Assessment and management of potential impacts of prawn trawling on estuarine assemblages

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Australian Government

Fisheries Research and Development Corporation

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Centre for Research on Ecological Impacts of Coastal Cities
Marine Ecology Laboratories, A11
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1. Non-Technical Summary

No: 2000/176 Assessment and management of potential impacts of prawn-trawling on estuarine assemblages

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OBJECTIVES

1. To quantify benthic assemblages from trawls in areas and times that are trawled and untrawled in an estuarine prawn-trawl fishery;
2. to manipulate trawling effort in untrawled areas to determine the nature and magnitude of impacts. This could not be done because large-scale perturbations to the entire estuary caused delays and made the original comparisons more time-consuming;
3. to interpret results to help develop plans for management and mitigation to ameliorate any problematic impacts identified;
4. to identify on-going issues to underpin future research and management; and
5. to develop protocols, experimental designs and the basis for calculations of power to measure and interpret impacts of fishing practices in other (e.g. offshore) habitats.

NON-TECHNICAL SUMMARY

Prawn trawling in the Clarence River estuary is a major activity, of great commercial value and integral to Australian consumption of quality seafood. The Industry depends for its sustainability on the continued productivity of estuarine habitats. Management of fisheries includes requirements for monitoring and, where necessary, controlling activities, including being precautionary about environmental and ecological damage it may cause.

At the same time, there is very considerable public concern and criticism of virtually all activities of fisheries. Much of the concern and responses to it by politicians, regulators, the fishing industry itself, is made difficult by the lack of adequate, well-constructed research to provide the appropriate information to assess problems, to understand their causes and to solve them.

This study was done to resolve long-standing issues about perceptions of ecological impacts caused by trawling for prawns in the Clarence River. The specific aims were to understand what, if any, impacts were actually happening that affected the invertebrate, benthic fauna. These are the numerous and diverse species that live in and on muddy and sandy sediments which form the habitat in which prawns are caught. They are a large component of natural

biodiversity of estuarine species and may be disturbed or killed, or their habitats altered by the activities associated with trawling. No current study can investigate historical impacts caused long ago or because of many decades of activities – there are no reference or control, untrawled locations which can serve to allow evaluation of these. The study can, however, unambiguously identify the sorts of current impacts which are the focus of concerns.

Sampling to detect impacts in estuaries is necessarily complex and requires certain types of sampling to guarantee technical capacity to analyse and interpret data. The issues involve adequate sampling in time, to ensure reliable estimates of densities and types of animals present. In the Clarence River, regulation of the fishery closes the entire area, preventing any trawling from June to November. Temporal sampling was done at 4 independent times in each of the Open (December to May) and Closed (June to November) seasons, in each of 2 years. This provides sufficient sampling in time.

Great spatial variability in the densities of animals often exists at many overlapping scales. Here, 3 regions (Ulmarra, Brushgrove and The Broadwater) were sampled. In each, there were areas closed to trawling at all times and areas that are available for trawling during the Open season. In each (trawled or untrawled) type of area, 2 randomly-chosen locations were sampled; in each of these, 3 randomly-chosen, smaller sites were sampled, each with 6 replicate core-samples. Altogether, 105 different types of animals were reliably identified in the samples over 2 years.

Impacts would be detected as statistical interactions. Any effect of trawling can only occur in trawled areas and should be happening during the Open season. So, ecological assemblages of species should show more change in trawled areas, becoming less like untrawled areas, as the Open season progresses. Searches for such interactions were made using various kinds of statistical procedures.

Attempts were made exhaustively, because analyses failed to find any evidence for impacts due to trawling. Not only was this an unexpected result, given the perception of potential damage by the industry, but it was also remarkably consistent across all 3 regions and both years. The finding was supported by a massive impact to fauna caused by a large flood in the first year. As a result, animals disappeared from many areas – a much larger effect than anything the fishery could possibly do. Within a few months, however, animals recovered and there was no trace in the samples that the flood had ever happened. It is unrealistic, in the light of this type of capacity to cope with disturbances, that the fauna would be much affected by the smaller disturbances due to trawling.

Altogether, this study had much greater replication in time and space than most analyses of effects of trawling. It is much more believable that the failure to find impacts was because there was none, than being due to inadequacy of data or statistical power to detect impacts. As a consequence of the finding of no ecological impacts to animals in sediments, no experimental alterations to trawling were done and no recommendations are needed about changed practices, methods, gear, etc., in the industry.

KEYWORDS: ecological impact, Clarence River, prawn-trawling

2. Acknowledgements

I am grateful to the Fisheries Research and Development Corporation for the extensive grant which enabled this work to be done. In particular, I am grateful to Dr Patrick Hone for his patience and forbearance when serious illness (twice) prevented completion of the project. Dr Steve Kennelly was the main instigator of the proposed work and would have done the project but for changed employment soon after it started. His ideas and insights are gratefully acknowledged. Many colleagues assisted with the research and the report. In particular, I thank Peter Barnes for organizing and managing all the fieldwork and laboratory sorting, Kade Mills for many analyses, Penny Harrington for production of graphics and text, Dr Theresa Lasiak and Dr Julie People for considerable assistance with analyses and production of the report. I am grateful to the University of Sydney and the Australian Research Council (through its Special Research Centres programme) for funding for infrastructure, laboratories and my time. Finally, I thank Professor Gee Chapman for all of her ideas, insights, advice and comments on the report.

3. Background

Humans began catching fish at least 90,000 years ago and, since then, methods have developed to catch more and more fish of an ever-increasing variety. Large numbers of fish and marine invertebrates are often caught by trawling, which has been in use since at least the thirteenth century (de Groot, 1984). When trawling first began, relatively light gear was towed by sailing vessels at slow speed in shallow water. With the introduction of steam vessels in the 1900s, the weight and size of the trawl gear increased, as did the speed at which it was towed (Jones, 1992; Jennings & Kaiser, 1998). Recently, the depth at which trawl nets are used has also increased (Jennings & Kaiser, 1998).

Although concern for the environmental effects of trawling began as early as the thirteenth century, this concern was centred on the stocks of fish, damage to fishing gear and the effects these would have on subsequent catches (de Groot, 1984; Jennings & Kaiser, 1998). It has only been in the last few decades that attention has shifted towards the wider environmental issues connected with fishing. This began with concerns over the so-called "by-catch" of charismatic species like dolphins (in tuna purse-seines) and turtles (in shrimp trawls) and, after substantial research, various gear-based and operational solutions were developed (e.g. Hall, 1994).

While this was occurring, however, people's attention shifted to a broader issue concerning the by-catch, discard and wastage of not-so-charismatic species, like the juvenile fish killed by trawling for prawns and fish (Gray et al., 2003). Once again, scientists and fishermen started to investigate this problem and, again after a great deal of research, various solutions were developed to modify gear and operations to ameliorate some of the problems (e.g. various grids and panels developed in Norway - Isaksen & Valdemarsen, 1986, the US - Watson, 1989 and in N.S.W.'s prawn-trawl fisheries - for a summary see Kennelly et al., 1998).

During this work, however, public interests broadened once again to encompass much wider concerns about the impact of fishing methods, particularly trawling, on environments as a whole. Thus, anxieties are now expressed about the actual and potential impacts of fishing on all species in these systems, not just those species caught, retained or discarded (see Kaiser et al., 1998; Freese et al., 1999; Lindegarth et al., 2000a, b). As a consequence of this latest stage in the public's interest in environmental impacts of fishing, there have been several initiatives throughout the world calling for "ecosystem-based" approaches to fisheries management, including the Rio Convention on Biodiversity, the US Magnuson-Stevens Fishery Conservation and Management Act and the Australian Environment, Conservation and Biodiversity Protection Act. These initiatives have added considerable fuel to debates surrounding this issue and outcries for scientific information on how to deal with it.

Various types of trawling gear are commonly used for catching fish and benthic organisms, such as bivalves and prawns, that live or feed in benthic habitats. Of these, the effects that otter-trawls, beam-trawls and scallop-dredges have on the seabed have received the most attention (e.g. Collie at al., 2000a; Kaiser et al., 2002). Otter-trawls are the lightest of these gears. They consist of a funnel of net connected to two otter-boards. The boards are placed on opposite sides of the net to spread it open as it is towed behind a boat. Otter-boards often weigh more than 100 kg each and are dragged over the seafloor. Beam-trawls use a beam to keep the net open. This beam is connected to two shoes that open the net vertically and are in permanent contact with the seabed. This gear often weighs up to eight tonnes, but can be heavier. Otter-and beam-trawls can have tickler-chains, which are connected to the net and penetrate the sediment to disturb and dislodge organisms. Dredges can either be mechanical or hydraulic. Mechanical dredges consist of a bag attached to a rigid metal frame that is dragged over the seabed. The lower edge of the opening of the bag is fitted with long metal teeth, which rake through the sediment. Hydraulic dredges use jets of water or air to lift organisms and sediment onto a boat. Shellfish-dredges and beam-trawls can have the greatest effects on the seabed, followed by otter-trawls (Hall, 1994).

The benthic effects of trawling occur when trawls physically disturb the sediment and damage, dislodge or displace organisms that live on or in the sediment. Physical marks and tracks are often left in the sediment by trawling (Brylinski et al., 1994; Thrush et al., 1995; Collie et al., 1997; Schwinghamer et al., 1998; Thrush et al., 1998; Tuck et al., 1998). They are made by the boards, ground-ropes, chains and other parts of the gear that come into direct contact with the seabed. These can change the structure of the sediment by digging up and displacing boulders, scraping and scouring away sediments at the surface and smoothing out ripples and biogenic features (Schwinghammer et al., 1998). All of these change the habitat (Jennings & Kaiser, 1998).

In shallow areas subject to strong tides or currents, these effects may last only a few hours (Eleftheriou & Robertson, 1992), but, in deeper, more stable environments, they may persist for decades (Jennings & Kaiser, 1998; Schwinghamer et al., 1998). The ploughing motion of the trawling gear also resuspends sediment. The grain-size and degree of compaction of the sediment determine the amount of material resuspended. The suspension of sediment in the water-column reduces the penetration of light. In addition, when resuspended sediment eventually settles, it may clog the feeding apparatus of organisms (Rhoads, 1974), inhibit their settlement and growth or smother them (Jones, 1992). The physical disturbance of the sediment may, however, also have positive effects. Turnover and mixing of the sediment surface may result in oxygenation of deeper sediments and release of buried organic material and nutrients (Krost et al., 1990; Smith et al., 2000) and the chemical changes associated with the turnover of the sediment may increase local production (Smith et al., 2000). Despite these being increases, rather than decreases, in environmental variables, they are environmental impacts.

During the past decade, there have been many attempts to assess the impact of bottom-trawling on benthic organisms (e.g. Brylinsky et al., 1994; Kaiser & Spencer, 1996; Pitcher et al., 2000; Tuck et al., 1998; Piet et al., 2000; Sanchez et al., 2000). The susceptibility of organisms to damage from trawling depends on their positions on or in the sediment and the nature and stability of the substratum. Large organisms that live on or close to the surface of the sediment, such as corals and large sponges, are most prone to damage and destruction by trawling (Jennings & Kaiser, 1998; Collie et al., 2000a; Kaiser et al., 2000; Pitcher et al., 2000). Their biomasses and abundances often decrease in areas that are trawled (Jennings et al., 2001); dead and damaged animals can be seen along fresh tracks left by trawling gear (Pranovi et al., 2000). This can lead to increases in scavengers, which are attracted to freshly trawled areas by the availability of extra food from dead and damaged organisms (Ramsay et al., 1998). It is also thought that the disturbance and destruction of large habitat-forming organisms can potentially affect the abundances and distribution of smaller organisms that inhabit them (de Groot, 1984; Jones, 1992; Dayton et al., 1995), although Kaiser et al. (1999) found no difference in the fauna associated with worm tubes in trawled and untrawled areas.

Responses of smaller species that live in the sediments, such as polychaete worms and amphipods are mixed (Jennings & Kaiser, 1998). In some cases, the abundances of these organisms decrease after trawling (Bergman & Hup, 1992; Hansson et al., 2000), while in others they do not change (Brylinski et al., 1994), or their numbers increase (Ball et al., 2000). Generally, animals living in fairly deep burrows within sediments are not as prone to damage by trawl gear as those are found closer to the surface . The mortality of benthic organisms is also size-dependent and, in the case of bivalves, also varies with the thickness of the shell (Rumohr & Krost, 1991; Bergman & van Santbrink, 2000; Duplisea et al., 2002). The passage of trawl-gear also redistributes small organisms and increases the susceptibility of organisms, particularly those left exposed on the surface of the sediment, to attack by scavengers and predators (Caddy, 1973; Kaiser & Spencer, 1996; Ramsay et al., 1998). In general, it is thought that the increased damage to larger organisms by trawling can result in assemblages being dominated by small-bodied (Kaiser et al., 2002) and less vulnerable species (Pitcher et al., 2000).

The duration of the effects of trawling on marine organisms can vary greatly. In the cases of large, slow-growing macrofauna, colonies may not recover for decades (Collie et al., 1997; Pitcher et al., 2000). In the case of opportunistic species, such as some worms (spionids and capitellids) and small crustaceans (amphipods), which recolonize disturbed areas quickly, the effects may be short-lived (Jennings & Kaiser, 1998; Pranovi et al., 2000). Effects are also likely to be more short-lived in assemblages subject to frequent natural perturbations, because animals in unconsolidated sediments are probably those with life-histories well-suited to frequent disturbance by currents and resuspension of sediment (Jennings & Kaiser, 1998; Collie et al., 2000a).

The effects of trawling on the seabed are therefore varied and can depend on a number of different factors, including the size, weight and type of gear used, the amount of contact with the seabed, speed of towing, type of sediment, depth of water, intensity of fishing, strength of currents and tides and any other natural disturbances in the fished area (Jones, 1992; Prena et al., 1999; Bergman & van Santbrink, 2000; Collie et al., 2000a, b; Kaiser et al., 2000).

Most studies on effects of bottom trawling on benthic organisms have considered otter-trawling (Collie et al., 2000a). Gibbs et al. (1980) examined the operation of a prawn otter-trawl over a sandy substratum in Botany Bay, N.S.W. They found that the bottom edge of the otter board created a noticeable furrow in the sediment and a plume of sand. The foot rope, in contrast, skimmed over the bottom and created only minimal disturbance. Drabsch et al. (2001) noted that the tracks of otter boards and skids were apparent within all their trawl corridors in the Gulf of St Vincent, South Australia. They also pointed out that the footline and net removed topographic features of the sediment, such as the mounds created by burrowing animals.

There have been several studies specifically on the impact of prawn-trawling on benthic organisms. Gibbs et al. (1980) compared the macrobenthos at three trawled sites with that an undisturbed control site in Botany Bay, before trawling commenced, after a week of trawling and at the end of the commercial trawling season. These authors noted that there were differences in assemblages among sites and between seasons. These differences, however, reflected the patchy distribution of the animals rather than the effects of trawling. Van Dolah et al. (1991) examined the effects of commercial shrimp-trawling on infaunal assemblages in two sounds in South Carolina, U.S.A. Two areas in each sound, one fished actively by trawlers and the other closed to fishing, were sampled before and five months after the opening of the fishing season. The species composition of the trawled sites was similar to that of the closed sites. A reduction in faunal abundance and number of species at all four sites was noted during the second sampling period. This reduction was attributed to natural seasonal effects rather than disturbances due to fishing.

Lindegarth et al. (2000a) investigated the effects of otter-trawling on the benthos in Gullmarsfjorden, Sweden, an area that used to support a small shrimp fishery but which had been closed to trawling for 6.5 years. They compared the results from a Before and After experiment involving replicate trawled and control sites with those obtained by analysing the individual pairs of trawl and control sites. The complete experimental design indicated that changes in total number of individuals, number of species and abundances of two taxa from before to after trawling varied among sites and treatments. Short-term temporal changes in abundances of individual taxa or number of species were not affected by the treatments. Comparisons based on pairs of sites, however, showed that differences in temporal changes in abundances and number of species between control sites were as common as differences between trawled and control sites. This study shows how patterns of natural variability among sites can be confounded with the effects of trawling. It is obvious from this study (apart from well-known issues of logic) that no study without appropriately replicated trawled and untrawled areas can possibly be used to identify impacts of trawling.

Drabsch et al. (2001) also used a Before-After, Control-Impact design, with adjacent fished and control corridors in three locations, to examine the effects of otter-trawling on the benthos in the Gulf of St Vincent. Changes in the structure of the infaunal assemblages consistent with the effects of trawling were found at only one of the three locations. Changes in the abundance of infauna, ctenodrilid polychaetes and tanaid crustaceans that were indicative of an impact were also detected, but only at one location. Drabsch et al. (2001) suggested that the lack of response was either due to differences in the susceptibility of the various locations and taxa to trawling or to asynchrony in natural temporal and spatial variability.

Sparks-McConkey & Watling (2001) studied the effects of small-intensity, experimental shrimp-trawling in a muddy region of Penobscot Bay, Maine (U.S.A.) that had been closed to trawling for 20 years. Trawled sites were swept four times in one afternoon with commercial gear that had been modified to lessen the damage on the seabed. Sparks-McConkey & Watling (2001) found that chlorophyll *a* values were significantly greater in the sediments that had been subjected to trawling than in the reference areas, immediately after trawling. The numbers of individuals and of species, infaunal diversity and abundances of four species of polychaetes and three species of bivalves were significantly smaller in the post-trawl areas than in the references areas, immediately after trawling. Nemerteans increased in abundance after trawling. Differences in the overall structure of the infaunal assemblages were also evident after trawling. Most of these effects were not evident in the subsequent post-trawl samples.

In many studies concerned with the impacts of trawling, such as those in the North Sea, quantification of effects of trawling has been hampered by the lack of unfished areas (Jennings & Kaiser, 1998). If large-scale changes in assemblages occurred during the initial period of trawling, it may not be possible to detect further impacts, either because the existing assemblages are resilient to trawling, or because the effects are now smaller than those which occurred in the past (Tuck et al., 1998). In areas that have never been fished or have not been fished for lengthy periods, changes in the structure of assemblages can be measured before, during and after periods of experimental fishing (Kaiser et al., 1996; Pitcher et al., 2000; Tuck et al., 1998).

Changes in benthic assemblages have also been measured in areas subject to different intensities of fishing (Kaiser et al., 1996; Jennings et al., 2001) and in areas where commercial fishing has ceased. Effects have also been assessed after single (Bergman & Hup, 1992; Kaiser & Spencer, 1996) and repeated trawling (Tuck et al., 1998; Lindegarth et al., 2000a, b). Many of these studies have failed to account for the natural temporal and spatial variability in benthic populations (Underwood, 1991; Morrisey et al., 1992a, b). Repeated comparisons of the biota at a single site before and after trawling (Bergman & Hup, 1992) can only be used to establish whether a change occurred at the same time as the onset of trawling. These changes cannot be attributed solely to the effects of trawling because some other totally unexpected disturbance may have coincided with trawling (Underwood, 1991). Similarly, trawling is often regulated by closed seasons, so the opening to fishing may always start at the same time as natural seasonal changes. Comparisons of biota at a trawled site and an adjacent undisturbed site (Tuck et al., 1998) cannot distinguish between ecological impacts and natural spatial variability (Underwood, 1991, 1992). Also, control sites directly adjacent to trawled sites may be affected by trawling (e.g. resuspension and subsequent settlement of sediment may occur over the control sites).

Rigorous tests of hypotheses about the effects of trawling require the temporal changes in the fauna in single or multiple fished areas to be contrasted with those in multiple undisturbed control/reference areas before and after trawling (Underwood, 1992, 1994). Designing experiments to detect the effects of trawling is therefore very problematic. Even the relatively few studies concerned with measuring the impacts of trawling on benthic organisms that have used good experimental designs were necessarily done in areas that had previously been fished (e.g. Lindegarth et al., 2000a, b; Drabsch et al., 2001).

Most studies on the effects of trawling have used changes in abundances of benthic organisms to detect effects (e.g. Bergman & Hupp, 1992; Thrush et al., 1995; Currie & Parry, 1996; Collie et al., 1997, 2000a, b; Kaiser et al., 1998, 1999, 2000; Lindegarth et al., 2000a; Smith et al., 2000; Drabsch et al., 2001). The abundances of marine organisms vary naturally at a range of scales (Morrisey et al., 1992a, b). Changes in the variability of organisms can also be used to detect impacts (Warwick & Clarke, 1993; Chapman et al., 1995). Effects of trawling may therefore also be detected by measuring differences in variability rather than, or along with, changes in abundances. This approach was used by Lindegarth et al. (2000b).

Prawn trawling is permitted in few estuaries in N.S.W., the Clarence, Hawkesbury and Hunter rivers and, at the start of this study, in Port Jackson and Botany Bay. The Clarence River is the largest of these. Otter-trawl nets are used to catch prawns. Generally, only one net is used, except in the Clarence River, where the majority of trawlers simultaneously use two nets. In the Clarence River, only certain areas are open to trawling and approximately 50 % of the estuary is permanently closed to trawling. Most of this area is west of the Ulmarra ferry route, hence it occurs in the most inland part of the river. The estuarine prawn trawl fishery in the Clarence River is open to trawling from December to the following May and closed from June to November each year.

This study was designed to use the existence of spatial "treatments" (closed versus trawled areas) and temporal "treatments" (periods of the year open or closed to fishing) to test hypotheses about influences of trawling on benthic fauna in the sediments in the Clarence River. By nature, the study cannot possibly investigate potential long-term environmental changes caused by a long history of human activity (including trawling) that may have affected the benthic assemblages throughout the Clarence River. By designing the study to take into account extensive natural spatial and temporal variation in the system, it is, however, possible to provide unambiguous tests of hypotheses about effects of current practices.

Many studies of the impacts of trawling on assemblages of benthic organisms have trawled areas once only and/or have used only an experimental trawling regime (e.g. Brylinski et al., 1994; Currie & Parry, 1996; Kaiser et al., 1998, 1999; Bergman & van Santbrink, 2000; Hansson et al., 2000; Lindegarth et al., 2000a, b; Sanchez et al., 2000; Drabsch et al., 2001). This study uses areas that are trawled by commercial fishing vessels in their usual manner.

