallop meat weights (or product return) as a key determinant rather than the 20% discard and 90 mm minimum legal size limit. It was identified in Chapter 7 that differences in the relationships between shell length, height and depth can lead to differences in the meat weights. As such, smaller but deeper scallops can return an equivalent amount of product for any given amount of scallops relative to larger not so deep scallops. The assumption is that such scallops, though smaller than 90 mm shell length, have still had two major spawning events, as they are still in the 3+ year class or older. As such, there is potential for beds of strictly undersize scallops (if we only consider shell length) with good meat returns to be open to fishing (assuming they have met the two spawnings criteria). Such a situation occurred during 2005 within the Tasmanian fishery, where a known bed of scallops to the east of Flinders Island with greater than 20% discard rates was known to have met the two major spawnings criteria (because the scallops were known to be 5+ years old). This bed was showing signs of dieing off, and was subsequently opened to commercial fishing with an 80 mm minimum legal size exemption order being placed on the open area to the east of Flinders Island but not to any other parts of the Tasmanian or Commonwealth fisheries.

Such exemptions to size limits can only be placed on small areas of the fishery (known or particular beds) and as such could only be effectively implemented where 'the most closed, little open' management strategy is used across the scallop fishery's entire distribution without causing major problems for enforcement agencies and officers.

12.3.6 Fishery closures: insufficient scallop stocks

One of the objectives of management should be to permit a fishery every year if at all possible. In this way markets are protected, and processor facilities and expertise is not lost. However, it is possible that even with detailed spatial management there may come a time when most scallop beds contain only small or no scallops. In these circumstances it may be better to have a small fishery than none at all. This would require that information be available from across the complete fishery. Only then would it be possible to generate an estimate of the likely yield (TAC) in a particular year.

At no stage would it be desirable to open up the complete fishable area to enable the Industry to scratch around searching as this might have the effect of preventing successful recruitment. Only by developing a system of surveys that provide information about the complete resource can the fishing each year be adequately planned. Planning should project forward for multiple years so that at least some idea of where fishing will occur two years hence is known. Such an approach would permit surveys to be planned and Industry stakeholders to plan their fishing operations most efficiently.

12.4 Alternative Spatial Management Regimes.

12.4.1 Spatial management strategies revisited

Despite the implementation of management regulations aimed at increasing the chances of successful recruitment into the fishery (*i.e.* two major spawning criteria, minimum legal sizes), several years of adverse environmental conditions, where little reproduction or recruitment of juvenile scallops to the population occurs, may nullify these regulations (McLoughlin 1994, Fishery Assessment Report). Furthermore, successful scallop recruitment capable of supporting the scallop industry may be an infrequent event and / or restricted to isolated areas within the fishery. The continuation of fishing within all regions of the fishery would therefore have many potential negative effects on scallop stocks and recruitment, in particular, detrimental effects on newly settled scallops and the removal of adult broodstock.

One mechanism, which would greatly promote the chances of a broad or localised successful scallop recruitment event is to protect a broodstock of scallops within the fishery. It is this idea that has formed the basis of spatial management strategies. Two different approaches towards spatial management have been adopted within the

Commonwealth and Tasmanian fisheries. Within the Tasmanian fishery, discrete, relatively small areas of known scallop stocks are opened to commercial dredge fishing, with the remainder of the fishery subjected to one of three levels of closure, Scallop Limited Areas, Closed Area (class 1) and Closed Area (class 2).

Within the Commonwealth fishery, a decision rule was approved by the AFMA Board in May 2001, which required that at least one bed of scallops be closed in the east and west of the fishery each season to increase the probability of recovery of the broader population to support a sustainable fishery. The purpose was to always maintain a bed of scallops, and in the absence of more specific biological criteria that could be used, an operational definition of a minimum spawning stock was required. So, to prevent recruitment overfishing, a bed was provisionally defined as an area of scallops that can be effectively protected, with reproductive potential at least equivalent to the scallop bed east of Flinders Island that was closed to fishing in 2000 (estimated as 407 ± 338 tonnes shell weight (Semmens *et al.*, 2000). Consequently, the Commonwealth approach to spatial management is to close a small area of known scallops, while opening the remainder of the fishery to fishing. However, closures of known undersize scallop beds can also be implemented. Meanwhile, the Victorian fishery maintained its approach to management, with all areas of the fishery open to fishing, with scope for temporal closures.