4. Need

As mentioned above, one consequence of increasing concerns over environmental effects of fishing is that fisheries scientists, managers and fishermen are now being asked to consider not only the consequences of removing target species and non-target, by-catch species, but also the ecological implications of disrupting habitats and the many species living in these systems. Unfortunately, much of the life on and in the seabed influenced by fishing-gear like demersal trawls is unknown to the general public and, in Australia, much of it also remains unknown to science. While the species that comprise the biodiversity of these systems (sponges, ascidians, bryozoans, polychaetes, microscopic organisms, juveniles of commercially exploited species, etc.) have little charisma, public appeal or commercial priority, their role is a critical one because they underpin much of the local ecology. Add this to the fact that most of our commercial and recreational fisheries rely on the continued normal “functioning” of these habitats and it becomes obvious that the fishing industry itself should be (and some enlightened fisheries, are) concerned about these issues. Not only is it important for fishermen to understand these environments in order to answer public outcries, but, also it makes good business sense for them to be actively involved in the maintenance of the systems upon which their fisheries depend.

Issues concerning biodiversity and environmental effects of fishing are key to most managerial plans for commercial fisheries in Australia, where there are policies to manage in an “ecologically sustainable” manner. Ecological sustainability is not actually possible without sustaining the diversity of the system, so the examination of processes sustaining biodiversity and the inclusion of such issues in managerial plans is a high priority for most fisheries agencies, including the N.S.W. Fisheries (now in the Department of Primary Industries).

Maintaining the ecological sustainability of estuaries is particularly important in a broader context because most of the species exploited in oceanic and estuarine waters rely on these estuaries for critical parts of their life-cycle. For example, the very large Clarence River in N.S.W. is known to be important habitat for the juvenile stages of eastern king prawns and many species of fish that are exploited in oceanic waters. Protecting the ecology of such systems will obviously have major benefits for all fisheries based on such species, not just those exploited within the estuary.

The estuarine prawn-trawl fisheries of N.S.W. also provide a unique opportunity to develop experimental designs and sampling protocols to investigate ecological impacts of trawling. These fisheries occur in shallow, calm water and, most importantly, already have various areas and times that are open and closed to trawling, providing excellent replicable treatments to incorporate in experimental comparisons. These factors combine to make these particular trawl fisheries ideal case-studies for studying impacts of trawling on ecosystems and to provide measurable indices of biodiversity that can be used as E.S.D. performance indicators. This research is particularly important in providing a model for how future studies (in more difficult habitats) may proceed.

5. Objectives

1. To quantify benthic assemblages from trawls in areas and times that are trawled and untrawled in an estuarine prawn-trawl fishery;
2. to manipulate trawling effort in untrawled areas to determine the nature and magnitude of impacts. This could not be done because large-scale perturbations to the entire estuary caused delays and made the original comparisons more time-consuming;
3. to interpret results to help develop plans for management and mitigation to ameliorate any problematic impacts identified;
4. to identify on-going issues to underpin future research and management; and
5. to develop protocols, experimental designs and the basis for calculations of power to measure and interpret impacts of fishing practices in other (e.g. offshore) habitats.

The impacts of trawling in the Clarence River are intrinsically confounded with any natural seasonal differences because trawling is only allowed during the Open season from December to May. Consequently, if there are consistent, natural seasonal differences in benthic fauna between this period and the season open for trawling, differences would be confused with changes due to trawling. Because of this, it is crucial to examine natural (i.e. untrawled) ecological changes in areas not subjected to trawling and to identify any changes in trawled areas that are due to trawling. These would appear as different types or sizes of change between Open and Closed seasons in trawled areas compared with what happens in untrawled areas.

Specifically, predictions were made that if there was an effect of trawling, then:

1. The types and abundances of benthic organisms in trawled areas will differ more from those in control, untrawled areas during open seasons than during closed seasons. Several scenarios could occur, two of which are illustrated in Figures 1 and 2. In each case, during the open season (from December to May), the change from one sampling time to the next shows differences in the assemblages due to temporal change and trawling. During the closed season (from June to November), the change from one sampling time to the next shows differences in the assemblages due to temporal change and recovery from trawling.
2. Assemblages in trawled areas will be less variable (i.e. more similar in the replicates) than those in control areas, particularly during the open season. An example of the patterns expected if this prediction is correct is shown in Figure 3. To identify impacts due to trawling, it is therefore necessary to examine the patterns in assemblages from open to closed seasons to detect changes in trawled areas that do not match the natural changes in closed areas. It is also necessary to examine patterns of variability in assemblages to determine whether their average composition is or is not affected by trawling. The logical requirements and necessity for these comparisons and the appropriate ways to interpret any patterns have been explained in detail in Green (1979), Clarke & Green (1988), Clarke (1993) and Underwood (1991, 1992, 1993, 1994). This study was designed to be able to examine any effects of trawling by testing the predictions (hypotheses) about patterns of difference between trawled and untrawled areas, about patterns of temporal change in trawled and untrawled areas and about patterns of change in variability in trawled and untrawled areas.

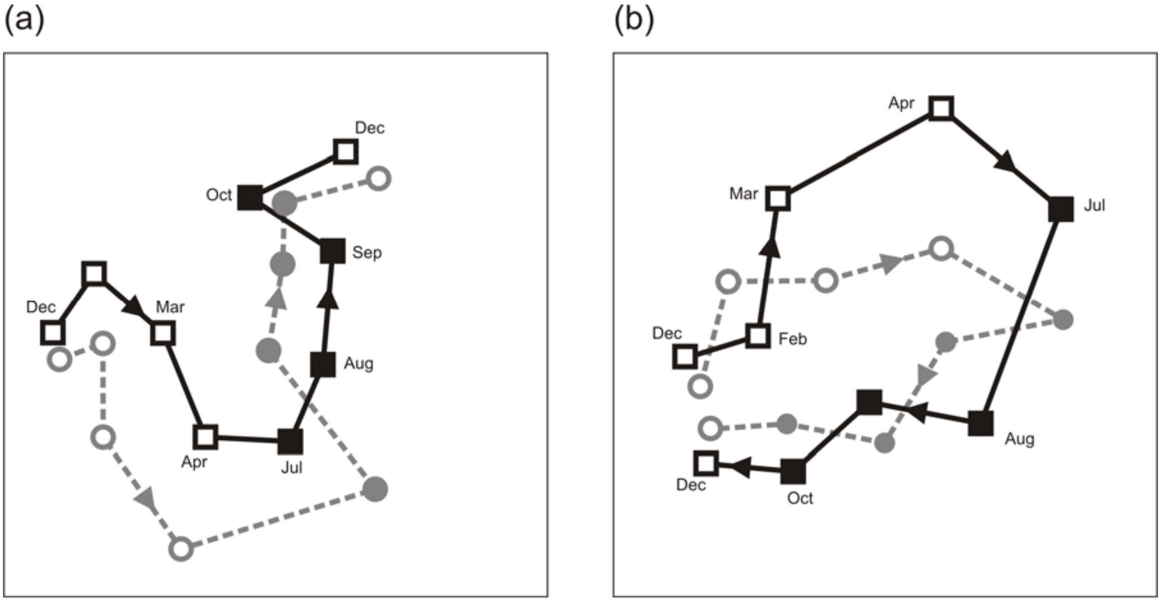


Figure 1. Illustration of hypothetical patterns in assemblages of benthic species affected by trawling. In the diagrams (which are nMDS – non-metric multi-dimensional scaling diagrams), each point represents the species present (with their relative abundances) in a sample. The closer together two points are, the more similar the assemblages. Grey symbols (○ , ●) represent samples from areas closed to trawling. Black symbols (□, ■) represent samples from areas which are trawled. Empty symbols are the open season; filled symbols are when the areas are closed to trawling. Refer to Section 6.2 for description of the methods used to display and analyse the data.

a) Time-course of assemblages if there is natural change from time to time and trawling causes differences, but recovery occurs during the period closed to trawling. So in December, at the left-hand end of the diagram, assemblages in trawled (black) and closed (grey) areas are naturally different. As the open season progresses (December to April), the assemblages change naturally, but trawling causes increasing difference from untrawled areas. During the closed period, assemblages recover and those in previously trawled areas start to become like those in the closed areas.

b) Time-course of assemblages if there is natural change from time to time that is seasonal, so that assemblages change during the year, but become similar again by the end of the year. So, assemblages in December at the start are quite similar to those in December a year later, even though they change substantially throughout the year. Again, trawling from December to April causes changes in fauna. When trawling stops after April, assemblages start to recover, so that, by October, assemblages in trawled and closed areas are similar again.

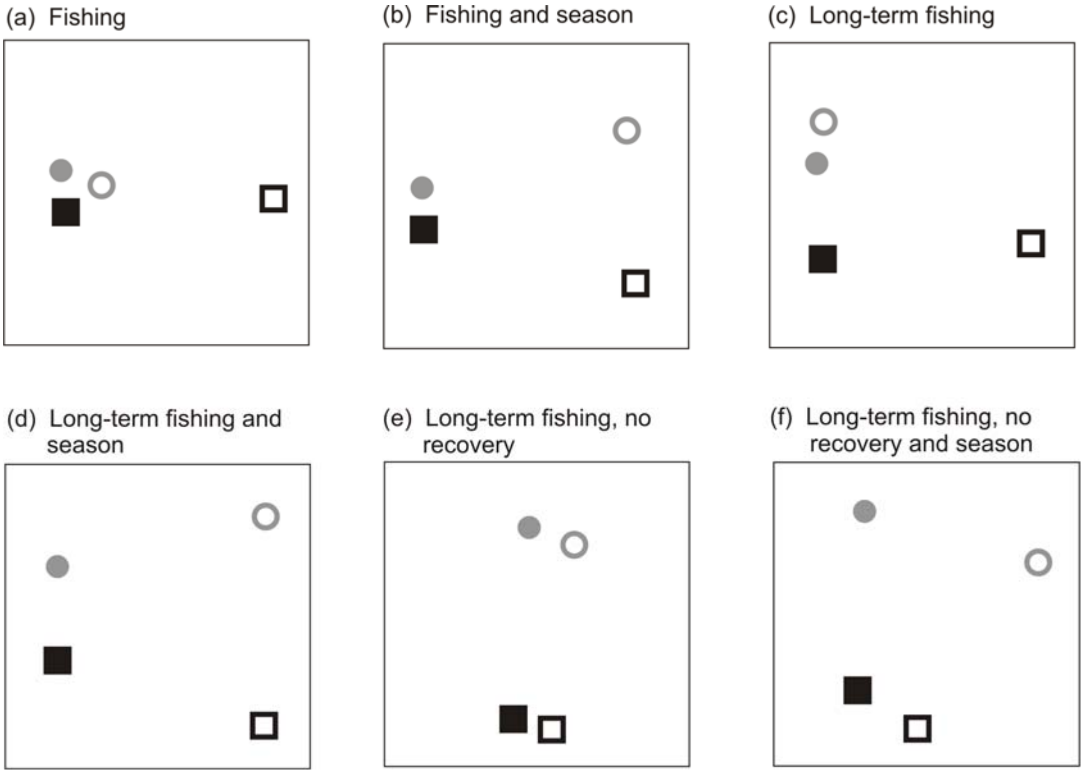


Figure 2. Illustration of patterns that might occur if trawling affects assemblages analysed separately.

(a) shows what would happen if trawling affects assemblages which otherwise show no seasonal differences and assemblages recover when trawling stops. So, samples from the open areas in the open season (□) are different from all others;

(b) trawling affects assemblages, which also show natural seasonal differences. When trawling ends, assemblages in trawled (■) and closed (●) areas are similar. At the end of the open season, they differ (□ , ○); note that, in each area, the assemblages differ between the 2 seasons;

(c) there is an effect of trawling, there are no natural seasonal differences, but the closed season is not long enough to allow assemblages to recover. So, in the closed season, trawled areas (■) are more like untrawled areas (●, ○) than during the open season (□), but have not completely recovered;

(d) shows the same outcome as (c), except that there is natural seasonal variation;

(e) shows what would happen if there is an effect of trawling, but no recovery during the closed season and there is no natural seasonal variation. So, assemblages in trawled areas (□, ■) are like each other during the trawled and closed seasons. They differ from those in closed areas (○ , ●), which are similar in trawled and closed seasons;

(f) is the same scenario as (e), but with natural seasonal variation.

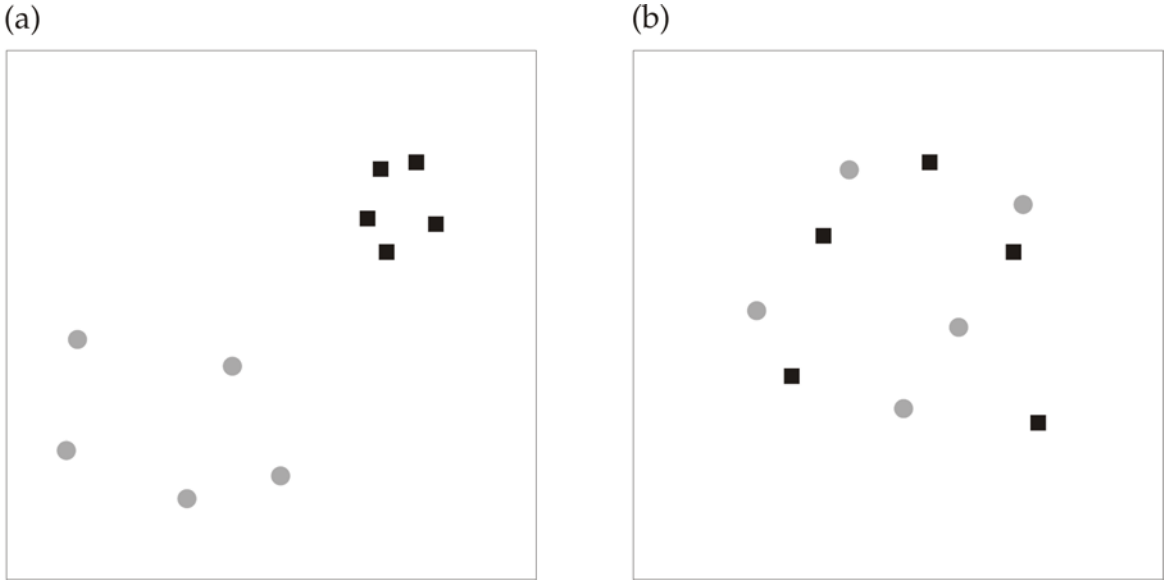


Figure 3. Illustration of impacts of trawling affecting the variation in assemblages at any single time of sampling. Again, points close together represent samples with similar types and numbers of animals.

(a) at the end of a period of trawling, samples from trawled areas (■) differ from those in closed areas (○), due to trawling. In addition, replicate samples from open areas (●) are quite scattered, representing natural variability. Those from trawled areas (■) are much closer because trawling disturbs the area and the disturbed assemblages are very like each other;

(b) at the end of the closed season, animals have recovered, so that previously trawled (■) and closed (●) areas have similar assemblages and similar large variation among replicate samples.

6. Methods

6.1 Sampling

Three regions within the Clarence River were sampled. These were in the vicinity of Ulmarra, Brushgrove and the Broadwater (Fig. 4). Each region included two locations that were trawled during the open season and, as controls, two that are permanently closed to trawling. At Ulmarra, the trawled locations were selected below the ferry line and the control locations above the ferry line. At the Island near Brushgrove, the trawled locations were selected in the main channel and the control locations in the small northern channel. At Broadwater, the trawled locations were selected in the main channel and the control locations in the entrance to Broadwater. At each location, three sites approximately 4 m x 4 m and approximately 50 – 100 m apart were selected. Five replicate 10 cm diameter, 10 cm deep cores were collected by divers approximately 1-2 m apart at each site.

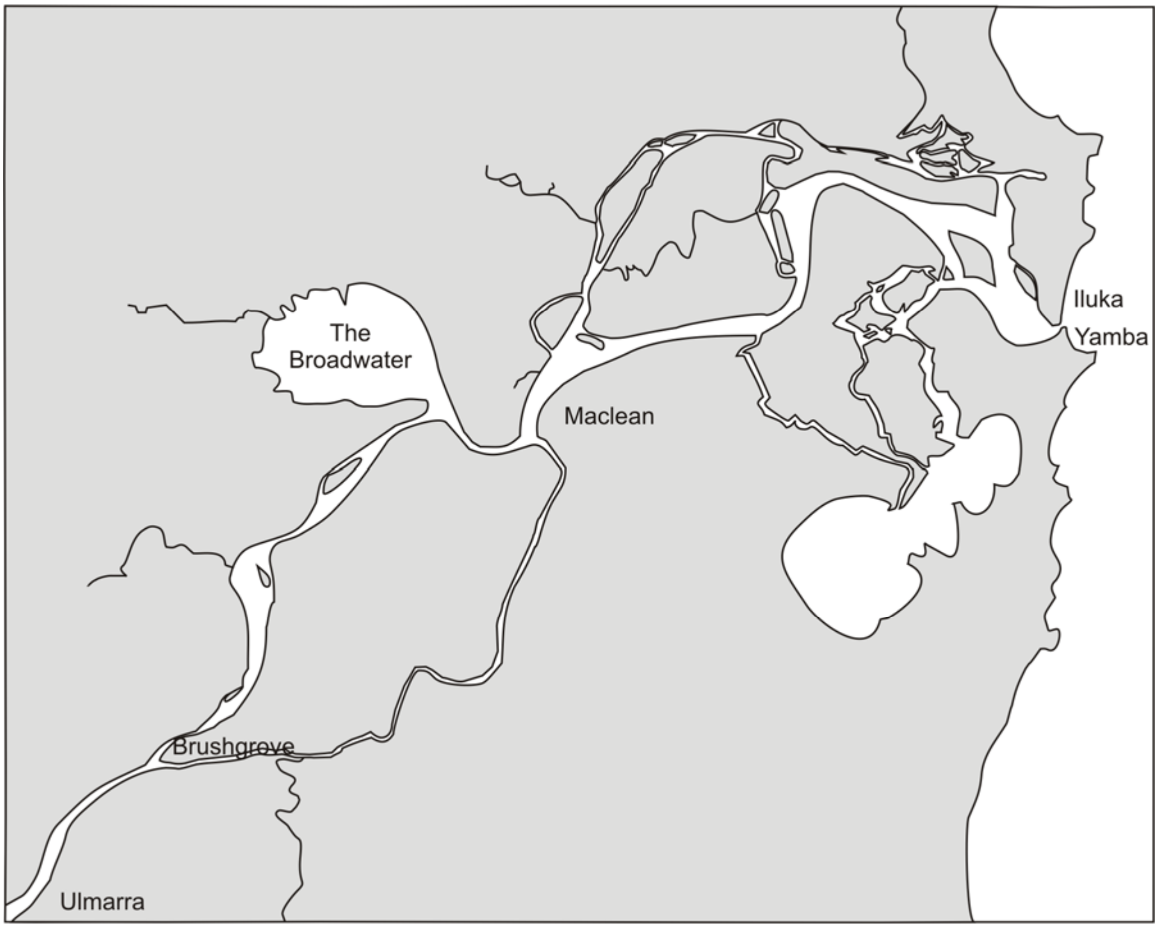


Figure 4. Map of the Clarence River showing the positions of Ulmarra, Brushgrove and the Broadwater, the regions in which samples were collected.

It was necessary to use several nested or hierarchical spatial scales of sampling, because nothing was previously known about spatial variability in the benthic assemblages in the Clarence River. There is usually considerable variability in the numbers of these animals from place to place at small scales (1 to a few m apart) and among sites 10s or 100s of m apart (see particularly Morrisey et al. (1992a, b)). How this translates to multivariate dissimilarities from one place to another is not known. Because resources for sampling are obviously limited, it was important to examine spatial variability at as many scales as was practical without reducing replication below that necessary for reliable statistical analyses.

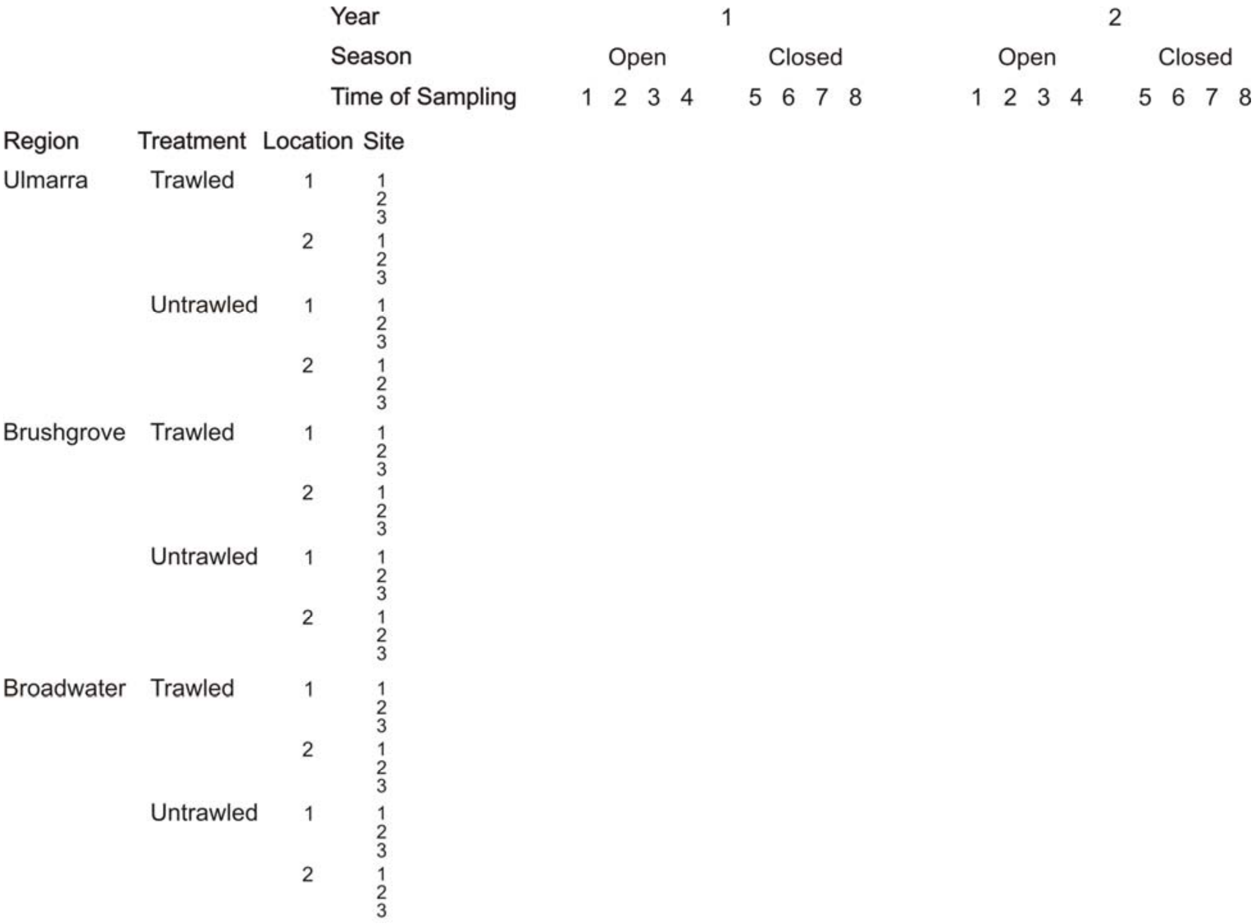


Figure 5. Design of sampling. There are 4 spatial scales (3 Regions, 2 trawled and 2 untrawled locations in each Region, 3 Sites in each Location and n = 6 replicate core-samples in each Site at each Time). There are 3 temporal scales (2 Years, Open versus Closed Seasons in each Year and 4 Times of sampling in each Season). The entire design involves 3,456 samples.

Samples were collected 16 times over two years: four times in each open or closed season per year. Samples were collected in December, January, March and April for the open season in each year. For the closed season, they were collected in July, August, September and October in year 1 and in June, July, September and October in year 2. Time 1 of the sampling began in December 2000. Broadwater time 1 control (untrawled) location 2 was not sampled; but it was added after the results of the first time of sampling were analysed. A different location was originally chosen and sampled, but turned out to have very different sediments and fauna and could not therefore be considered to be a valid control area.

The river flooded in March 2001 and by April 2001, trawling had recommenced in all regions except Ulmarra. Hence, Ulmarra was not sampled in April 2001 (Time 3).

Samples were sieved through a 500 µm sieve and sorted using dissecting microscopes. In some cases, samples contained large amounts of coarse material. These samples were sieved using 1 mm and 500 µm sieves. The 1 mm fraction was sorted by eye under a fluorescent lamp. Organisms in each sample were counted and identified to the taxonomic levels described below (Table 1).

Table 1. The taxonomic resolution to which organisms were identified.

Taxa	**Level of identification**
Oligochaetes	Class Oligochaeta
Polychaetes	Family
Amphipods	Species
Isopods	Species, except Sub-order Anthuridea, which were called Anthuridea
Crabs	Species
Other Crustaceans	Order, except Family Penaeidae, which were called Penaeidae
Ophistobranch	Subclass Ophistobranchia
Gastropods	Species
Bivalves	Species
Nematodes	Phylum
Nemerteans	Phylum
Insects	Adult insect, colembola, Insect larvae
Chelicerata	Spider, mite, pycnogonid
Hemichordates	Class Enteropneusta
Chordata	Class Osteichthyes, Osteichthyes larvae

6.2 Statistical Analyses

6.2.1 Multivariate analyses

Two basic strategies were used to analyse multivariate data: a graphical method and statistical tests. The graphical method is designed to show patterns in two or three dimensions which represent the patterns of overall differences (of a more complex nature) between assemblages of species in the samples. The method used is called non-metric multi-dimensional scaling, or nMDS. The statistical tests, by contrast, are designed to give a rigorous measure of how likely the patterns graphs (or, generally, in the data) represent real differences. Statistical tests were using analyses of similarities (ANOSIM and PERMANOVA).

6.2.1.1 Non-metric multidimensional scaling (nMDS)

Details of calculations for nMDS can be found in Kruskal & Wish (1978). In essence, nMDS is a plot of the samples in any particular study or experiment, with each replicate sample (i.e. a single core of sediment) being represented by "C" for replicates from control areas or "T" for replicates from trawled areas (Fig. 6). The distance on the plot between any two replicates is a measure of how different those replicates are from one another in terms of the kinds of species they contained and the abundances of those species.

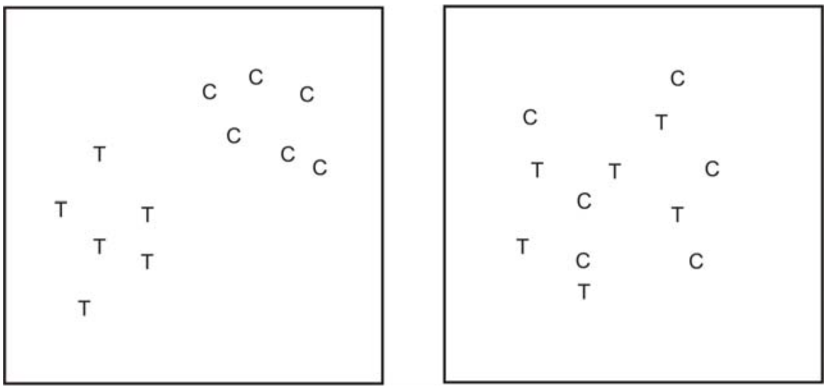


Figure 6. Patterns in assemblages, illustrated as an nMDS (non-metric Multi-Dimensional Scaling plot). Cs represent samples from Control (untrawled) areas, Ts from Trawled areas. On the left, Cs and Ts are clearly separated, indicating a major impact of trawling. On the right, Cs and Ts are mixed together. There is no impact – samples could equally well be from untrawled or trawled areas.

Examples of two hypothetical nMDS plots are in Fig. 6. In the plot on the left (Plot 1), the "C" symbols are in their own group and are clearly separated from the "T" symbols. This is the pattern one would expect if there was a clear impact of trawling on benthic fauna. The separation of the "T" symbols indicates that the composition and numbers of organisms in replicates from trawled areas are nothing like those in replicates from controls.

In contrast, the plot on the right (Plot 2) shows the patterns one would expect if there were no impact. The symbols are equally scattered and well-mixed, indicating that the sets of animals in samples from trawled areas do not differ from those obtained at control areas.

Plot 1 above shows one kind of impact. The reason that trawling is believed to be having an effect in that case is because the plot shows these replicates in a different location on the plot relative to controls. There is another way that an impact can be suggested by patterns on a nMDS plot.

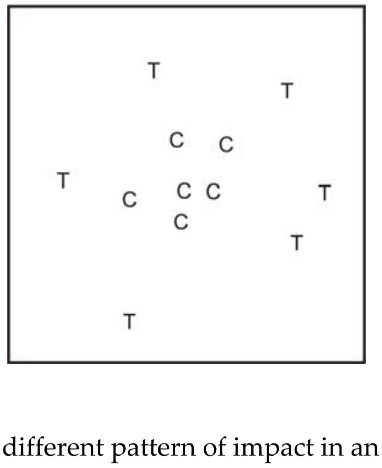


Figure 7. A different pattern of impact in an nMDS. Cs represent samples from Control (untrawled) areas, Ts from Trawled areas. Samples from Control and from Trawled areas are centred together, but the Ts are much more scattered. The impact of trawling is to change the variability in fauna from place to place in trawled areas.

Consider the hypothetical nMDS plot in Fig. 7. In this case, the "C" symbols are all clumped in the middle and the other symbols are scattered at much greater distances, dispersed all around the plot. This means that assemblages of organisms in replicates from control areas are very similar to each other, but those from trawled areas are extremely different and highly variable. This is the expected pattern if the impact due to trawling caused great variation among the replicates. A measure of such variation is referred to as a measure of multivariate dispersion, or a measure of "within-group heterogeneity".

6.2.1.2 ANOSIM and PERMANOVA

Although patterns on nMDS plots often give a good idea of whether or not an impact is happening, proper statistical tests are also needed.

One major problem with statistical analyses of multivariate data, in comparison with univariate data, is that measures of dissimilarity (the difference across all species) between replicates within or between samples are not independent. Each replicate is used many times. To solve this, statistical tests have been developed which generate the necessary probabilities used in the tests be permutation of the data (i.e. random shuffling of replicates from one treatment to another).

ANOSIM (Clarke, 1993) and PERMANOVA (Anderson, 2001) are such tests. They make few assumptions about the kind of data to be analysed and the results should be consistent with the kinds of patterns in the nMDS plot.

The corresponding problem, however, is that permutational tests are potentially problematic when used in complex experimental designs (where there are interactions, across many spatial and temporal scales), such as used here. In the present study, independently, randomly-chosen replicates from those available at each time of sampling and site were used to generate independent measures of dissimilarity which could then be used in the necessarily complex univariate analyses needed here. Because early analyses showed little consistent interaction across sites and times, these analyses were preferred over attempts to emulate complex analytical procedures using multivariate methods (Anderson, 2001).

6.2.2 Univariate analyses

There are two kinds of analyses for determining whether or not trawling is causing impacts on individual species or types of animals: graphical representations for viewing patterns and analysis of variance (ANOVA) as a statistical test.

6.2.2.1 Graphical representations

In general, the univariate graphics used were bar graphs which showed: (1) the average abundance for that species or group of animals at the designated location and (2) a measure of variability (standard error) for the set of replicates contributing to that average. A hypothetical graphic of this nature is shown in Fig. 8. This graph is what one expects if trawling were causing a reduction in the abundance of a particular animal. Similar graphics were used for univariate calculations of mean values of multivariate dissimilarities.

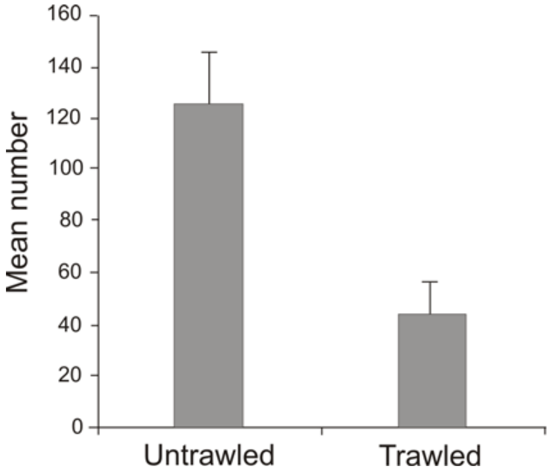


Figure 8. A typical graph summarizing univariate data. The bars are the average (or mean) numbers of a particular species in Untrawled (Control) and in Trawled areas. The error bars indicate imprecision or "noise" in the data. They are Standard Errors and indicate whether mean sampled numbers are likely to represent really different numbers of the population. Here, trawling has reduced the numbers and thus has an impact.

6.2.2.2 Analysis of variance

The use of analysis of variance for traditional univariate tests is widely known (e.g. see Sokal & Rohlf 1981, Snedecor & Cochran 1989 or Winer et al. 1991). Further details concerning its use with complex experimental designs in ecology, such as for the experiments done for this project, are described by Underwood (1981, 1997).

7. Results

7.1 The assemblages sampled

In general, assemblages were quite diverse; a total of 105 taxa was used in analyses. These were a mix of numerous (21) families of polychaetes, 20 types of amphipods, 8 isopods, 9 bivalves, 9 gastropods and a scattering of other taxa (crustaceans, worms, etc.). As is typical of estuarine benthic assemblages, most of these taxa were rare or were only locally abundant (at some times, in some sites or in only a few cases).

7.2 Variability in assemblages

Before attempting to analyse differences between trawled and untrawled areas, it was necessary to simplify the complexity of spatial differences, so that analyses of differences in assemblages would be robust. The first step was to consider spatial variability among replicate sites, i.e. small-scale variations in relative abundances of species and composition of taxa in assemblages. Not only is such variation generally large, requiring appropriate replication at several spatial scales (Morrisey et al., 1995; Underwood and Chapman, 1996), but it is often affected by environmental disturbances. So, trawling might have increased (e.g. Warwick & Clarke, 1993) or decreased (Chapman et al., 1995) spatial variation.

7.2.1 Variability within and between sites

Data from Ulmarra and Brushgrove were analysed for the two years. Broadwater could not be included because it was not sampled at Time 1. Also, data from Times 3 – 4 at Ulmarra could not be included because they were not sampled or contained no animals, presumably as a result of the flood (see later); there were therefore only 2 times of sampling in the open season of Year 1 for all regions. Two times were therefore chosen for the other regions. Each Region was analysed separately. So, for each Region, analyses contained data from:

2 years (random);
2 seasons, open versus closed (a fixed factor);
2 treatments, trawled versus untrawled (a fixed factor);
2 locations in each treatment (random, nested in treatments);
2 times in each season (random, nested in seasons);
3 sites in each location (random, nested in location in each treatment).

For year 1, times 1 and 2 were in the open season, times 7 and 8 in the closed season. For year 2, the corresponding times were 9, 10 and 15, 16.

Variability in assemblages was measured by constructing replicated, independent measures of Bray-Curtis dissimilarity from the 6 replicate cores in each site at each time of sampling. Four replicates were chosen, at random, in 2 pairs. Each pair then generated 1 measure of dissimilarity, giving 2 replicate measures for each site and time. These data could be used in analyses of variance (e.g. Table 2).

Variability between sites was analysed in a similar way for all treatments, locations, seasons and times. For each location and time, dissimilarities were calculated between replicates from each site. Two independent replicates were used for each combination. Thus, for dissimilarity between site 1 and site 2, $n = 2$ independent dissimilarities were calculated, using 2 replicate cores from each site. A further $n = 2$ were available between sites 1 and 3 and between sites 2 and 3, using up all 6 replicate cores in each site. These are referred to as the factor Comparison in the analyses (e.g. Table 4).

The complete set of data for all 3 regions were analysed for year 2, when no samples were missing. The within and between sites dissimilarities were calculated as before for every time of sampling. For these analyses, the design included:

2 seasons, open versus closed (a fixed factor);
2 treatments, trawled versus untrawled (a fixed factor);
2 locations in each treatment (random, nested in treatments);
2 times in each season (random, nested in seasons);
3 sites in each location (random, nested in location in each treatment) or 3 comparisons between pairs of sites for analyses among sites (called Comparison in analyses and also nested in each location in each treatment;
4 times in each season (random, nested in seasons).

7.2.1.1 Variation within sites (Years 1 and 2)

Variability between replicates, i.e. the small-scale natural variation from across the few m^2 of each site, was remarkably similar for all sites and times of sampling (Table 2). In fact, the variation among replicate measures of dissimilarity within sites was virtually identical for Ulmarra and Brushgrove (note Residuals in Table 2).

Table 2: Analysis of dissimilarities between pairs of replicates within each site for 2 times in each season, each treatment and all locations in Years 1 and 2; n = 2 pairs of replicates for each site. In this and all subsequent Tables, * indicates $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; ns, $P > 0.05$.

(a) **Ulmarra** Cochran's *C* = 0.09 ns

Source	df	MS	*F*	*P*
Year = Yr	1	3,863.7	NT	
Season = Se	1	459.3	NT	
Treatment = Tr	1	0.1	NT	
Location = L(Tr)	2	767.1	NT	
Time = T(Yr x Se)	4	1,227.9	3.78	ns
Site = S(L(Tr))	8	688.7	1.62	ns
Yr x Se	1	4.7	NT	
Yr x Tr	1	93.8	0.20[1]	ns
Yr x L(Tr)	2	35.8	0.54[2]	ns
Yr x S(L(Tr))	8	232.3	0.54	ns
Se x Tr	1	335.5	0.27	ns
Se x L(Tr)	2	1,253.5	NT	
Se x S(L(Tr))	8	742.7	1.74	ns
Tr x T(Yr x Se)	4	1,119.6	3.44	ns
L(Tr) x T(Yr x Se)	8	325.1	0.76	ns
T(Yr x Se) x S(L(Tr))	32	426.4	1.13	ns
Yr x Se x Tr	1	4.1	< 0.001	ns
Yr x Se x L(Tr)	2	4,165.2	9.92[3]	***
Yr x Se x S(L(Tr))	8	487.5	1.14	ns
Residual	96	376.7		

Pooling procedures – [1] test against Tr x T(Yr x Se) after pooling Yr x L(Tr) and Yr x S(L(Tr)); [2] test against S(L(Tr)) x T(Yr x Se) after pooling Yr x S(L(Tr)) and T(Yr x Se) x L(Tr); [3] test against S(L(Tr)) x T(Yr x Se) after pooling T(Yr x Se) x L(Tr) and Yr x Se x S(L(Tr))

(b) **Brushgrove** Cochran's *C* = 0.08 ns

Source	df	MS	*F*	*P*
Year = Yr	1	825	3.03[1]	ns
Season = Se	1	863	NT	
Treatment = Tr	1	39	NT	
Location = L(Tr)	2	776	2.51[2]	ns
Time = T(Yr x Se)	4	429	1.22	ns
Site = S(L(Tr))	8	405	1.47	ns
Yr x Se	1	1,939	6.54[3]	*
Yr x Tr	1	252	0.93[4]	ns
Yr x L(Tr)	2	229	0.88[5]	ns
Yr x S(L(Tr))	8	115	0.42	ns
Se x Tr	1	18	0.01	ns
Se x L(Tr)	2	1,783	4.16[6]	*
Se x S(L(Tr))	8	526	1.91	ns
Tr x T(Yr x Se)	4	389	1.11	ns
T(Yr x Se) x L(Tr)	8	350	1.27	ns
S(L(Tr)) x T(Yr x Se)	32	275	0.73	ns
Yr x Se x Tr	1	187	0.67[7]	ns
Yr x Se x L(Tr)	2	30	0.10[8]	ns
Yr x Se x S(L(Tr))	8	300	1.09	ns
Residual	96	377		

Pooling procedures – test against T(Yr x Se) x L(Tr) after pooling [1] T(Yr x Se), Yr xL(Tr), Yr x S(L(Tr)) and T(Yr x Se) x L(Tr); [2] S(L(Tr)) and T(Yr x Se) x L(Tr); 4 Yr x L(Tr), Yr x S(L(Tr)), Tr x T(Yr x Se) and T(Yr x Se) x L(Tr); 5 Yr x S(L(Tr)) and T(Yr x Se) x L(Tr); 7 Tr x T(Yr x Se), T(Yr x Se) x L(Tr), Yr x Se x L(Tr) and Yr x Se x S(L(Tr)); 8 T(Yr x Se) x L(Tr) and Yr x Se x S(L(Tr)); 3 test against Yr x Se x L(Tr) after pooling T(Yr x Se); [6] test against Se x S(L(Tr)) after pooling Tr x T(Yr x Se) and T(Yr x Se) x L(Tr).

For Ulmarra (Table 2(a)), the only significant term was the complex interaction Yr x Se x L(Tr), which does not implicate trawling as a factor influencing variability. This term measures differences from year to year in the patterns of variation among sites. Detailed examination of all possible multiple comparison (not presented here) found no patterns. Sometimes, in one or other year, the differences between some sites were significant. This is just "noise" – small-scale spatial differences varying from one year to the next.

For Brushgrove (Table 2(b)), there was even less structure in the data. There was variability in the differences between closed and open seasons between the two years (a significant Yr x Se interaction in Table 2(b)) and differences among locations also varied between seasons (a significant Se x L(Tr) interaction). Neither of these identify any consequences of trawling and each is a measure of variability in natural differences from time to time or place to place.

7.2.1.2 Variation within sites (Year 2)

With the greater number of times of sampling, analyses of each region again showed very little evidence of any consistent differences among the different conditions sampled (Table 3; Fig. 9). Variances among replicate measures of dissimilarity were smaller than for the data used in the previous analyses (compare Residuals in Table 3 with those in Table 2). Data from Broadwater were less variable than those from the other two regions.

Table 3: Analysis of dissimilarities between pairs of replicates within each site for all 4 times in each season, each treatment and all locations in Year 2; *n* = 2 pairs of replicates per site.

(a) Ulmarra Cochran's C = 0.12 ns

Source	df	MS	*F*	*P*
Season = Se	1	2,586	1.20[3]	ns
Treatment = Tr	1	1,055	1.64[2]	ns
Location = L(Tr)	2	271	NT	
Time = T(Se)	6	2,155	3.34	*
Site = S(L(Tr))	8	237	0.85	ns
Se x Tr	1	289	0.48[1]	ns
Se x L(Tr)	2	312	0.93[1]	ns
Se x S(L(Tr))	8	275	0.99	ns
Tr x T(Se)	6	371	0.58	ns
L(Tr) x T(Se)	12	645	2.32	*
T(Se) x S(L(Tr))	48	278	0.98	ns
Residual	96	284		

Pooling procedures – [1]tests against pooled Res and S(L(Tr)) x T(Se), after eliminating Tr x T(Se) and Se x S(L(Tr)); [2]test against T(Se) x L(Tr) and [3]test against T(Se) after eliminating Se x L(Tr), Se x Tr, S(L(Tr)) and L(Tr).

(b) Brushgrove Cochran's C = 0.12 ns

Source	df	MS	*F*	*P*
Season = Se	1	302	0.78[3]	ns
Treatment = Tr	1	411	NT	
Location = L(Tr)	2	1,229	3.08[4]	ns
Time = T(Se)	6	388	0.97	ns
Site = S(L(Tr))	8	245	0.81	ns
Se x Tr	1	360	0.38[2]	ns
Se x L(Tr)	2	29	0.07[1]	ns
Se x S(L(Tr))	8	323	1.07	ns
Tr x T(Se)	6	956	2.40	ns
L(Tr) x T(Se)	12	398	1.32	ns
T(Se) x S(L(Tr))	48	301	1.42	ns
Residual	96	213		

Pooling procedures – [1]test against T(Se) x L(Tr) after eliminating Se x S(L(Tr)); [2]test against Tr x T(Se) and [3]test against T(Se) after eliminating Se x L(Tr); [4]test against T(Se) x L(Tr) after eliminating Se x Tr, S(L(Tr)) and T(Se).

(c) Broadwater Cochran's C = 0.07 ns

Source	df	MS	*F*	*P*
Season = Se	1	512	NT	
Treatment = Tr	1	398	1.67[4]	ns
Location = L(Tr)	2	238	0.52[2]	ns
Time = T(Se)	6	383	2.40	ns
Site = S(L(Tr))	8	462	2.08	ns
Se x Tr	1	81	0.12[3]	ns
Se x L(Tr)	2	664	5.56[1]	*
Se x S(L(Tr))	8	113	0.51	ns
Tr x T(Se)	6	175	1.09	ns
L(Tr) x T(Se)	12	160	0.72	ns
T(Se) x S(L(Tr))	48	222	1.87	**
Residual	96	118		

Pooling procedures – [1]test against Se x S(L(Tr)) and [2]test against S(L(Tr)) after pooling T(Se) x L(Tr) ; [3]test against T(Se) after eliminating Se x L(Tr); [4]test against L(Tr) after eliminating Tr x T(Se) and Se x Tr.