12.4.2 Advantages and disadvantages of different spatial management approaches

In response to the OCS options paper (see 14.2.1), the authors of this report submitted a discussion paper titled, “Discussion of OCS options for the Bass Strait Scallop Fishery’ (Haddon *et al*. 2004b), to AFMA and other interested parties. Part of this discussion paper was a list of the advantages and disadvantages of each management strategy:

1) Most areas closed, small area open (Tasmania).

Advantages:

1. The greater the spawning biomass available (closed areas) to generate larvae, the greater the larval biomass produced, which, given suitable environmental conditions, will increase the chance of successful settlement.
2. Recruitment is not guaranteed and tends to be patchy both geographically and in time, therefore, the more patches that are managed separately the greater the chance of securing the future of scallop beds through recruitment recovery.
3. With many patches managed separately and with most being closed, the separate patches will be rested longer between being fished. Therefore, there will be a greater chance of scallops growing beyond the 90mm size limit, allowing these scallops to have at least 2 significant spawning events.
4. Allows for within-season rotation between open and closed areas; e.g. if an area is opened and scallops are in poor condition, it can be closed and another area opened.
5. The above advantages, which minimize the impact of fishing on scallops also applies to by-product and bycatch species, allowing bycatch greater opportunities for maintaining their populations through time.

Disadvantages:

1. Limits the total catch to the exploitable stock within one or two areas; however this may be out-weighed by maintaining annual market continuity.

2. Limits exploratory fishing during the open season.
3. Relatively complex to manage because it has a requirement for stock information (size structure, condition, and ideally biomass) within each of the areas managed separately within the fishery.

2) Most areas open, small area closed (Commonwealth).

Advantages (relative to option 1)

1. Freedom to fish over larger area, permitting exploratory fishing for both previously undiscovered beds and those beds with scallops in premium market condition, without the delay of opening a new area.
2. Will maximize annual catches if sufficient stocks are available.
3. Relatively simple to manage as the minimum requirements are based on two decision rules (trashing rate rule and closed area with mature scallops).

Disadvantages (relative to option 1)

1. More likely to be a periodic, 'boom and bust' fishery, *i.e.* if all mature scallops (which take at least three years to reach 90mm shell length) are removed from the open areas, there may be years with no fishery.
2. There is little scope for insurance against recruitment failure across a number of years, which will ultimately lead to the closure of the fishery e.g. 1999 – 2002 in the Commonwealth.
3. If the stocks in the open beds are depleted, only a relatively small spawning biomass is left in the closed area to provide for the recovery of the entire fishery.
4. Applying the relatively simple decision rules across the whole fishery instead of smaller sub-areas, can have the effect of reducing the protection that they afford to undersized animals and the breeding stock.
5. Will result in disturbance of not only scallops but also all other benthic species across the larger open area that is fished. This may impact on future recruitment of both scallops and other benthic bycatch species.

3) All Beds Open, potential for Temporal Closures (Victoria)

Advantages (relative to option 1)

1. Freedom to fish over larger area, permitting exploratory fishing for both previously undiscovered beds and those beds with scallops in premium market condition, without the delay of opening a new area (TAS).
2. Will maximize annual catches if sufficient stocks are available.
3. Guaranteed start to the fishing each year.
4. Most simple management strategy to operate.

Disadvantages (relative to option 1)

1. More likely to be a periodic, 'boom and bust' fishery, i.e. if all mature scallops (which take at least three years to reach 90mm shell length) are removed, there may be years with only a very small fishery, as seen from 2000, where only small annual catchs have been recorded,
2. With no formal trashing rate rule there is the potential to inhibit recruitment.
3. Temporal closures for only part of a season may not permit sufficient time for new recruits to grow through to legal size.