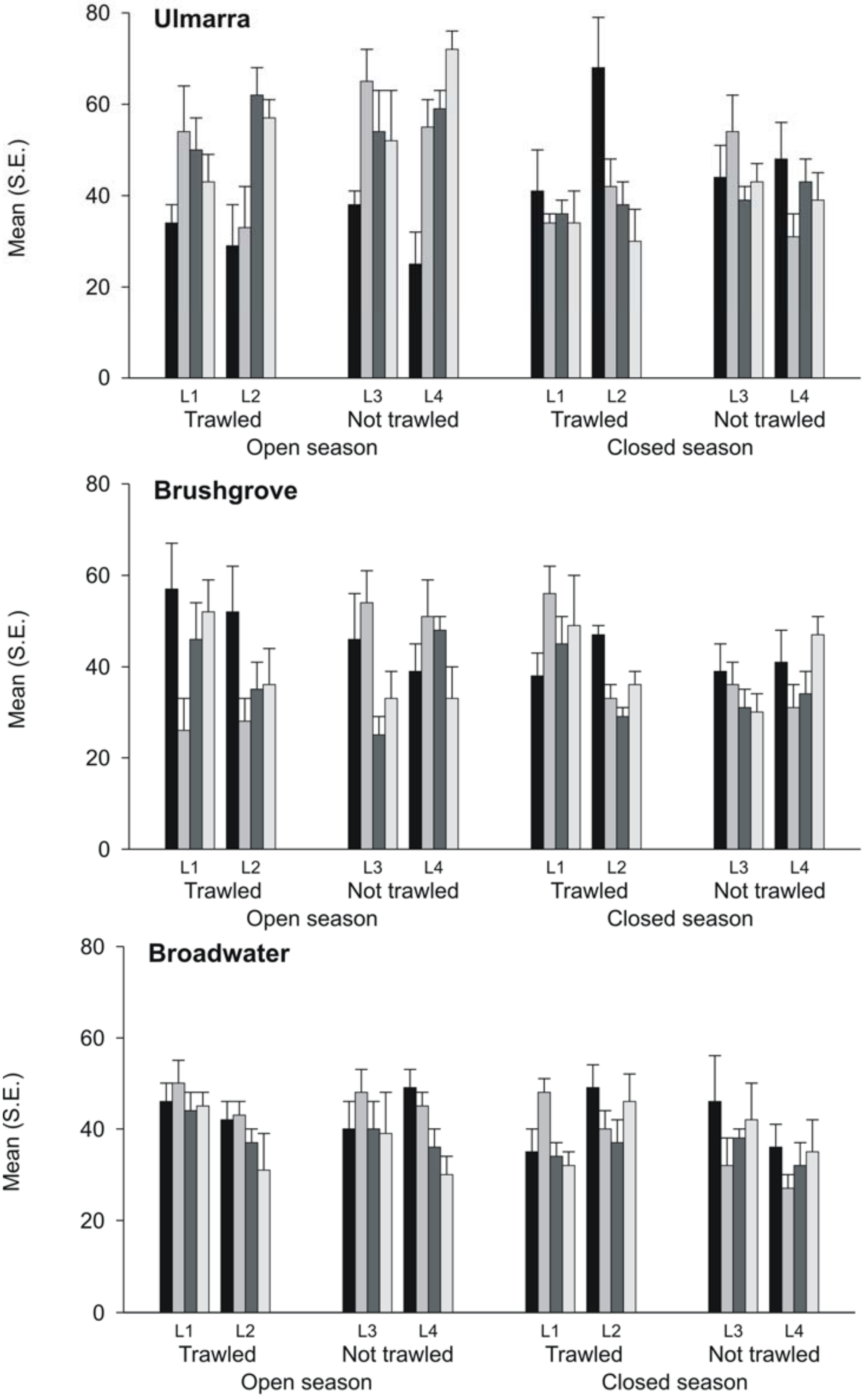


Figure 9. Mean (+ S.E.; n = 6, 2 measures from 3 sites) dissimilarity within sites in 2 trawled (L1, L2) and 2 untrawled (L3, L4) locations in Year 2. The 4 adjacent bars in each season are the 4 times of sampling.

For Ulmarra (Table 3(a)), there was, again, evidence of small-scale spatial and temporal noise (the significant T(Se) x L(Tr) interaction). This reflects the fact that changes from time to time were not consistent from one location to another (as is easily seen by comparing the 4 times of sampling for the 4 locations in each season in Fig. 9(a); note, for example, the difference between Time 1 and the other times in Location 2 of the trawled area during the closed season). There was also an indication that there were differences (average across trawled and non-trawled areas) in each season (the significant T(Se) term in Table 3(a)). This is, however, meaningless given the interaction just described.

For Brushgrove, no term in the analysis was significant (Table 3(b)), even though the data varied from time to time (as in Fig. 9(b)).

In Broadwater, there was also evidence of small-scale noise – differences within sites were not the same from time to time (significant S(L(Tr)) x T(Se) interaction in Table 3(c) and Fig. 9(c)). Differences among locations were also inconsistent between seasons (significant Se x L(Tr) in Table 3(c)). As for other analyses, these only indicate noise – chance differences from time to time or site to site and do not identify any influence of trawling.

Despite extensive analysis, there was no indication of any consistent differences among sites, nor between times in the variability of assemblages in the different sites and times sampled.

7.2.1.3 Variation among sites (Years 1 and 2)

Dissimilarities from one site to another at Ulmarra also only showed random variability. There was, as for the dissimilarities within sites, a significant Y x Se x S (L(Tr)) interaction (Table 4(a)), which is due to differences between pairs of sites varying from season to season and year to year. Trawling had absolutely no effect.

Table 4: Analysis of dissimilarities between pairs of replicates within pairs of sites and between pairs of sites in each location. (Comp. is Comparison = 3 levels; Site 1 vs 2, Site 1 vs 3, Site 2 vs 3) for all 4 times in each season, each treatment and all locations in Year 2; *n* = 2 for each comparison.

(a) **Ulmarra** Cochran's *C* = 0.09 ns

Source	df	MS	*F*	*P*
Year = Yr	1	3,218	NT	
Season = Se	1	1,575	NT	
Treatment = Tr	1	1,051	NT	
Location = L(Tr)	2	1,444	NT	
Time = T(Yr x Se)	4	443	1.24	ns
Comp. = C(L(Tr))	8	384	0.70	ns
Yr x Se	1	121	NT	
Yr x Tr	1	1,744		
Yr x L(Tr)	2	185		
Yr x C(L(Tr))	8	974	1.77	ns
Se x Tr	1	830	0.66	ns
Se x L(Tr)	2	1,259	NT	
Se x C(L(Tr))	8	447	0.81	ns
Tr x T(Yr x Se)	4	563	1.57	ns
L(Tr) x T(Yr x Se)	8	358	0.65	ns
T(Yr x Se) x C(L(Tr))	32	551	1.28	ns
Yr x Se x Tr	1	2,372		
Yr x Se x L(Tr)	2	2,670	4.84[1]	***
Yr x Se x C(L(Tr))	8	697	1.26	ns
Residual	430			

Pooling procedures – [1] test against S(L(TR)) x T(Yr x Se) after pooling T(Yr x Se) x L(Tr)) and Y x Se x S(L(Tr))

(b) **Brushgrove** Cochran's *C* = 0.08 ns

Source	df	MS	*F*	*P*
Year = Yr	1	367	1.17[6]	ns
Season = Se	1	2,413	7.68[5]	**
Treatment = Tr	1	345	NT	
Location = L(Tr)	2	592	NT	
Time = T(Yr x Se)	4	259	1.39	ns
Comp. = C(L(Tr))	8	581	1.85	ns
Yr x Se	1	315	1.00[4]	ns
Yr x Tr	1	162	NT	
Yr x L(Tr)	2	174	NT	
Yr x S(L(Tr))	8	870	2.77	*
Se x Tr	1	62	0.26	ns
Se x L(Tr)	2	242	0.77[3]	ns
Se x C(L(Tr))	8	436	1.39	ns
Tr x T(Yr x Se)	4	21	0.59	ns
L(Tr) x T(Yr x Se)	8	186	1.39	ns
T(Yr x Se) x C(L(Tr))	32	314	0.91	ns
Yr x Se x Tr	1	317	1.00[2]	ns
Yr x Se x L(Tr)	2	142	0.45[1]	ns
Yr x Se x C(L(Tr))	8	284	0.90	ns
Residual	96	343		

Pooling procedures – test against S(L(Tr)) x T(Yr x Se) after pooling [1] T(Yr x Se) x L(Tr) and Y x Se x S(L(Tr)); [2] Tr x T(Yr x Se), T(Yr x Se) x L(Tr), Yr x Se x L(Tr) and Yr x Se x S(L(Tr)); [3] Se x S(L(Tr)), Tr x T(Yr x Se) and T(Yr x Se) x L(Tr); [4] T(Yr x Se), Tr x T(Yr x Se), Yr x Se x L(Tr) and Yr x Se x S(L(Tr)); [5] T(Yr x Se), Se x L(Tr), Se x S(L(Tr)) and T(yr x Se) x L(Tr); [6] T(Yr x Se), Yr x L(Tr), Yr x S(L(Tr)) and T(Yr x Se) x L(Tr)

At Brushgrove, there was less small-scale variation; differences between pairs of sites were not the same in each year (the significant Y x S(L(Tr)) interaction in Table 4(b)).

There was, however, a significant difference between seasons (Se in Table 4(b)); dissimilarities among sites were greater in the open than in the closed season. This was unaffected by trawling (there was no effect of trawling, nor any interactions with trawling in the analysis in Table 4(b)). This is considered further in the next section.

7.2.1.4 Variation among sites (Year 2)

The analyses of all times of sampling in Year 2 confirmed that there were neither substantial, nor consistent, differences in the dissimilarities among sites due to trawling. There were some temporal differences at Ulmarra (Fig. 10(a); significant T(Se) in Table 5(a)), reflecting natural variation. These were in no way influenced by trawling.

Table 5: Analysis of dissimilarities among replicates paired across sites in each location (Comp. is Comparison = 3 levels; Site 1 vs 2, Site 1 vs 3, Site 2 vs 3) for all 4 times in each season, each treatment and all locations in Year 2; n = 2 for each comparison.

(a) Ulmarra Cochran's *C* = 0.08 ns

Source	df	MS	*F*	*P*
Season = Se	1	287	NT	
Treatment = Tr	1	3,222	4.39[3]	ns
Location = L(Tr)	1	5	0.01[2]	ns
Time = T(Se)	6	2,396	6.49	**
Comp. = C(L(Tr))	8	345	1.05	ns
Se x Tr	1	470	NT	
Se x L(Tr)	2	306	0.66[1]	ns
Se x C(L(Tr))	8	466	1.22	ns
Tr x T(Se)	6	734	1.99	ns
T(Se) x L(Tr)	12	369	1.13	ns
C(L(Tr)) x T(Se)	48	328	1.92	ns
Residual	96	358		

Pooling procedures – [1]test against Se x C (L(Tr)) and [2]test against C(L(Tr)) after pooling T(Se) x L(Tr) and C(L(Tr)) x T(Se); [3]test against Tr x T(Se) after eliminating Se x L(Tr), C(L(Tr)) and L(Tr).

(b) Brushgrove Cochran's *C* = 0.10 ns

Source	df	MS	*F*	*P*
Season = Se	1	104	0.18[5]	ns
Treatment = Tr	1	867	2.27[4]	ns
Location = L(Tr)	1	41	0.11[3]	ns
Time = T(Se)	6	568	1.49	ns
Comp. = C(L(Tr))	8	253	1.46	ns
Se x Tr	1	39	0.35[2]	ns
Se x L(Tr)	2	134	1.13[1]	ns
Se x C(L(Tr))	8	302	1.74	ns
Tr x T(Se)	6	233	0.61	ns
T(Se) x L(Tr)	12	381	2.19	*
C(L(Tr)) x T(Se)	48	174	0.55	ns
Residual	96	315		

Pooling procedures – [1]test against Se x C (L(Tr)) after pooling T(Se) x L(Tr) and C(L(Tr)) x T(Se); [2]test against Se x L(Tr) after eliminating Se x C(L(Tr)); [3]test against T(Se) x L(Tr) after eliminating Se x L(Tr), Se x Tr and C(L(Tr)); [4]test against T(Se) x L(Tr) and [5]test against T(Se) after eliminating L(Tr).

(c) Broadwater Cochran's *C* = 0.07 ns

Source	df	MS	*F*	*P*
Season = Se	1	105	0.16[3]	ns
Treatment = Tr	1	338	0.52[3]	ns
Location = L(Tr)	1	220	NT	
Time = T(Se)	6	199	1.49	ns
Comp. = C(L(Tr))	8	165	1.46	ns
Se x Tr	1	2,862	5.17[2]	ns
Se x L(Tr)	2	554	0.85[1]	ns
Se x C(L(Tr))	8	228	1.74	ns
Tr x T(Se)	6	493	0.61	ns
T(Se) x L(Tr)	12	654	2.19	*
C(L(Tr)) x T(Se)	48	248	0.55	ns
Residual	96	209		

Pooling procedures – [1]test against T(Se) x L(Tr) and [2]test against Se x L(Tr) after eliminating Tr x T(Se) and Se x C(L(Tr)); [3]test against T(Se) x L(Tr) after eliminating Se x L(Tr), C(L(Tr)), T(Se) and (L(Tr).

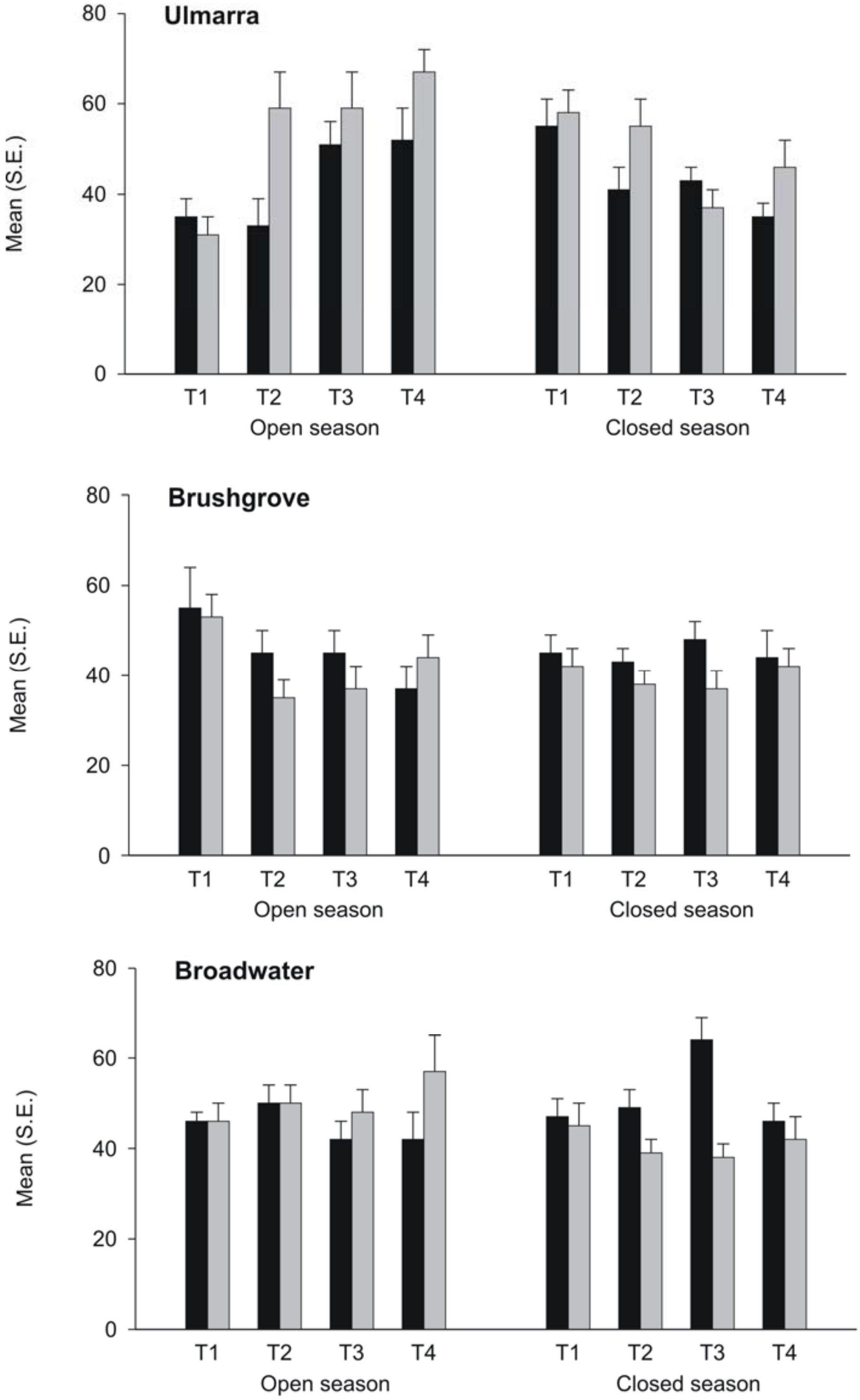


Figure 10. Mean + S.E.; n = 12, 2 measures between each of 3 possible pairs of sites in each of 2 locations) dissimilarity among sites in trawled (■) and untrawled (▨) areas in Year 2. T1 – T4 are the 4 times of sampling in each season.

The analysis of data from Brushgrove showed no evidence for a seasonal difference (i.e. a change from the closed to the open season), as had been found in the analysis using 2 times for each of 2 years (see previous section). This contradiction is due to using only 2 times in the previous analysis. Choosing to include Time 9 in the open season from Year 2 increased the mean value for that season (as can be seen in Fig. 10(b), the mean value for T1 (the first time in Year 2) is larger than the others). When all 4 times were averaged, this anomalous value no longer caused the mean of the open season to be significantly larger than that of the closed season.

As with dissimilarities within samples, differences in dissimilarities among sites showed little significance, no consistency and absolutely no influence of trawling.

7.2.2 Variability among locations

The previous analyses identified no patterns associated with trawling and nothing consistent in any differences in the variability within sites and the variability among sites for the different seasons, years and trawled versus non-trawled areas. There were also no patterns indicating that data from different times of sampling in the open or closed seasons were systematically different. As a result, the analyses can be greatly simplified. This was an unexpected result, given the large variation at many scales from place to place that has usually been identified in analyses of these fauna. It was, however, an important discovery because it meant that reducing the complexity of analyses would greatly increase the capacity to find impacts, if they exist. Increased capacity would come from less “noise” interfering with interpretations of interactions due to impacts and from increased numbers of replicates (from the different sites and times of sampling) for the most important comparisons. Differences in variability within or among sites and times were not found, so those components of potential spatial and temporal variation did not need to be included in subsequent analyses. Therefore, data from the 3 sites sampled at each time and from the 4 times sampled in each season could be pooled together to analyse for effects of trawling or seasonal closures.

Thus, the 6 replicate cores from 3 sites and 4 times of sampling made a total of 72 independent replicates for each combination of year, season, trawled versus non-trawled and the 2 locations in each of the trawled and untrawled areas. For the first year, as described with the previous analyses, only 2 times of sampling could be used, so there were only 36 replicates (i.e. 6 replicate cores from 3 sites and 2 times, as identified previously). So, analyses were done separately for each year, to maximize the numbers of replicates.

Analyses of differences among locations were done as described before. To compare seasons and trawled versus non-trawled areas in Year 1, 20 of the 36 replicates were chosen at random, to make 10 pairs of cores in each location. These made 10 independent measures of dissimilarity of assemblages within each location. Of the remaining 16 replicates, 10 were chosen at random from each location that was trawled and, separately, from each untrawled location. These were then paired between locations to give 10 independent replicated measures of dissimilarity between locations. The remaining 6 replicates were not used. Thus, there were $n = 10$ replicate measures of dissimilarity within each and 10 replicate measures of dissimilarity between the 2 locations that were trawled. There were 3 similar sets of 10 replicates within and between the 2 untrawled locations. Such sets of data were assembled for each year and season.

A similar procedure was used for the data from the second year, except that 40 replicates were randomly chosen from the 72 available to create 20 replicate measures of dissimilarity between locations.

The analyses for each year gave similar results. In all cases but one (Tables 6 and 7), differences between dissimilarities within each location and between the 2 locations were inconsistent from the open to the closed season (significant Se x C(Tr) interactions). The exception was Brushgrove in Year 1 (Table 6(b)). In that case, there were no interactions, but dissimilarities differed significantly among the 3 conditions (within location 1, within Location 2, between Locations 1 and 2).

For all except the last case, the analyses provide no evidence for any systematic differences between locations. In each year, there are 12 comparisons (trawled or untrawled in closed or open seasons, for 3 regions). The only possible evidence that supports locations being different is that dissimilarity within each location is smaller than dissimilarity between locations. In each year, 10 of the 12 comparisons had greater within one or both locations than was found between locations (Figs. 11 and 12). Of the 4 exceptions, 2 were in trawled locations (e.g. Table 6(c), in Broadwater in the closed season) and 2 in untrawled locations (e.g. Table 6(a), in Ulmarra also in the closed season). Of the 4 cases, 2 were in the open season and 2 in the closed season.

Table 6: Analysis of dissimilarities among replicates within and between locations (Comp. = 3 levels; within Location 1, within Location 2, between Location 1 and 2) for each season and each treatment in Year 1; n = 10, samples obtained from data for 4 times and 3 sites paired randomly (see text for details).

		(a) Ulmarra			**(b) Brushgrove**			**(c) Broadwater**		
Source	df	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
Season = Se	1	9,376	20.95	***	6,947	18.88	***	10,393	29.46	***
Treatment = Tr	1	2,615	5.84	*	757	2.06	ns	105	0.30	ns
Comp. = C(Tr)	4	3,472	7.77	***	1,187	3.23	**	974	2.76	*
Se x Tr	1	2,135	4.77	*	5	0.01	ns	9	0.03	ns
Se x C(Tr)	4	4,731	10.58	***	311	0.85	ns	3,213	9.10	***
Residual	108	447			367			353		
Cochran's C			0.21	*		0.21	ns		0.24	**

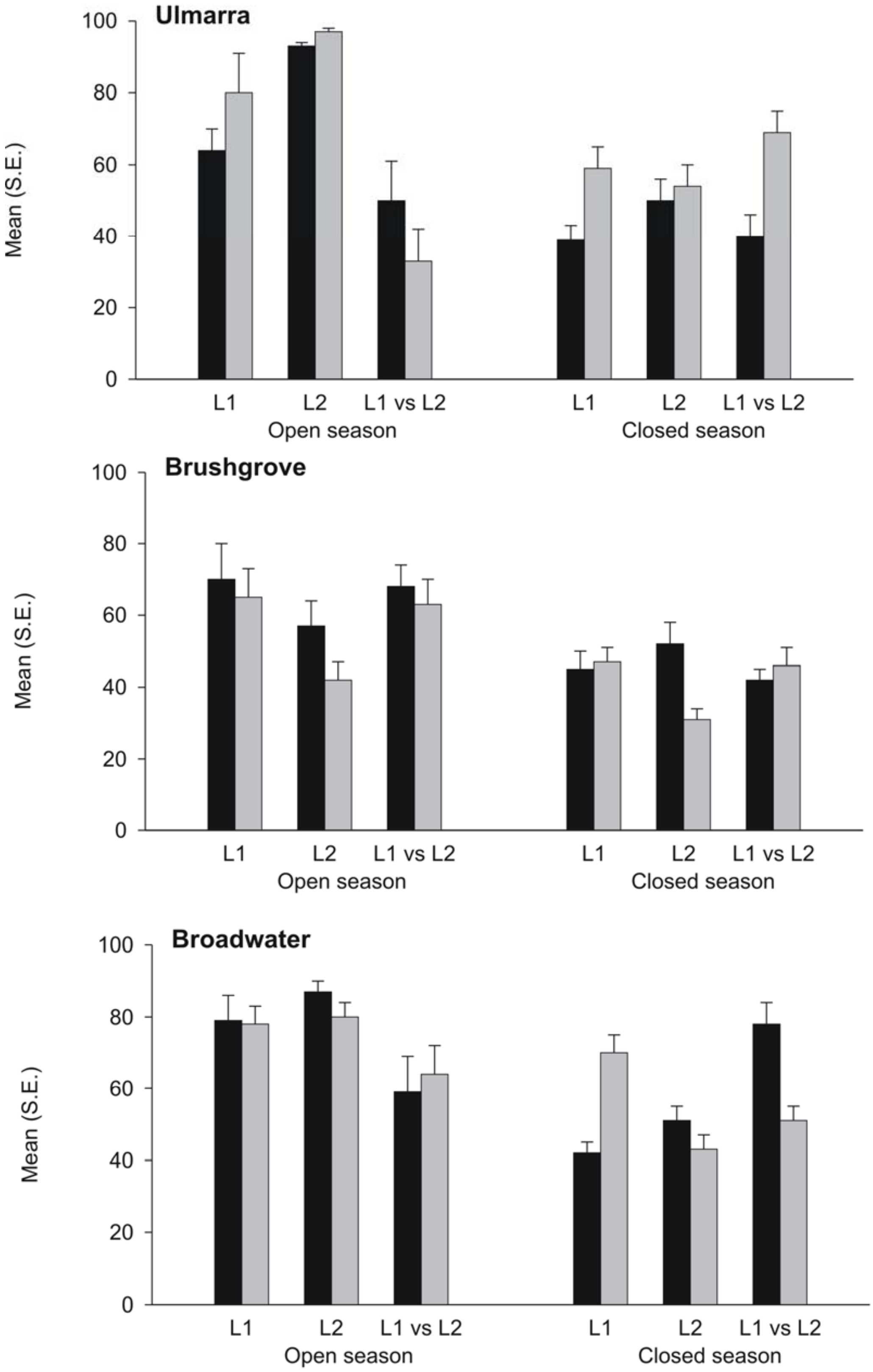


Figure 11. Mean (+ S.E.; *n* = 10, see text for details) dissimilarity in and between each trawled (■) or untrawled (▨) location in Year 1. L1 and L2 are within the 2 locations (trawled or untrawled). L1 vs L2 are dissimilarities between the 2 locations.

Table 7: Analysis of dissimilarities among replicates within and between locations (Comp. = 3 levels; within Location 1, within Location 2, between Location 1 and 2) for each season and each treatment in Year 2; n = 20, samples obtained from data for 4 times and 3 sites paired randomly (see text for details).

		(a) **Ulmarra**			**(b)** **Brushgrove**			**(c)** **Broadwater**		
Source	df	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
Season = Se	1	14,806	8.81	**	767	1.18	ns	4,008	3.85	ns
Treatment = Tr	1	5,909	2.51	ns	547	0.60	ns	4,743	4.24	ns
Comp. = C(Tr)	4	2,352	6.61	***	919	3.56	***	1,119	4.51	***
Se x Tr	1	13	0.01	ns	876	1.34	ns	171	0.16	ns
Se x C(Tr)	4	1,681	4.72	***	653	2.53	**	1,041	4.20	**
Residual	228	356			258			248		
Cochran's C			0.15	ns		0.17	*		0.25	**

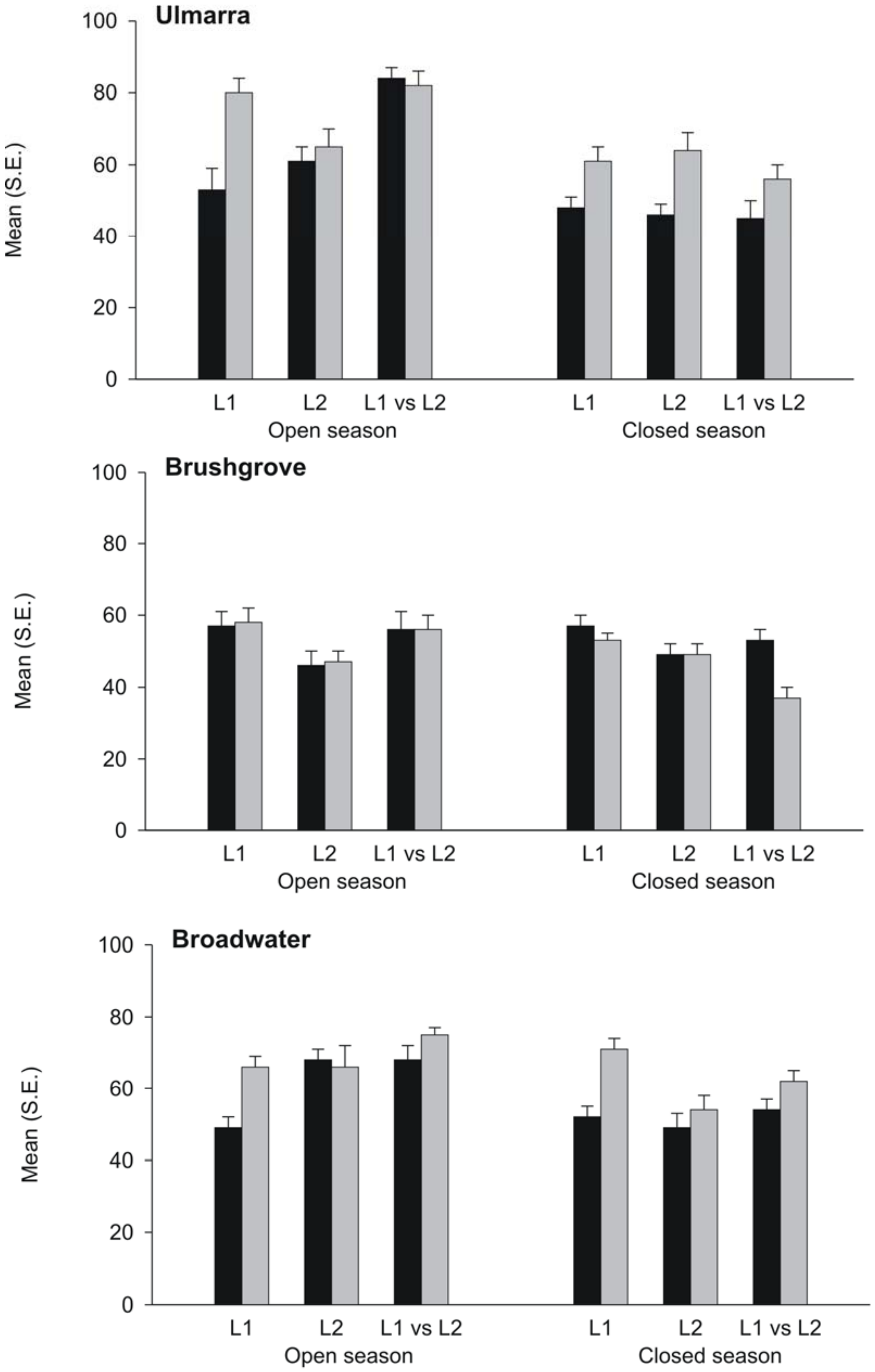


Figure 12. Mean (+ S.E; $n = 20$, see text for details) dissimilarity in each trawled (■) or untrawled (▨) location in Year 1. L1 and L2 are within the 2 locations (trawled or untrawled). L1 vs L2 are dissimilarities between the 2 locations.

Thus, although in 4 cases of the 24 possible comparisons, there was evidence that assemblages probably differed between the two randomly-chosen locations, there was no pattern in the circumstances under which these difference occurred. It was therefore decided to treat the two locations as not being different (which was correct for 83% of cases examined). The consequences of this decision are that, for those seasons and whether trawled or not trawled, there is potentially more variability amongst all replicates across the two locations in the four cases where the locations may have differed. The gain in power of tests from pooling across locations (i.e. doubling the total amount of available replication for each combination of season and trawling) almost certainly makes it more likely to detect differences between trawled and untrawled areas. If locations had not been pooled, the loss of precision (and therefore power) that would have occurred would probably have been a greater problem for detection of effects of trawling. Note, yet again, that any error due to pooling can only affect 17 % of the data and the effect is equally spread across the four combinations of open versus closed season and trawled versus untrawled locations.

7.3 Testing for effects of trawling

By pooling replicates across 4 times of sampling in each season, 3 sites in each location and 2 locations that were either trawled or not, a total of 4 x 3 x 2 x 6 = 144 replicates is notionally available for each combination of trawling and season. In fact, as explained earlier, only 2 times of sampling were useable in the first year, so only 72 independent replicates were available for that year.

7.3.1 Analysis of trawling in Years 1 and 2

Further analyses across seasons and trawled and untrawled conditions were done for both years together and for the second year on its own. For the first of these, 10 replicate measures of dissimilarity within each of trawled and untrawled sets in each season were constructed, as before, from 20 randomly-chosen replicates of each condition in each season. A further 10 randomly-chosen replicates were chosen in each set to construct 10 replicated measures of dissimilarity between trawled and untrawled areas. For the analyses using data from only the second year, 40 measures of dissimilarity within trawled or untrawled conditions were calculated using 80 randomly-chosen replicates from each set in each season. A further 40 replicate measures of dissimilarity between trawled and untrawled conditions were calculated from a different 40 replicates in each set.

The analyses of data from Ulmarra across the two years demonstrated that differences between the three sets of data (dissimilarities within trawled areas, within untrawled areas and between trawled and untrawled areas) were not the same in each year and season (see the Y x Se x C interaction in Table 8(a)). In fact, dissimilarities between trawled and untrawled areas were significantly larger than those within each type of area for the open season in each year (Fig. 13(a)). These two differences could indicate a response to trawling and will be considered further in the next section.

Table 8: Analysis of dissimilarities among replicates within and between treatments (Comp. = 3, within trawled locations, within untrawled locations, between trawled and untrawled locations) for each season and year; n = 20, samples obtained from data for 4 times, 3 sites and 2 locations paired randomly (see text for details).

		(a) Ulmarra			**(b) Brushgrove**			**(c) Broadwater**		
Source	df	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
Year = Y	1	107	0.29	ns	5	0.01	ns	1,625	4.31	*
Season = Se	1	21,280	49.28	ns	5,657	7.24	ns	4,470	1.03	ns
Comp. = C	2	14,292	20.79	*	3,430	6.02	ns	855	0.79	ns
Y x Se	1	432	1.17	ns	781	2.16	ns	4,326	11.47	***
Se x C	2	687	1.87	ns	570	1.58	ns	1,086	2.88	ns
Y x C	2	3,608	0.75	ns	317	1.39	ns	406	1.27	ns
Y x Se x C	2	4,802	13.03	***	228	0.63	ns	319	0.85	ns
Residual	228	368			361			377		
Cochran's C			0.19	*		0.21	**		0.18	*

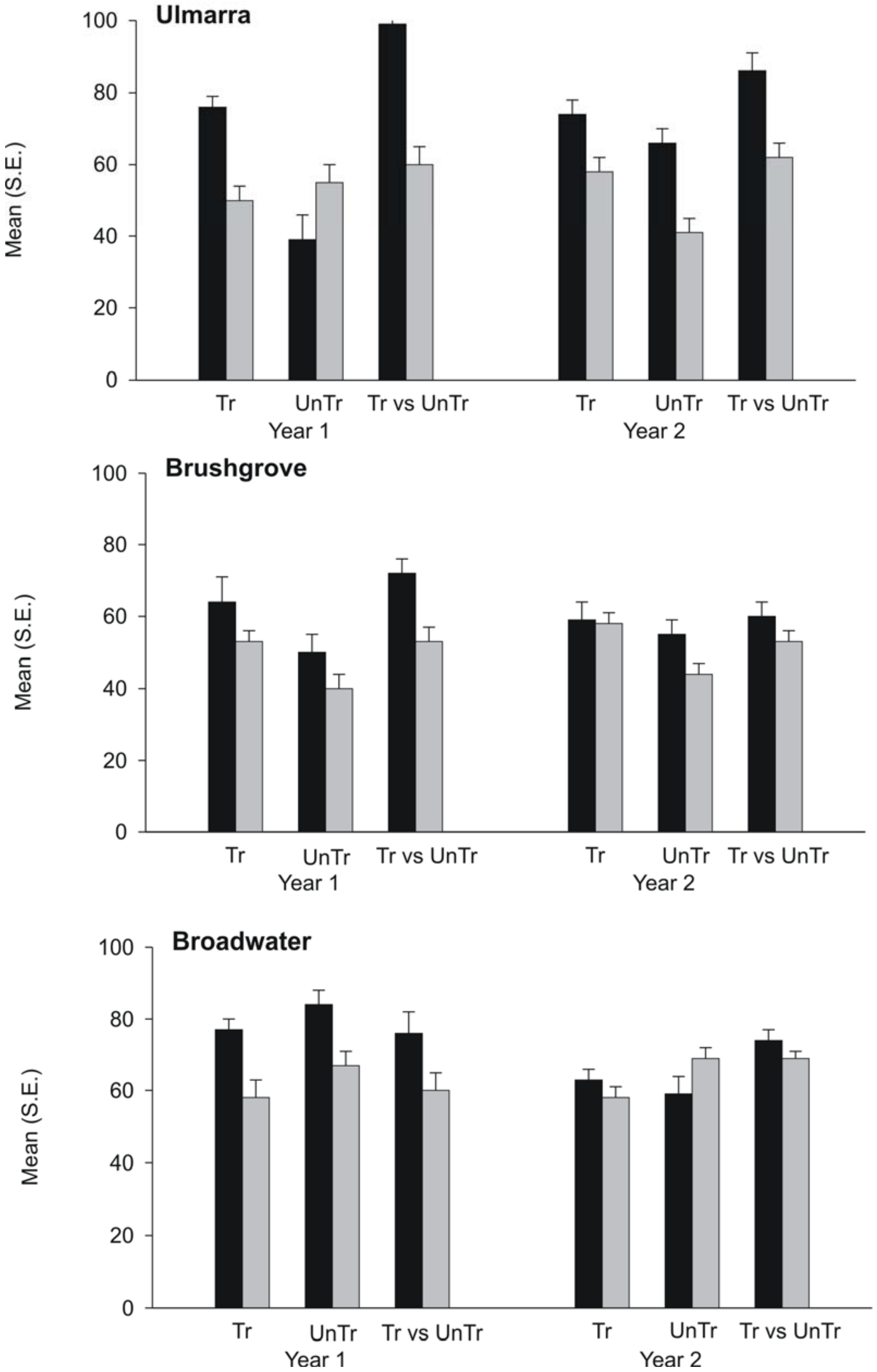


Figure 13. Mean (+ S.E.; *n* = 10, see text for details) dissimilarity within Trawled (Tr) and Untrawled (UnTr) areas and between Trawled and Untrawled areas in each year. ■ is the Open Season; ▨ is the Closed Season.

Data from Brushgrove showed no differences between the three sets, nor between season or years (Table 8(b), Fig. 13(b)).

The analysis for Broadwater showed some temporal variation (the significant Y x Se interaction in Table 8(c); differences between the open and closed seasons were not the same from year to year. This has no relevance to influences of trawling, which were not significant in the analysis. This is also evident from the mean values in Fig. 13(c). Only the data for the open season in Year 2 had greater dissimilarity between trawled and untrawled areas than within either type of area – but the difference was not significant.

So, the only evidence for effects of trawling was for 2 of 4 comparisons for Ulmarra.

7.3.2 Analysis of trawling in Year 2

By and large, the data averaged over 4 times of sampling in Year 2 showed the same patterns as in the analysis over both years (compare Fig. 14 with Fig. 13). For Ulmarra and Broadwater, there were seasonal differences that might be due to trawling (the significant Se x C interactions in Table 9(a) and (c)). At Brushgrove, there were seasonally consistent differences in the mean dissimilarities within and between trawled and untrawled areas (significant C in Table 9(b)).

Table 9: Analysis of dissimilarities among replicates within and between Treatments (Comparison = 3, within trawled locations, within untrawled locations, between trawled and untrawled locations) for each season in Year 2; n = 40, samples obtained from data for all times, 3 sites and 2 locations paired randomly (see text for details)

			(a) Ulmarra			**(b) Brushgrove**			**(c) Broadwater**	
Source	df	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
Season = Se	1	29,561	88.04	***	275	1.05	ns	0	0	ns
Comparison = C	2	9,209	27.43	***	1,573	6.01	**	1,824	6.92	**
Se x C	2	1039	3.09	*	279	1.07	ns	1,073	4.07	*
Residual	234	336			262			264		
Cochran's C			0.19	ns		0.22	ns		0.34	**

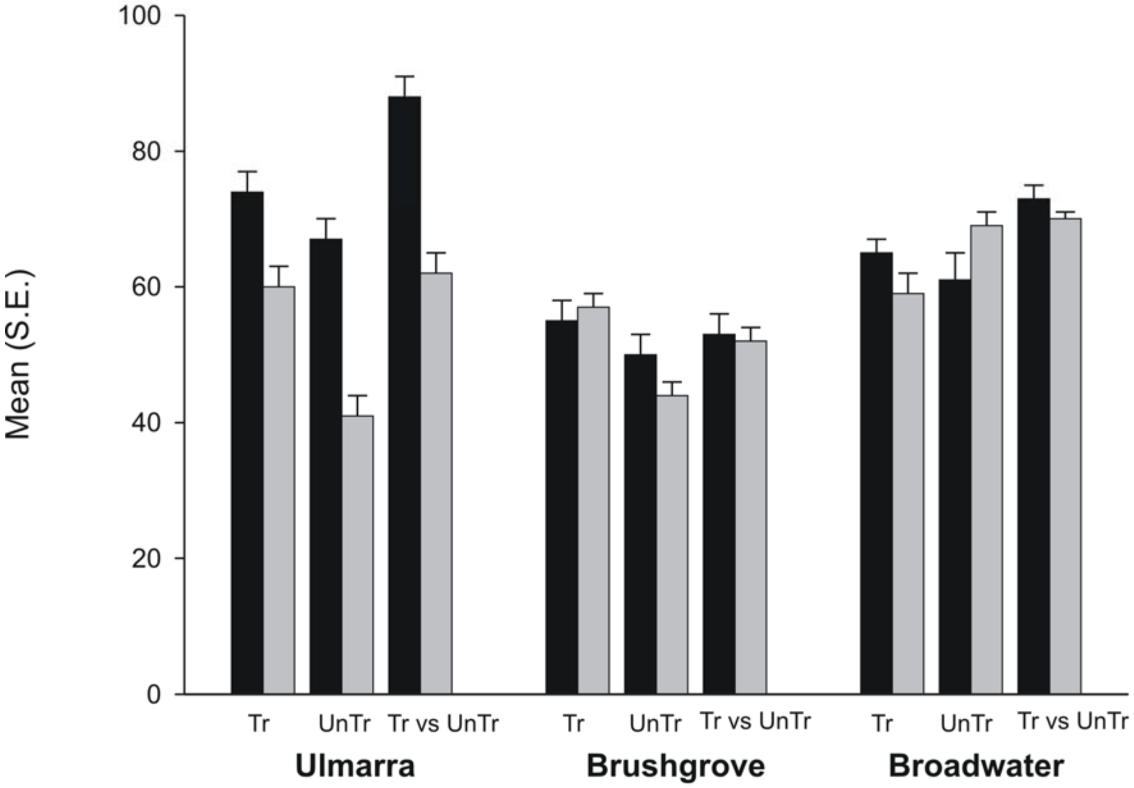


Figure 14. Mean (+ S.E.; *n* = 40, see text for details) dissimilarity within Trawled (Tr) and Untrawled (UnTr) areas and between Trawled and Non-trawled (Both) areas in Year 2. ■ is the Open Season; ■ is the Closed Season.

As evident from the means (Fig. 14), multiple comparisons revealed only two cases where trawling might have been affecting the assemblages of species. These were in the open season at Ulmarra (as found in the analysis in the previous section; see Fig. 14(a)) and in the open season at Broadwater (Fig. 14(c)). These are considered in more detail in the next section.

7.3.3 Multivariate analyses of effects of trawling

The previous analyses revealed very few potential effects of trawling, notably in the open season in Year 1 at Ulmarra and in the open season in Year 2 at Ulmarra and Broadwater (see previous section). In these three cases, out of the many examined, the mean dissimilarity between trawled and untrawled areas was larger than the dissimilarity within each type of area.