4. No options for alternative harvest areas if closures occur, resulting in an all or nothing fishery.
5. If severe depletion occurs, the guaranteed opening may make it difficult to recover from such a situation.
6. Will result in disturbance of not only scallops but also all other benthic species across the entire fished region, and will possibly impact on future recruitment of scallops and other benthic bycatch species.

12.4.3 Which strategy is the best?

Of the three management strategies currently in use, it is clear that the first, 'most areas closed, small area open', has numerous advantages over the alternative options in terms of sustainability and the possibility of a commercial fishery each year. Rotational harvest strategies of relatively small areas, so-called paddock fishing, will maximize the chance of a worthwhile annual fishery, permit the selection of scallops in the best condition, enable greater control over the exploitation of an easily targeted, easily depleted species, and maximise the chances of successful recruitment into the fishery. Several theoretical studies have highlighted these potential benefits (Beukers-Stewart *et al.* 2005, Smith and Rago, 2004, Hart, 2003, Myers *et al.* 2000). Because of these advantages, any management arrangement that uses a most areas closed, small areas open approach is to be preferred over alternative harvest strategies.

12.4.4 Other management requirements in a most closed / little open spatial management regime

Although a most closed, little open strategy of spatial management has been identified as the preferred spatial management regime for promoting sustainability and continuity of the scallop resource, several other management requirements will also influence the effective management of scallop stocks. Inconsistencies in scallop reproduction, settlement and growth, make it difficult to predict when and where scallops will be in appropriate harvesting condition and whether the discard rate rule for a previously surveyed area will still be applicable. Consequently, the management organisation with control over the scallop resource must have a degree of flexibility in the decision making process and the ability to alter already instigated harvest strategies in order to have the most appropriate area (paddock) open. Several instances of a need for within season management have already occurred within the Tasmania fishery. For example, during the 2005 open season, an area to the east of Eddystone Point was open to commercial dredge fishing, however, reports of relatively large numbers of undersize scallops within the area led to the rapid closure of this area, and the opening of an alternative area. Without flexibility in management protocols and procedures, such a rapid change in harvest strategy could not occur. There is obviously a cost to implementing a most closed little open strategy and that cost is to have sufficient quality information of available stocks available and the ability to make within season responses to the state of the fishery.

Under a most open, little closed strategy such responses would not be needed. Rather, the fishers would be expected to stop fishing the particular bed that was not in best condition and find another bed themselves.

In order to both make educated decisions about harvesting strategies, as well as educated changes to any already implemented strategies, knowledge of scallops across the entire extent of the fishery is an essential requirement. Fishery Independent surveys would be prohibitively expensive over such an area so the only alternative is to develop a scheme where Industry vessels find ways to survey the fishery and provide the necessary information in a reliable and credible fashion. A new FRDC project (2005/025) will address this requirement in more detail.

Other management regulations, as already outlined in this chapter, need to be maintained, but in some circumstances, flexibility of the regulation is required *e.g.* the 80 mm exemption for the declining beds in Tasmanian waters east of Flinders Island.

12.5 Spatial Management and a Fishery Each Year.

Given the results presented in this report, the vision of the authors is of an on-going Victorian, Commonwealth, and Tasmanian scallop fishery managed at a small spatial scale, with most areas being closed to fishing, and only small discrete areas open, potentially on a bed by bed approach. Flexibility in the management regime / protocols will allow for rapid changes to harvesting strategies and plans, should the need arise. It is anticipated that the data requirements for such spatial management regimes will be collected by industry itself, within a scheme of organised industry-dependent surveys, the final protocols of which will be developed as part of FRDC 2005/027. Although regulations implemented by management organisations have the potential to control where and when beds will be opened, it is visualised that a well organised industry association can not only collect data, but also provide the necessary advice as to where and when to open within the fishery, potentially under their own Scallop Association Code of Practice.

13. REFERENCES

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