These findings and the hypotheses about patterns of difference between trawled and untrawled areas through time (see Introduction) required further analyses. Some of the analyses done here kept the two locations separate in each of the trawled and untrawled areas. This was done despite the earlier findings that locations were rarely different. It was, however, necessary to compare differences between trawled and untrawled areas with natural differences (i.e. not due to trawling) between locations in different places.

Results were consistent in the lack of effects of trawling. This is demonstrated by several different analyses. The most revealing analysis was done using 30 replicates (from $n = 5$ cases in each of 3 sites in each of 2 locations that were trawled or untrawled), compared for each of the 16 times. At Ulmarra, only 14 times of sampling were available (there were no animals in samples from Time 3 and from nearly all replicates at Time 4 because of the flood). Of the 14 times of sampling, trawled areas differed from untrawled areas in multiple comparisons (using Permanova) on 2 occasions (Times 7 and 12 in Table 10(a)). There was only one other occasion when dissimilarity between trawled and untrawled areas exceeded natural variability within each area (Time 11), but this was not significant in statistical tests. At the other 11 times, dissimilarity among replicates exceeded that between trawled and untrawled areas. The only two significant differences due to trawling were one in the closed season of Year 1 and one in the open season of year 2.

Table 10. Mean Bray-Curtis dissimilarities between and within untrawled and trawled areas (within dissimilarities are from all possible pairs of replicates within untrawled and, separately, trawled areas; these were then averaged across the two types of area); n = 5 replicates from each of 3 sites in each of 2 locations = 30 for each of trawled and untrawled areas. There are 30 x 29 = 870 paired dissimilarities within each area (1,740 total) and 30 x 30 = 900 between untrawled and trawled areas.

			(a) Ulmarra			**(b) Brushgrove**			**(c) Broadwater**		
			Mean Within	Mean Between		Mean Within	Mean Between		Mean Within	Mean Between	
Year	Season	Time									
1	Open	1	56	46		25	20		-	-	b
		2	74	53		26	22		61	44	
		3	-	-	a	26	26	c	38	46	+*c
		4	-	-	a	31	27	c	35	57	+*c
	Closed	5	36	35		25	24		52	52	
		6	41	39		27	28	+	27	42	+*
		7	34	43	+*	29	30	+	46	44	
		8	27	22		22	28	+*	33	32	
2	Open	9	47	35		18	22	+*	47	45	
		10	66	52		28	26		42	40	
		11	42	45	+	36	36		41	37	
		12	30	47	+*	21	20		57	41	
	Closed	13	28	21		33	29		58	56	
		14	42	33		24	24		29	45	+*
		15	27	23		33	29		56	51	
		16	44	36		31	23		38	36	
	Mean		39	38		27	26		44	45	

a No data due to flooding
b Not sampled at Time 1
c Very few animals in many replicates
\+ Between > Within
* Between significantly > Within at $P < 0.05$

At Brushgrove, there were also two occasions when assemblages in trawled areas differed significantly from those in untrawled areas (Times 8 and 9 in Table 10(b)). At Times 6 and 7, the dissimilarity between trawled and untrawled areas was also greater than that among replicates within each area, but not significantly so. This cluster of times when dissimilarity between trawled and untrawled areas exceeded that within those areas was in or immediately after the closed season. It is theoretically possible that this represents an effect due to trawling – i.e. natural differences between trawled and untrawled areas disappear in the open season when trawling occurs. This is extremely unlikely because it did not occur during the second year and was not evident at Time 1, immediately after the previous closed season. Furthermore, the smaller mean dissimilarity within trawled and untrawled areas at Time 8 was 22 %. This is the average of 8 % in untrawled areas and 36 % in trawled areas. 8 % was the smallest observed value of dissimilarity among replicates. The other 31 values at Brushgrove (i.e. within untrawled and within trawled for 16 times of sampling) were in the range 16 to 43 %, with a mean of 27 % over all times. Why the value should be so small at this one time of sampling is inexplicable, but it clearly contributed to the significance of the dissimilarity between trawled and untrawled areas at Time 8, which was otherwise unremarkable (it was 28 % compared with the average of 26 %; Table 10(b)).

Finally, at Broadwater, four of the 15 times of sampling produced significantly greater dissimilarity between than within trawled or untrawled areas (Table 10(c)). These were Times 3, 4, 6 and 14. Of these, the first two were the times after flooding, when there were very few animals in many replicate cores and results are not reliable (see next section).

The overall patterns of dissimilarity between and within trawled and untrawled areas were very similar in all 3 regions. Over all times of sampling, the mean dissimilarity within was very similar to that between in each of three regions (Table 10).

7.3.4 Time-courses of assemblages in trawled and untrawled areas

The final requirement for attempting to identify impacts due to trawling is to examine the time-courses of differences in assemblages. These were predicted to be divergent, in various possible patterns, if trawling had any influence (see hypotheses in the Introduction). The graphic presentation of time-courses over a maximum of 16 times of sampling is difficult to interpret. Here, a series of simpler graphics is presented first (for Brushgrove because that has all 16 times of sampling), to provide familiarization.

In Year 1, the two untrawled locations had similar assemblages at the first time of sampling (Fig. 15(a)). There was quite a lot of change between the first and second times of sampling, but the two untrawled locations changed in similar ways. Between times 2 and 3, there was a very major shift in assemblages – again similarly in the 2 locations (Fig. 15). This was the result of a major freshwater flood through the estuary between Times 2 and 3. Many replicates at Times 3 and 4 had very few organisms (and for Ulmarra at these times, there was no macrofauna in any samples). Through Times 5 and 6, the assemblages were recovering and, certainly by Time 7, were similar to the situation before the flood. Throughout the 8 times of sampling in the first year, the two randomly-chosen trawled locations tracked each other – i.e. changes from time to time were similar between the two locations.

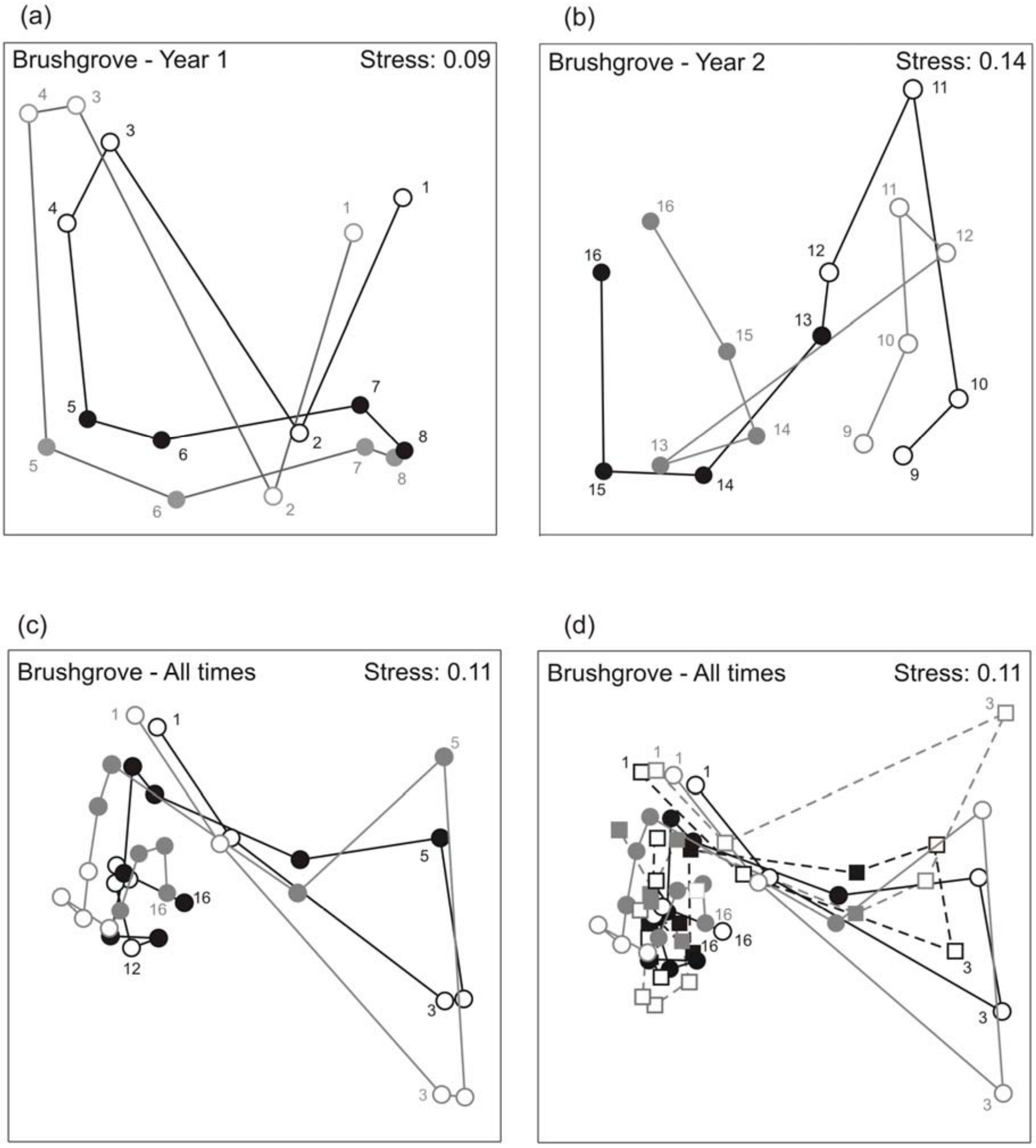


Figure 15. nMDS for centroids of locations at Brushgrove. (a) two untrawled locations (—— , -----) in Year 1 (times 1 – 8); (b) two untrawled locations in Year 2 (times 9 – 16); (c) two untrawled locations over both years (Times 1 – 16); (d) two trawled and two untrawled locations over both years (Times 1 – 16). ■, ■, ▣, □ are trawled; ●, ●, ○, ◎ are untrawled; empty symbols are the Open season; filled symbols are the Closed season.

During the second year of sampling, data from the two untrawled locations at Brushgrove continued to change in similar ways (Fig. 15(b)). There was slightly more divergence between the two locations at Times 13 and 15 (both in the Closed season), but no significant discrepancies between the two locations.

When the data for these two locations were plotted together over all times of sampling, two major features are easily seen. First, the two locations mostly change together from one time to another (Fig. 15(c)). Second, the extremely large and obvious shift in assemblages because of major reductions and discrepancies is during the flood (Time 3 compared with 1, 2, 6 – 16 in Fig. 15(c)). The rapid recovery through Times 4 and 5 is also obvious and was very similar in both locations.

When the trawled locations are plotted with the untrawled locations (Fig. 15(d)), the graphic is obviously more complex. The major features are, however, still readily recognizable. All four locations started out being quite similar in their assemblages, which changed in similar ways from Time 1 to Time 2. All four locations showed a major shift as a result of the flood, but rapidly recovered, being like each other again by Time 4 and converging back to normal after Time 5. The assemblages then wandered around due to random and seasonal changes for the remaining times of sampling (Fig. 15(d)). At all times, the 2 trawled and the 2 untrawled locations had very similar assemblages, which never showed any evidence of trawling (as found in all earlier analyses).

To make the graphics simpler, they are shown (Fig. 16) for each region using the centroid (average) of the two locations, so that there is only one plot for each of the trawled and untrawled areas. So, the data for Brushgrove (Fig. 16(a)) show essentially the same pattern as described previously (Fig. 15(d)). The assemblages in trawled and untrawled areas are never far apart (except at Times 4 - 6 during the recovery from the flood when relatively few taxa were present in the samples).

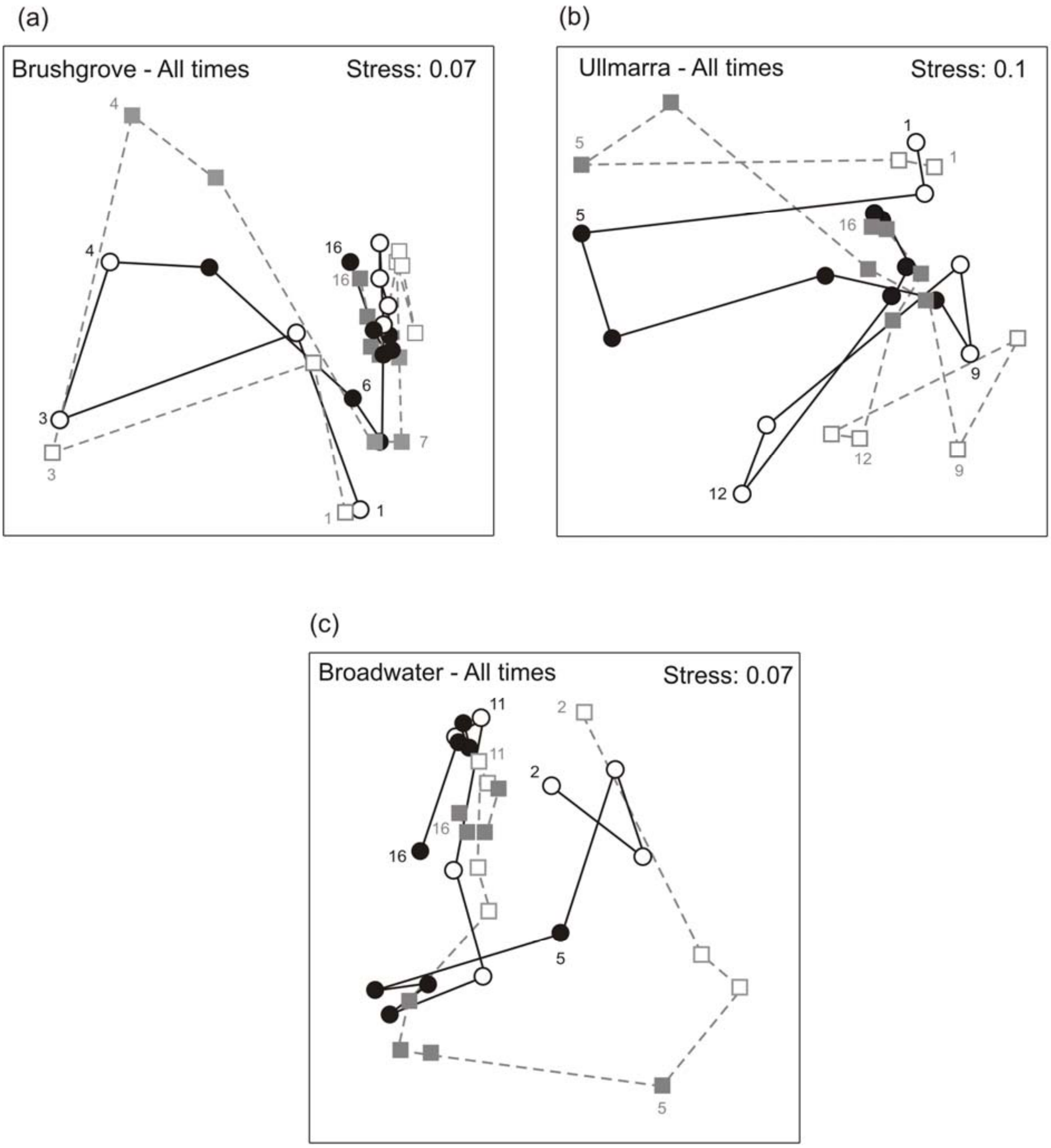


Figure 16. nMDS for centroids of trawled (■, □, -----) and untrawled (●, ○, ——) areas for all times over 2 years; 2 locations are averaged. (a) Brushgrove; (b) Ulmarra; (c) Broadwater.

The last graphical analysis is as just described, except that times of sampling were omitted that were obviously affected by the flood. Times 3 and 4 were clearly affected. At Ulmarra, they contained no organisms; in the other regions, there were very few organisms in many replicates (see Fig. 16(b)). Recovery was clearly not complete by Time 6. At Brushgrove and Broadwater, recovery was definitely not complete by Time 5 (Figs. 16(a) and (c)). So, Times 3 – 6 were omitted from the graphical analysis.

When the anomalous, flood-affected data were included in nMDS plots, it makes patterns for other times very difficult to discern. This is because, in nMDS, the most different samples must be the furthest apart. Consequently, because flood-affected samples were abnormally dissimilar from normal times of sampling, they were as far apart as possible on the graphics. All other times of sampling therefore had to be compressed together. By omitting times of sampling that had been affected by the flood, the other times become more separated and any patterns easier to see.

Natural temporal change at Brushgrove was very similar in trawled and untrawled areas at all times of sampling (Fig. 17(a)). At Ulmarra, trawled and untrawled areas were more different at Times 10, 11 and 12 than at any other time (Fig. 17(b)), but these differences were not significant (Table 10(a)). All other times showed parallel tracking and no effects of trawling. At Broadwater, there was mostly similar temporal change in trawled and untrawled areas from one time of sampling to the next (Fig. 17(c)).

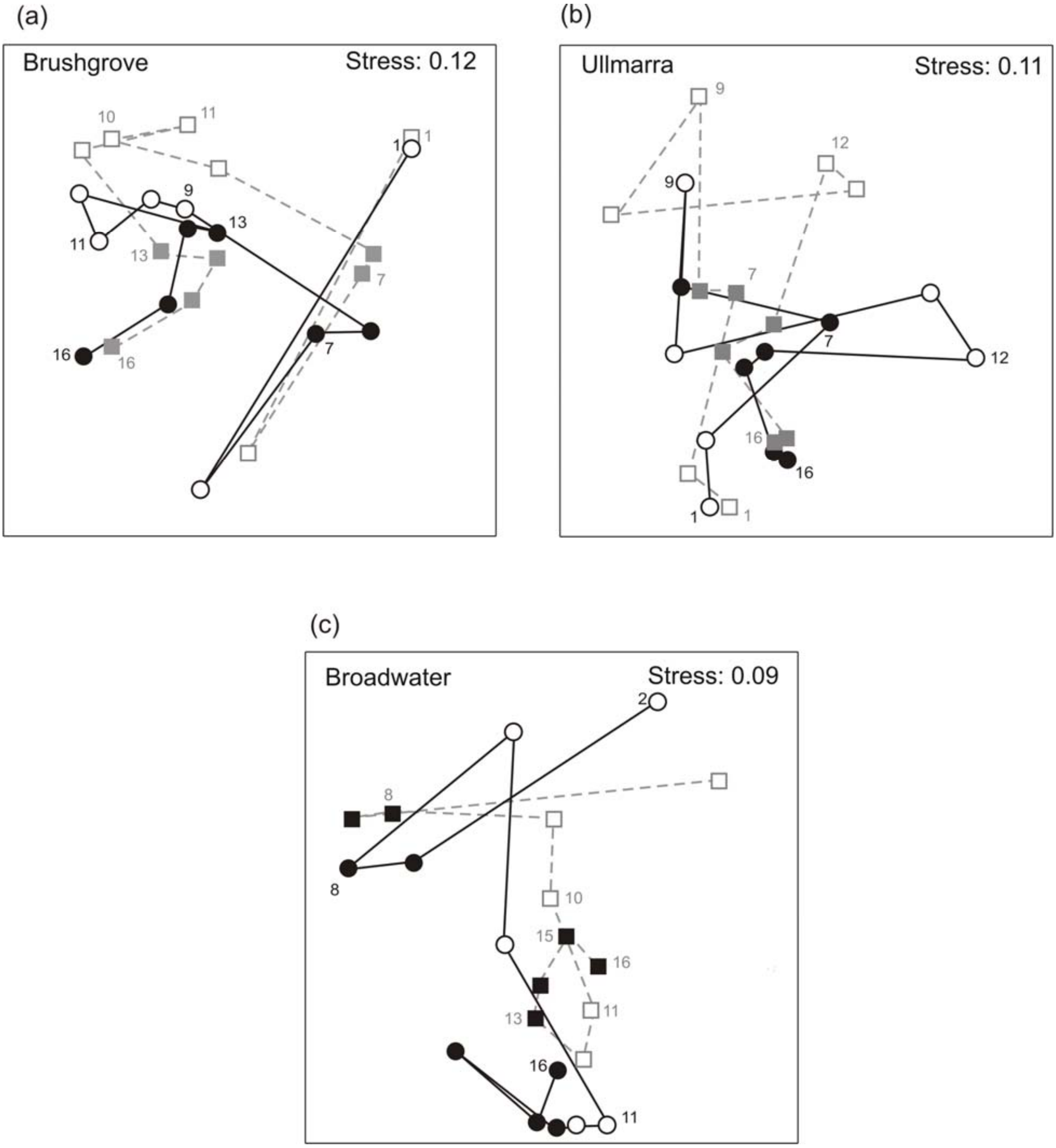


Figure 17. nMDS for centroids of trawled (■, □, -----) and untrawled (●, ○, ——) areas for times 1, 2, 7 – 16 (i.e. not including flood-affected times of sampling); 2 locations are averaged. (a) Brushgrove; (b) Ulmarra; (c) Broadwater.

None of the graphical presentation of temporal trends indicated any effect of trawling on the benthic assemblages sampled.

7.3.5 Abundances of individual taxa

Several individual taxa were sufficiently widespread and numerous in each region to allow useful analysis. At Ulmarra, densities of juvenile bivalves (which were too small (< 8 mm) to be reliably identified) showed no patterns that were in any way related to influences of trawling (Table 11(a)). There was variation from time to time in the differences between locations (T(Se) x L(Tr) interaction in Table 11(a)). This is because temporal variability was not exactly the same in each location. Because various other interactions were not significant at very large probabilities (all P > 0.25; most P > 0.50), they could be pooled to generate powerful tests.

Table 11: Analysis of mean numbers of individual taxa at Ulmarra in year 2. Data are from 4 Times of sampling (random) in each of the open and closed seasons (fixed), for 3 sites (random) in each of 2 locations (random) in each of trawled or untrawled areas (fixed); n = 5 replicate samples

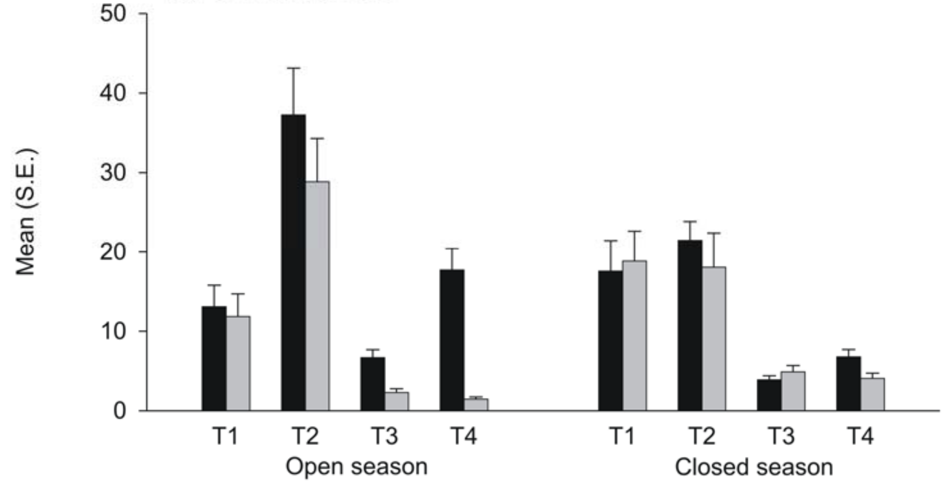
		(a) **juvenile bivalves**			**(b)** **Bivalve 12**			**(c)** ***Gammaropsis* sp.**		
Source	df	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
Season = Se	1	856			7,069			86,591		
Trawled = Tr	1	1,813	2.47[4]	ns	14,830	0.34[4]	ns[4]	7,434		
Location = L(Tr)	2	1,486			83,687			38,141		
Time = T(Se)	8	5,364			94,938			42,798		
Site = S(L(Tr))	6	310			1,759			349		
Se x Tr	1	1,095	1.66[2]	ns	8,267	0.21[2]	ns	4,656	0.18[3]	ns
Se x L(Tr))	2	467	0.69[1]	ns	38,418	0.98[1]	ns	25,963	3.44[1]	ns
Se x S(L(Tr))	6	276	1.07	ns	1,158	1.37	ns	286	0.87	ns
Tr x Ti (Se)	8	335	0.39	ns	16,995	0.34	ns	3,938	0.42	ns
T(Se) x L(Tr)	12	853	3.30	**	50,479	59.92	***	9,346	28.39	***
T(Se) x S(L(Tr))	48	258	0.84	ns	842	0.41	ns	329	0.79	ns
Residual	384	305			2,060			415		

Pooling procedures - [1] Tested against pooled T(Se) x L(Tr) and Tr x T(Se); [2] Tested atainst p pooled T(Se) x L(Tr), Tr x T(Se) and Se x L(Tr); [3] Tested against Se x L(Tr); [4] Tested against p_2 pooled T(Se) x L(Tr), Tr x T(Se), S(L(Tr) and L(Tr)

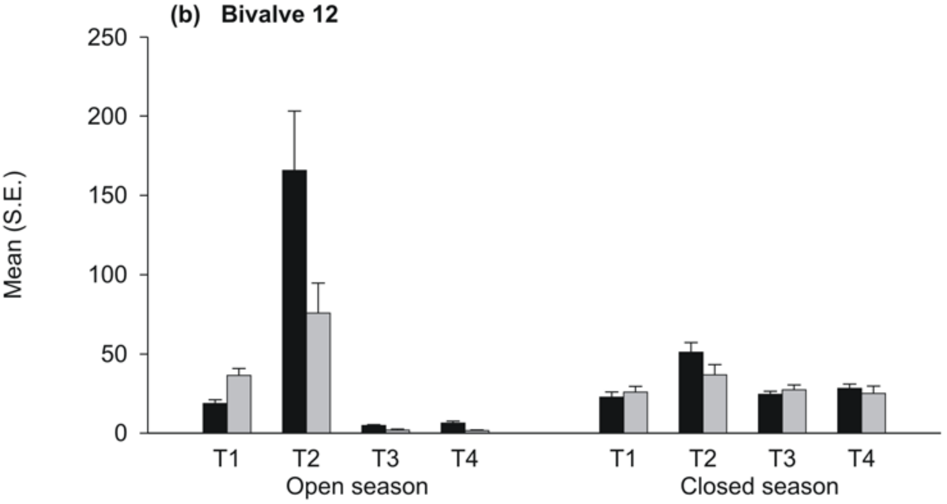
Two particular comparisons are most relevant. First is the interaction between Trawling and Season. This is relevant because under some hypotheses about trawling, its effects should be greater in the open season (when it happens) than in the Closed season, leading to an interaction Se x Tr (see Introduction for development of hypotheses). Second is the main effect of trawling, if it persists throughout the open season (also see the Introduction).

For juvenile bivalves, there was no significant interaction between season and trawling (Table 11(a), test of Se x Tr was not significant at $P > 0.23$). When pooling everything possible, the test for trawling (Tr in Table 11(a)) was not significant (at $P > 0.12$). There is clearly no pattern of difference due to trawling in the mean numbers (Fig. 18(a)).

(a) juvenile bivalve



(b) Bivalve 12



(c) *Gammaropsis* sp.

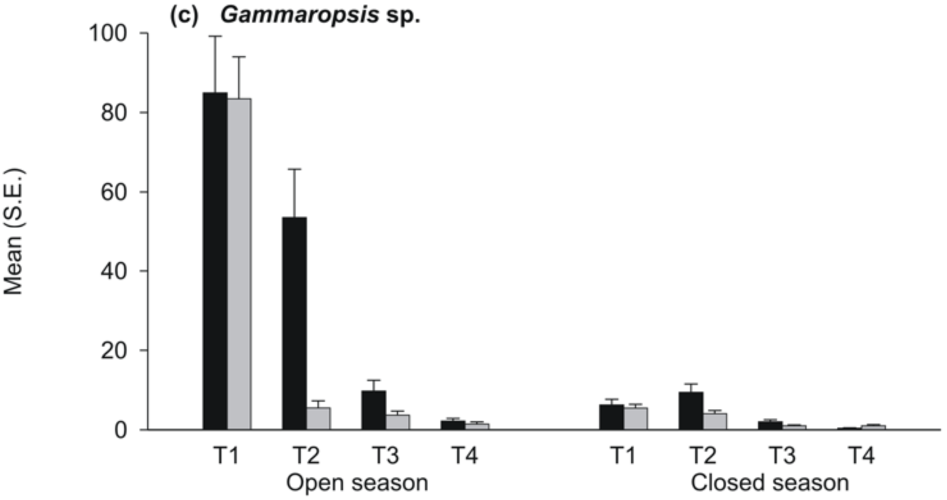


Figure 18. Mean (+ S.E.; *n* = 30 from 5 replicate areas in 3 sites and 2 locations) densities of individual taxa in trawled (■) and untrawled (■) areas at Ulmarra in Year 2 (T1 – T4 are 4 times of sampling). (a) juvenile bibalves; (b) Bivalve 12; (c) *Gammaropsis* sp.

Results for Bivalve 12 (which cannot be identified to species because of lack of shell-features that are used to make a proper taxonomic identification; it may be a conglomerate of indistinguishable taxa) were exactly the same. There was no interaction between season and trawling (Se x Tr in Table 11(b); $P > 0.65$), nor any difference between numbers in trawled and non-trawled areas (Tr in Table 11(b); $P > 0.55$). Again, the mean numbers showed no differences due to trawling (Fig. 18(b)).

These results are very convincing, given the size of the tests and that the non-significant results have quite large probabilities.

Results for *Gammaropsis (Podoceropsis* sp. unidentifiable to species; this is a Corophid amphipod) were less clear. It was not possible to pool any of the higher-order interactions, so the only test for the interaction between Season and Trawling had only 1 and 2 degrees of freedom (Table 11(c)). This was, unsurprizingly, not significant. A good indication that there was no evidence for an influence of trawling is provided by the sizes of mean squares in the analyses. Thus, the mean square for Trawling (Tr in Table 11(c)) was 7,434 and that for the interaction (Se x Tr in Table 11(c)) was 4,656. Both are smaller than that for small-scale spatial and temporal variability (T(Se) x L(Tr) = 9,346 in Table 11(c)). Even if other terms could have been pooled to test Trawling or Season x Trawling, they would have had to be pooled with this last term (T(Se) x L(Tr)). No test of Trawling or Season x Trawling could have been significant because their mean squares were smaller. Note that the mean numbers showed no indication of any differences due to trawling (Fig. 18(c)).

At Brushgrove, there was a significant interaction between Season and Trawling for juvenile bivalves (Table 12(a)). Multiple comparisons (SNK tests at P = 0.05) showed a significant difference between trawled (mean = 56) and untrawled (mean = 35) areas in the open season, but no difference in the closed season (means 16 and 19, respectively). This is obvious in Fig. 19(a). This may be an indication of an influence of trawling.

Table 12 Analysis of mean numbers of individual taxa at Brushgrove in year 2. Data are from 4 Times of sampling (random) in each of the open and closed seasons (fixed), for 3 sites (random) in each of 2 locations (random) in each of trawled or untrawled areas (fixed); n = 5 replicate samples

		(a) **juvenile bivalves**			**(b)** **Bivalve 12**			**(c)** ***Gammaropsis* sp.**			**(d)** **Orbiniidae**		
Source	df	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*	*MS*	*F*	*P*
Season = Se	1	87,967			3			1,159			0.05		
Trawled = Tr	1	9,083			3,658			327			50		
Location = L(Tr)	2	616			6,420			799			149		
Time = T(Se)	8	3,328			3,319			933			2,117		
Site = S(L(Tr))	6	142			556			95			19		
Se x Tr	1	18,725	1.66^{2}	ns	3,451	0.21^{3}	ns	48			109	0.19^{3}	ns
Se x L(Tr))	2	1,234	0.41^{1}	ns	9,342	4.47^{1}	*	230	0.79^{1}	ns	581	3.27^{1}	ns
Se x S(L(Tr))	6	747	0.42	ns	686	1.40	ns	155	1.28	ns	27	0.97	ns
Tr x Ti (Se)	8	652	0.15	ns	1,893	0.87	ns	385	1.58	ns	119	0.58	ns
T(Se) x L(Tr)	12	4,214	2.35	**	2,186	4.47	***	244	2.03	*	207	7.51	***
T(Se) x S(L(Tr))	48	1,791	4.10	***	489	0.98	ns	120	2.48	***	20	0.96	ns
Residual	384	437			498			49			29		

Pooling procedures - [1] Tested against pooled T(Se) x L(Tr) and Tr x T(Se); [2] Tested ataint p pooled T(Se) x L(Tr), Tr x T(Se) and Se x L(Tr); [3] No pooling possible; tested against Se x L(Tr)

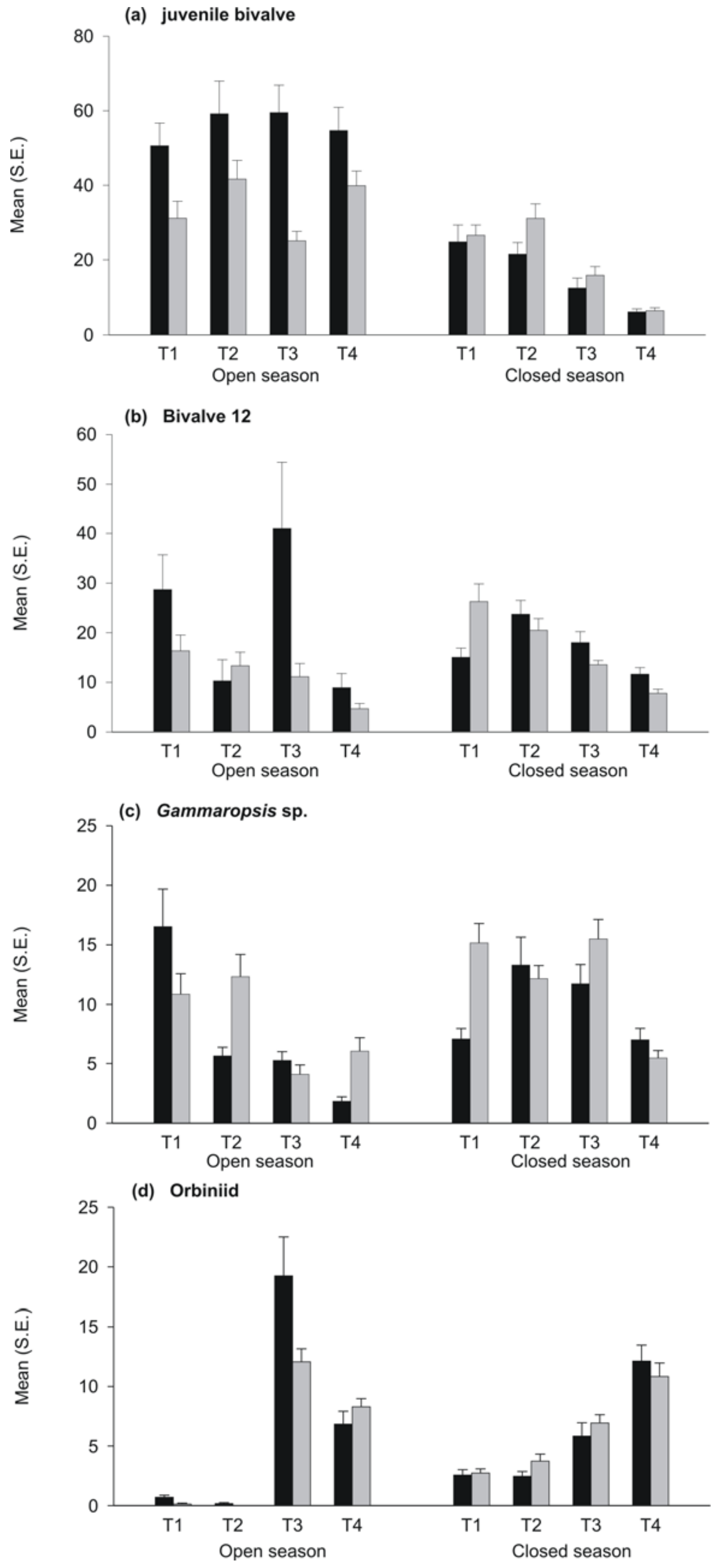


Figure 19. Mean (+ S.E.; *n* = 30 from 5 replicate areas in 3 sites and 2 locations) densities of individual taxa in trawled (■) and untrawled (▨) areas at Brushgrove in Year 2 (T1 – T4 are 4 times of sampling). (a) juvenile bivalves; (b) Bivalve 12; (c) *Gammaropsis* sp.; (d) Orbiniid polychaetes.

For other taxa (Bivalve 12 and *Gammaropsis* sp. and Orbiniidae worms), there were no significant interactions between Season and Trawling (Table 12(b), (c), (d)). In all cases, it was impossible to pool other interactions or sources of variation to make powerful tests for Trawling (which could only be tested against Locations(Trawling), with 1 and 2 d.f.). In all cases, the mean squares for differences due to trawling were smaller than the natural spatial variation between trawled or untrawled locations (compare Tr with L(Tr) in analyses in Table 12(b), (c) and (d)). Similarly, the mean densities of these taxa showed no pattern indicating differences between trawled and untrawled areas over the eight times of sampling (Fig. 19(b), (c), (d)).

At Broadwater, there was an interaction between Season and Trawling for densities of Amphipod 9 (an unidentifiable Gammarid in the Family Phoxocephalidae; note the significant Se x Tr interaction in Table 13(a)). There was no difference in mean number in trawled (mean = 3.2) and untrawled (0.9 in the open season, but a significantly larger number in untrawled areas (means = 7.6, 15.2, respectively) during the closed season (SNK tests at $P = 0.05$ on means in Fig. 20(a)).

Table 13: Analysis of mean numbers of individual taxa at Broadwater in year 2. Data are from 4 Times of sampling (random) in each of the open and closed seasons (fixed), for 3 sites (random) in each of 2 locations (random) in each of trawled or untrawled areas (fixed); n = 5 replicate samples

		(a) Gammarid Amphipod 9			**(b) Capitellidae**			**(c) Nereididae**		
Source	df	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
Season = Se	1	10,481			502			9,000		
Trawled = Tr	1	819			2,975			13,584		
Location = L(Tr)	2	311			9,329			4,657		
Time = T(Se)	8	356			6,234			4,637		
Site = S(L(Tr))	6	83			301			477		
Se x Tr	1	2,925	7.82[2]	*	462	0.41[2]	ns	6,413	No test	
Se x L(Tr))	2	107	0.26[1]	ns	446	0.37[1]	nsp	1,740	No test	
Se x S(L(Tr))	6	45	0.85	ns	120	0.42	ns	424	1.35	ns
Tr x Ti (Se)	8	590	1.90	ns	669	0.45	ns	3,256	14.55	***
T(Se) x L(Tr)	12	310	5.91	***	1,477	5.11	***	224	0.73	ns
T(Se) x S(L(Tr))	48	53	1.13	ns	289	2.11	***	307	3.55	***
Residual	384	47			137			87		

Pooling procedures - [1] Tested against pooled T(Se) x L(Tr) and Tr x T(Se) ; [2] Tested atainst p pooled T(Se) x L(Tr), Tr x T(Se) and Se x L(Tr)

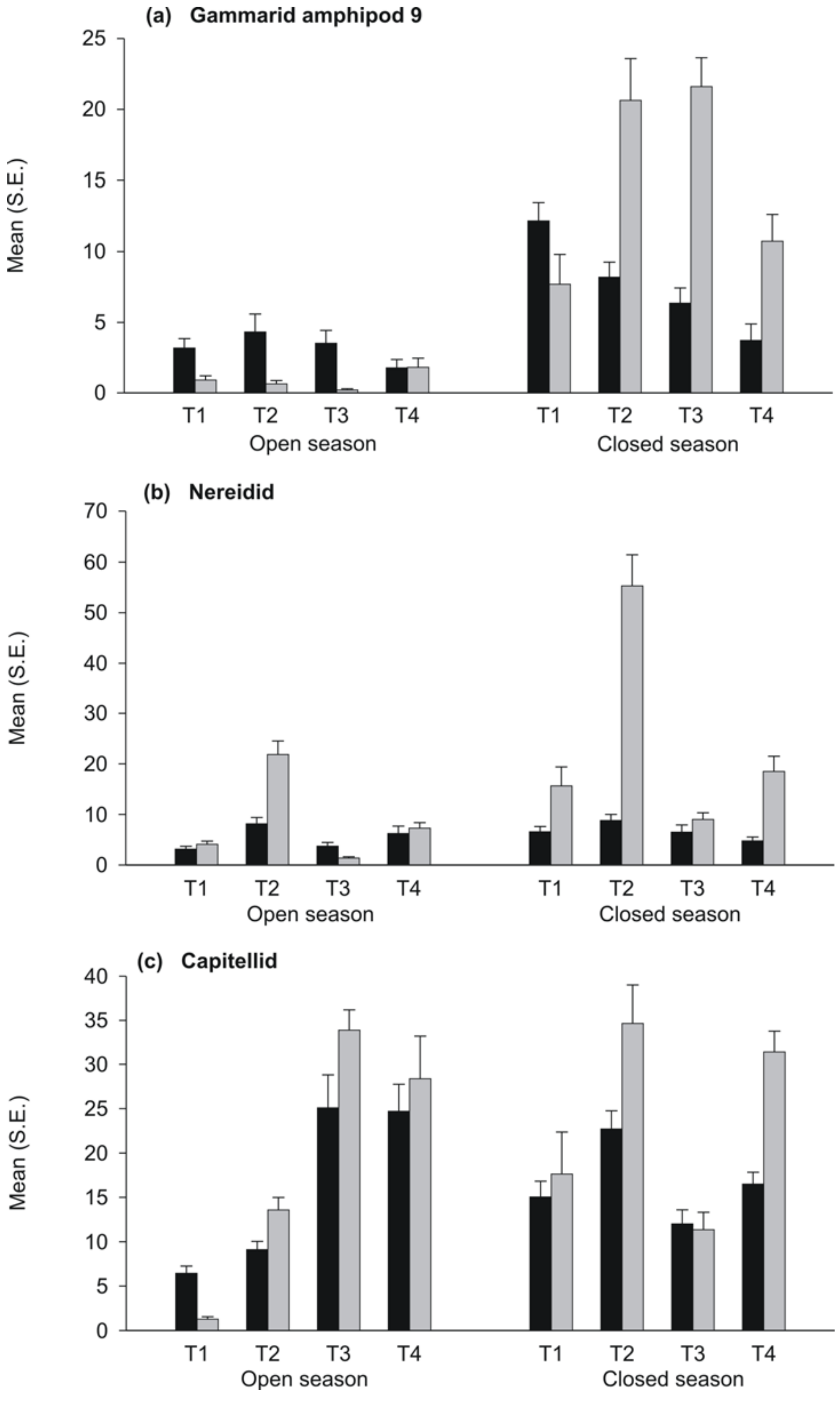


Figure 20. Mean (+ S.E.; *n* = 30 from 5 replicate areas in 3 sites and 2 locations) densities of individual taxa in trawled (■) and untrawled (▨) areas at Broadwater in Year 2 (T1 – T4 are 4 times of sampling). (a) Gammarid amphipod 9; (b) Capitellid worms; (c) Nereidid worms.

For the other taxa examined at Broadwater (the families of polychaete worms Nereididae and Capitellidae), there were no interactions of season with trawling (Table 13(b) and (c)). In both cases, there was substantial variation between locations (L(Tr) in analyses in Table 13(b) and (c)), so there is no prospect that trawling caused any substantial difference in numbers of these worms. In the case of Nereidids, there was one time of sampling (out of 8) when numbers were substantially greater in untrawled than in trawled areas (Time 2 in the Closed season; see Fig. 20(b)). This was transient and most probably a chance large density sampled at that time. For the Capitellids, there was no pattern of difference in mean density that could be attributed to trawling (Fig. 20(c)).

8. Discussion

The overwhelming conclusion from all analyses, in all three regions sampled, is that current practices of trawling for prawns in the Clarence River are not affecting the macrofauna in the sediments in trawled areas. This result was surprising, given the publicity and claims about this type of fishing having major effects on local biodiversity of infauna. As a consequence of preliminary analyses showing no impacts, subsequent analyses were done with every possible chance of demonstrating an impact, however small.

8.1 Design of sampling

For an impact to be identifiable, there must be some consistent pattern of difference in assemblages between trawled and closed areas. Alternatively, there would have to be a temporal interaction, so that the trawled areas became different from the untrawled areas during the open season, but then recover during the closed season. No such differences were found. Identifying either such pattern requires an appropriate sampling design, so that any pattern due to trawling would be reliably detected against the background, natural variation from place to place and time to time.

This is important because many previous studies of apparent or claimed impacts, including those associated with fishing, have used inadequate and/or confounded designs. As a result, it has been quite confusing to know the circumstances and examples where there has been unequivocal evidence for an impact.

The logical structure of an appropriate study was first analysed in detail by Green (1979), who demonstrated the crucial identification of an impact as an interaction between spatial and temporal differences. An impacted area must show ecological changes from before to after a disturbance, but there must be a different change in a disturbed place from natural change in an undisturbed place. This is so-called BACI sampling (Before versus After in Control versus Impacted sites). Improved designs were developed by Benstein & Zalinski (1984) and Stewart-Oaten et al. (1986), who demonstrated why it is essential to replicate the sampling in time. Thus, there must be several times of sampling nested or hierarchically arranged in the periods Before and After the disturbance.

Further (and the most recent) major improvements were by Underwood (1992, 1993, 1994), who demonstrated that spatial replication is crucial for valid interpretations of data about potential impacts. Because disturbances are usually singular (i.e. one power-station, outfall, marina, etc., is built or an oil-spill is in only one large area), replication is only possible for control locations. There are no replicated disturbances. Thus, data must be collected from the disturbed location and several randomly-sampled control locations at several times before and several times after the disturbance. These designs are now widely used and are often called “beyond BACI” asymmetrical analyses.

There are alternatives, where long time-courses of data are available and where natural interactions do not occur through time. The latter requires that changes from time to time in different control locations would be similar, so that a single control can represent a set of controls. Neither condition is likely for most ecological analyses of impacts. Long time-series of data are rarely obtainable before a disturbance. The only way to determine whether natural interactions are unimportant would be to measure what happens in more than one control through time (requiring replicated controls!). If these conditions can be met, there are alternative methods of detecting impacts which may be more useful than beyond BACI approaches (Stewart-Oaten & Bence, 2001).

Trawling in the Clarence River is a somewhat more straightforward type of disturbance. It occurs in many places (e.g. the 3 Regions studied here) and at many locations in those places, allowing independent, randomly-chosen locations and sites to sample for effects. It is persistently repeated during the open season, so its effects are likely to be more like press than pulse responses (Bender et al., 1984), which makes detection of impacts more straightforward (Underwood 1992, 1994). Regulation by closed areas and closed seasons provides untrawled controls in space and in time, allowing detection of interactive impacts, i.e. ones that increase in effect through time.

These conditions allowed the development of the sampling design used here, which estimated natural changes from time to time in untrawled, control locations in each of open and closed seasons. These could be compared with the ecological changes over the same times and seasons in areas that were trawled during the open season. Simultaneously, natural differences in fauna from site to site and location to location in each region could be estimated for each time of sampling, using appropriate replication in each of trawled and untrawled areas.

By having temporal and spatial replication in balanced designs, the analyses allow interactions – including any impacts caused by trawling – to be detected with minimal analytical complexity. The project also allowed considerable temporal and spatial replication, compared with many previous studies of impacts and, particularly, of impacts due to trawling.

There can be no doubt that the design and intensity of sampling (times, sites, locations, regions, 2 years and the number of replicated cores in each site at each time) provide an adequate basis for attempting to detect impacts due to prawn-trawling in the Clarence River.

8.2 Reasons for failing to detect impacts

As with all statistical analyses of data to test hypotheses about impacts, failing to find an impact may be due to circumstances relating to the analysis, rather than because there really was no impact. This is often raised as a valid criticism of studies involving limited replication. It is known as making a Type II error (e.g. Winer et al., 1991), i.e. failing to detect an impact that really exists. In the ecological context examined here, a Type II error would occur if assemblages failed to identify significant differences between trawled and untrawled areas under circumstances where trawling really did alter assemblages. Such errors occur when the variability in the system being measured is large, the size of the effects of trawling is small or both. Determining how likely it is to make a Type II error is called power analysis.

Power analysis requires examination of the variances in things being measured, consideration of the anticipated sizes of effects of trawling, if they occur (these are called "effect sizes") and understanding the relationships between these and the amount of replication used in analyses. Detailed descriptions of the consequences of different variances, effect sizes and replication were provided for ecological sampling and experiments by Underwood (1997).

The most crucial aspects of this for the present study are that power analysis is currently impossible for most multivariate analyses, including those used here. Effect-sizes are not estimable for trawling in the Clarence River, although previous studies elsewhere provide information about what effects have been identified as impacts due to trawling. Power analyses involve complex modelling and computer simulations of the numerous terms in analyses (Underwood & Chapman, 2003). Where impacts have been identified in previous studies, they have been identified using considerably less sampling and therefore very considerably less power than used here. So, it is simpler and more straightforward to comprehend that, relative to previous studies considered adequate to find effects of trawling, this study used much more replication (5 or 6 cores in 3 sites in 2 locations at 4 times in 2 seasons for 2 years in each of 3 regions) than most, if not all, previous studies.

Because preliminary analysis of the multivariate data showed that assemblages across sites and locations could be considered similar and changes in them from time to time were similar, replicates could be pooled to analyse for impacts due to trawling. No previous study has been found that has had available as many replicates (and therefore degrees of freedom) for analyses. Whatever the intrinsic variances in numbers of individual taxa and composition of assemblages, the capacity to detect any systematic differences due to trawling would be greater than any smaller study of the sort done previously. It is not realistic to conclude that the study failed to find impacts because of lack of power.

8.3 The nature of an impact due to trawling

8.3.1 Size of impact versus recovery

There are two other potential criticisms of the conclusion that trawling has no effect. The first is that the size of impact due to trawling is small and therefore difficult to detect (i.e. the effect-size really is small). This is not the sort of impact that prompted the study – public comments about effects of trawling are always phrased in terms that indicate large and destructive impacts.

Small impacts are very difficult to define, let alone detect in variable ecological systems. For example, if the numbers in a population of some relevant and important species of invertebrate change naturally, from year to year, between 100 and 200, small impacts cannot realistically be considered. An impact removing 5% of this species in one year means that numbers now vary from 95 to 190 from year to year. Unless, under some environmental conditions, 100 is a minimal number to guarantee reproductive success, this cannot be ecologically important (whether or not it could be detected).

It is already known for benthic animals in estuarine sediments that there are large, rapid changes in abundance from day to day which are often greater than seasonal changes in density (Morrisey et al., 1992a, b). It is difficult to understand how small impacts due to trawling would contribute much to all this natural variation.

In the Clarence River, a massive flood associated with large amounts of fresh-water removed substantial amounts of all benthic species (and, in some areas, all species). This was widespread throughout all the areas sampled. Yet, within a few months, recovery by recolonization of fauna was so substantial that there was no subsequent evidence from the data that this event ever occurred.

Given this information, it must be concluded that the assemblages in sediments are very robust, with enormous capacity to recover from widespread and serious disturbance. They have very great resilience – capacity to recover after their abundances are very substantially reduced (for discussions of resilience and the related term "amplitude", see Holling (1973); Orians (1974)). They also show very great stability – i.e. a fast rate of recovery after abundances are reduced (for discussions of stability and related concepts of "elasticity" and "resilience", see Boesch (1974); Connell & Sousa (1983)). The analysis of how impacts affect populations is part of the general ecological research programme on responses to disturbances (for review, see Underwood (1989)). Populations with great resilience and fast stability are unlikely to be greatly affected by such disturbances as trawling. The effects of trawling could never be as great as that due to the observed flood, yet the assemblages rapidly recovered from that much greater disturbance.

8.3.2 Pulse and press disturbances

The other major reason why an impact might be missed is that its ecological effects are transient, i.e. it is a pulse response (Bender et al., 1984; Underwood, 1991, 1994). For pulse responses, the disturbance due to trawling would be followed by a rapid change in fauna, which then recover by the time sampling is done, so that it was never detected (e.g. Underwood 1991, 1993).

This is an unlikely explanation for the lack of detectable impacts in the trawled areas of Clarence River. Trawled areas are trawled frequently throughout the open season, so that there would be very little time between successive disturbances for large-scale recovery of fauna between times of sampling.

A more realistic potential criticism is that each episode of trawling only disturbs a relatively small track across the bottom of the estuary. Where such small disturbances occur, recovery of fauna can be very rapid. For example, Bell & Devlin (1983) recorded very rapid recovery, after 8 hours, of fauna in patches of disturbed sediment. These were, however, very small patches (100 cm^2). Larger patches, 1,750 cm^2, showed recovery after 16 – 41 days in a different experimental study by Smith & Brumsickle (1989). At yet larger scales – the extensive areas disturbed by grey whales when feeding – Oliver & Slattery (1985) described amphipods moving in from surrounding undisturbed regions within minutes of whales moving out.

A relevant large experimental study of fauna in sediments on the coast of New South Wales was done by Lincoln Smith (1993). He used 1 m x 2 m plots (20,000 cm^2 – more than 10 times larger than those used by Smith & Brumsickle (1989)) in well-replicated and controlled experiments. Lincoln Smith (1993) showed that removal of sediments by dredges was followed by rapid recovery (within 4 – 8 weeks) of fauna. Assemblages and their entire sedimentary habitat were destroyed where dredges actually operated. After 4 weeks, however, assemblages in the newly-exposed sediments were indistinguishable from surrounding, undredged fauna. Trawling causes less physical disturbance to habitat than done by dredging, so recovery would be very rapid.

This is a valid point, but of little relevance where there are frequent repeated disturbances. The collection of small-scale disturbances would not be able to keep recovering from undisturbed areas if there are numerous disturbances over an area of floor of an estuary. It is much more likely that trawling disturbs the fauna, but many of them are simply redistributed through the water-column and assemblages are not being removed or seriously damaged.

8.4 Long-term patterns of disturbance

One very major problem about evaluating the effects of trawling is the consequence of historical, long-term disturbances. For example, trawling in many parts of the world has removed large fauna from the sea-bed (e.g. reviews by Hall, 1994; Kaiser et al., 1998; Thrush & Dayton, 2002). Thus, trawling in the Clarence River may have caused previous impacts that are no longer detectable because they have been widespread and long-term. There are now no areas which could be considered sufficiently undisturbed against which to compare the *current* effects of trawling.

For example, many large bivalves, patches of tube-worms, let alone seagrasses, may have thrived on the floor of the estuary before trawling began decades ago (Vorberg, 2000). As a result of the activities of trawlers over many years, these may have been removed or so substantially depleted so that they are now no longer found. Disturbances due to bottom-trawling cause major impacts on benthic megafauna in many parts of the world and are undoubtedly a historically important source of change which is no longer demonstrable in areas that have been trawled for long periods (e.g. Bergman & van Santrink, 2000; Hermsen et al., 2003).

Such impacts could have reduced the numbers of such organisms in areas that were not trawled, if they were a major part of the breeding populations in the estuary. Now, it is impossible to know what the diversity and structure of ecological assemblages might have been like before trawling. Thus, impacts caused before data were available about prevailing conditions cannot currently be detected by any programme of research.

This is not a unique problem and has widely been discussed with respect to historic patterns of disturbance by fisheries (notably the review by Thrush & Dayton, 2002). Among other consequences over long periods, it is believed that many natural ecological systems have long ago been so disturbed by fishing that it is now impossible to find relevant undisturbed reference or control sites. Without these, it is not possible to know what have been the long-term effects of any particular fishery or fishing practice. Nor is it realistic to propose that removal of am estuarine fishery would allow a fished area to recover to some natural state, because of all the other changes over the last several hundred years.

This is a valid commentary, but not valid in the context of lack of impacts due to current prawn-trawling. There has been no suggestion that this project was about the present versus the past, i.e. before trawling began and therefore before it could have had any effects. Even if it were possible to know what was the situation in the past, it would still be impossible to separate the effects of trawling from other, confounded, long-term disturbances due to changes in the catchments, chemical contamination, sewage, excess nutrients, etc., which have also been on-going since development of modern Australia.

9. Conclusion

Current practices of prawn-trawling in the Clarence River are not causing detectable effects on diversity and ecology of organisms living in sediments in trawled areas. Any future public concern about this issue will have to be coupled with appropriate evidence that such impacts are occurring. This evidence would have to demonstrate that something is happening that is not demonstrable now with the relevant quantitative data..

The project met several objectives (see Section 5), but some others were discovered to be irrelevant or unnecessary as a result of the information gained as the project developed.

The first objective was to quantify assemblages in trawled or untrawled areas of the estuary. This was done very extensively, resulting in a large set of data and robust statistical analyses (uni- and multivariate) of any patterns attributable to trawling. This objective was completely achieved throughout the project.

The second objective was to manipulate experimental trawling to identify specific patterns and time-courses of impacts by controlled trawling in untrawled areas. This was not possible in the first year of the project because of large-scale severe perturbations of the entire estuary due to a flood which removed most benthic fauna during the season in which trawling is permitted. Analyses of data from the first year failed to find impacts, so specific testable hypotheses for experiments were irrelevant. Experimental work was therefore not done, in favour of a more complete time-course of sampled data throughout the trawled and closed seasons of the second year. These data completely supported the findings from the first year, so experimental trawling would have achieved nothing. Note that this objective could only be followed if data indicated, as had been anticipated, the nature of impacts. Obviously, in the absence of impacts, the experiments were not needed, but this could not have been known before the study was done.

Objectives 3 and 4 were to use data and findings to offer specific advice to the industry and to fisheries managers to allow better management of activities and amelioration of impacts. Because there were no impacts identified, these contributions to management and sustainability were not warranted or necessary. The results will be communicated to managers so that the lack of effects on benthic infauna can be noted in any future plans for different management.

The final objective was to develop protocols and experimental designs for other, future studies of impacts of fisheries in other habitats. This was achieved by demonstrating the appropriate elements of spatial and temporal sampling to ensure that impacts on individual taxa and whole assemblages would be reliably detected where they exist. Logical development of relevant testable hypotheses was coupled with sequential procedures for detecting impacts and simplifying components of designs where variability was small. The resulting sequence and set of sampling and tests can be modified for any other study of potential impacts.

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11. Outcomes

The outcomes of this research were to be estimates of the impacts of prawn trawling on the biodiversity of assemblages living in the Clarence River estuary. There were no impacts (i.e. impacts are estimated to be zero). Recommendations cannot be provided for future research and/or management strategies designed to ameliorate any problematic impacts identified, because there were none. One of the most useful outcomes of this research is the provision of quantitative methods to analyse biodiversity in fished estuaries which can be: (i) used as a benchmark for subsequent comparisons and therefore (ii) provide the required performance indicators for ESD objectives of management plans for the fishery (see Appendix 3). As a consequence, the eventual beneficiaries of this research will be the estuarine prawn-trawl fishery itself because the work will provide a basis and guidelines for aspects of their sustainable management under ESD principles.

12. Benefits & Adoption

The research was intended to have broader implications for marine assemblages affected by fishing practices. By identifying possible impacts of trawling, this project was to identify gear-based or closure-based solutions to allow improved operation of these fisheries in an ecologically sustainable way with minimal impact on benthic species. This is now demonstrably unnecessary because current practices are not causing impacts on sedimentary infauna. Nevertheless, the finding of no impacts to benthic habitats and biodiversity due to prawn trawling is an important result that should be noted by the industry and managers. It should also be noted by the general public and environmental groups, because it is not as widely perceived. In general, it has been considered that prawn-trawling in the Clarence River is a cause of widespread environmental damage to fauna in sediments. It is not.

13. Further Development

Of wider importance is the fact that the project involved development of experimental and analytical protocols that can be adopted in other studies, having potential consequences for the research and management of those fisheries under ESD principles – particularly those in more difficult habitats like oceanic trawl fisheries. Some of the relevant procedural issues are summarized in Appendix 3.

14. Appendix 1 - Intellectual Property

No patentable or marketable products or processes were to be developed as part of this project. Relevant findings will be submitted to appropriate scientific journals.

15. Appendix 2 - Staff who worked on the project

Scientific Researchers (advice, analysis, design, interpretation)

Dr S.J. Kennelly, Prof. M.G. Chapman

Research Assistants (fieldwork, sorting samples, data-entry, analyses, graphics)

P. Barnes (Research Manager)

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Administrative Support

P. Harrington, V. Mathews, Dr E. Sakker

Preparation of the report

Dr T. Lasiak, Dr J. People

16. Appendix 3 - Comments about the design of studies to detect impacts

General considerations for detecting ecological impacts due to fishing

16.1 What sampling design?

All ecological measures – numbers of animals, sizes of fish, areas of seagrass, etc. – are naturally variable. They differ from time to time and place to place due to numerous interactive processes of responses to weather, direct and indirect ecological interactions, availability of food, etc., etc. It is therefore completely impossible to determine whether an impact exists, how much effect it has, over how large an area, etc., etc., unless natural variability is properly estimated.

In general, there are two methodologies to identifying and estimating sizes of impacts. One uses what is called interaction analysis. A disturbed area, where activity might be causing impacts, is compared with an undisturbed, or control, area. Long-term data must be collected before the disturbance starts, so that time-courses of the ecological measures in the two areas are well-understood. Then, the method is based on the fact that impacts after the disturbance starts will cause an unusual change in the temporal pattern for the impacted area. The control area will continue as before (Stewart-Oaten and Bence, 2001).

This approach may be justified where there are subtidal data from relatively long periods before the disturbance. It does, however, assume that there will be no coincident changes in the time-course of what is being measured in the control area. It also requires that the two areas track each other in some analysable way before the disturbance begins. If they do not, it will be impossible to distinguish an impact from any other change that differs between the two areas. This is well-known and has been well-described for many years (Green, 1979; Underwood, 1991). It is also unclear how multivariate data (numerous simultaneous measures) should be analysed.

Because most disturbances causing ecological impacts are already happening, or are a result of unplanned events (e.g. oil-spills) or are planned to occur within a short period (e.g. most coastal developments), the requirements of intervention analysis cannot actually be met. In many, if not most, cases of ecological measurement over long periods of time, areas do not simply track each other. Differences from time to time are not the same from place to place. Again, the requirements of intervention analysis cannot be met.

Instead, most studies are a modified or "beyond" BACI (Before-After, Control-Impact) design, in which data from before and after the disturbance are compared for the disturbed (i.e. potentially impacted) location and several, replicated control (i.e. undisturbed) areas. These designs have many advantages over previous methods (Green, 1979; Bernstein and Zalinski, 1983; Stewart-Oaten et al., 1986), particularly because they are replicated in space. By having several control areas, inferences about impacts can reliably be made. "Tracking" of measures is not necessary. Even if the measures in different places are not all following the same patterns of change through time, those in control areas can still be used to measure natural differences from place to place. These can then be compared with the differences in the disturbed place after the disturbance starts (as described in complete detail by Underwood, 1991, 1992, 1993, 1994). These designs are well-suited to statistical analyses (see particularly Underwood, 1993) and can be used with multivariate ecological data (Terlizzi et al., 2005).

16.2 Spatial and temporal variation

Successful sampling to be able to detect and quantify impacts must attempt to get good measures of natural "noise" in what is being sampled. It is expected that, for example, numbers of animals will change from time to time. Changes may be short-term, perhaps in response to sudden changes in weather, such as due to storms. They may be cyclic, in response to patterns of tides (the changes from spring to neap tides can have profound effects on estuarine species, causing alterations over periods of about a fortnight). They can be cyclic over monthly periods because of responses by animals to changes in moonlight.

Changes can be longer – for example, seasonal patterns of changing temperature can cause changes in number of animals from season to season. Breeding seasons can be once a year, causing annual changes in numbers.

Dealing with temporal variation requires sampling to be done independently among different times (see the discussion in Stewart-Oaten et al. 1986). Where the general nature of patterns of temporal change is well-understood, the times of sampling can be chosen to maximize the chances of detecting unusual changes due to impacts. Usually, sampling is best done at a hierarchy of time-scales (e.g. in different weeks in several different months in each season). Where the relevant information is not available to do better, times of sampling should still be in some hierarchy, but the longer and shorter periods will be more arbitrarily chosen (see Green, 1979; Underwood, 1991).

Numbers (sizes, etc.) of animals also vary from place to place in any area. Again, this can be due to variations in availability of habitat or food and the relevant spatial scales might be known from previous ecological studies. Variations can, however, also be due to all sorts of other influences. For example, there may be the arrival of large numbers of predators, causing smaller numbers of animals in some patches (Connell, 1975). There can be differences in the number of animals that actually arrive in and occupy different parts of a habitat (so-called "supply-side" ecological processes; see Underwood and Fairweather, 1989).

As with temporal sampling, spatial variation requires measurements to be made at more than one spatial scale. Where the processes causing spatial differences are known and are predictable, the relevant scales (and therefore places to sample) can be reliably planned. Where this information is not available, a less reliable hierarchy of spatial scales must be used.

As done in the Clarence River, sampling must include a series of measures to allow the amounts of natural change to be estimated. This was done by taking samples at 4 times in each season. In areas closed to trawling, these measures allow natural changes from time to time to be measured. In areas where trawling is done, these allow temporal differences to be measured where there are natural changes in conjunction with any impacts due to trawling.

Spatial variation was measured at each time, in each area sampled, by having 2 locations (i.e. two different parts of each area were sampled). At a smaller scale, 3 sites were sampled in every location, so that differences across a location could be measured. Finally, at the smallest scale, replicate samples were taken at distances of about 1 m from each other.

16.3 More than one measure of potential impacts

Wherever possible, much more reliable information can be gained by doing more than one study of a potential impact. Often, this is not possible. For trawling in the Clarence River, the study was done in each of two years, by comparing the open and closed seasons. In each year, effects of trawling (measured as differences between open and closed seasons compared between closed and trawled areas) were investigated in 3 different regions of the estuary. This provides 6 different assessments of any impacts of trawling (i.e. in 3 regions in each of 2 years).

Such repeated experimentation allows greater confidence to be placed in the findings than would be the case if analyses were done for only one year at only one regions (which might have been anomalous and impacts might have been missed).

By following the appropriate general principles for designing studies to detect impacts (Green, 1979) and the specific requirements of beyond-BACI analyses (Underwood, 1994), there will be the maximal chance of detecting the impacts that occur and of being able to interpret them collectively.