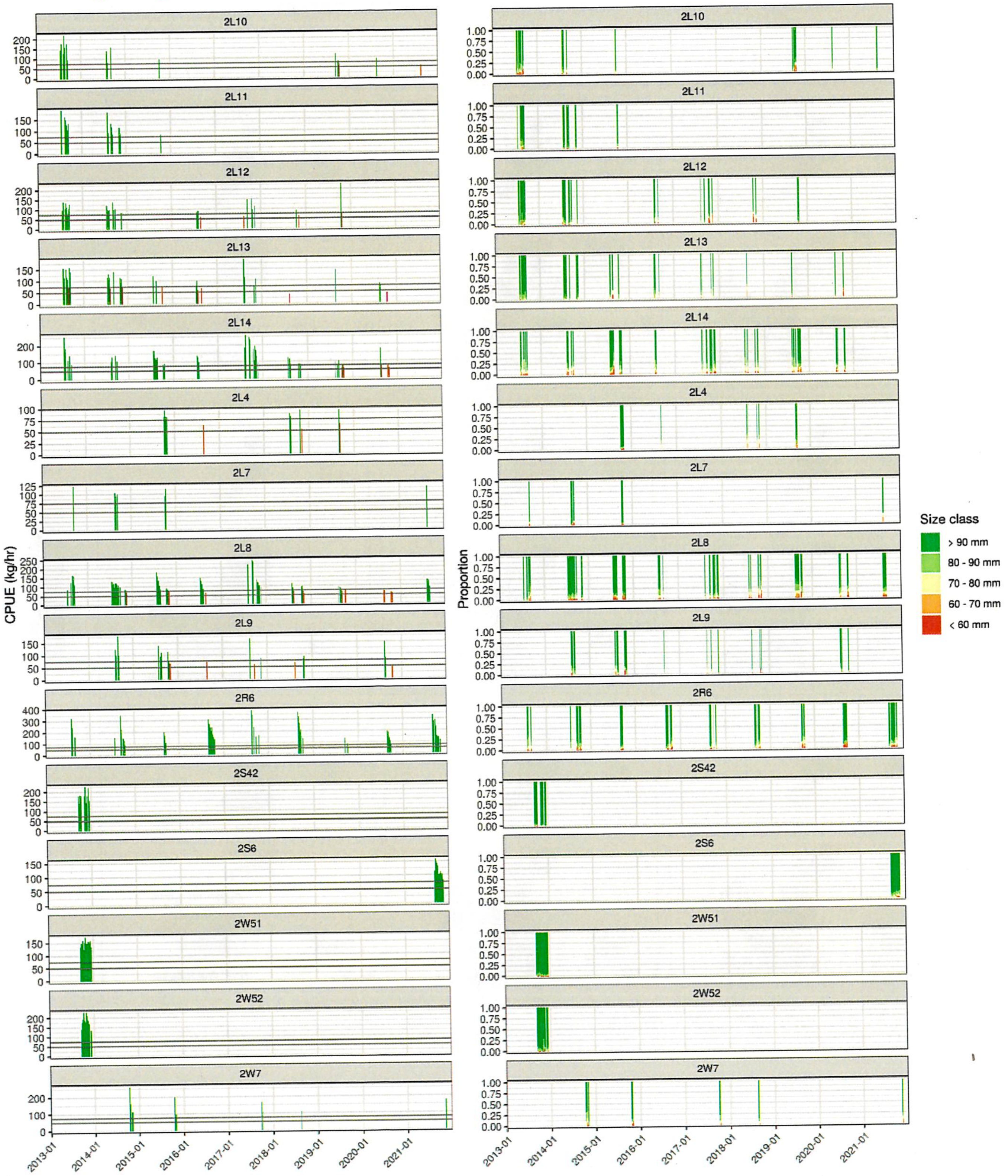
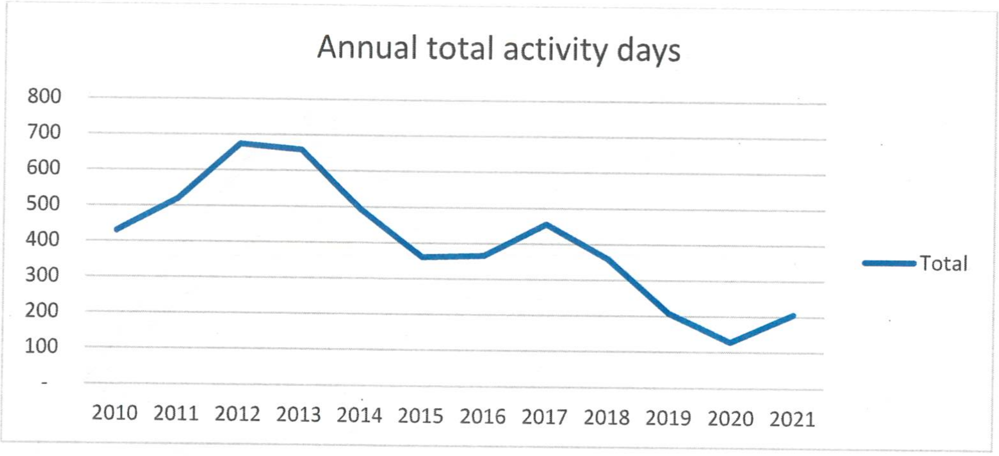
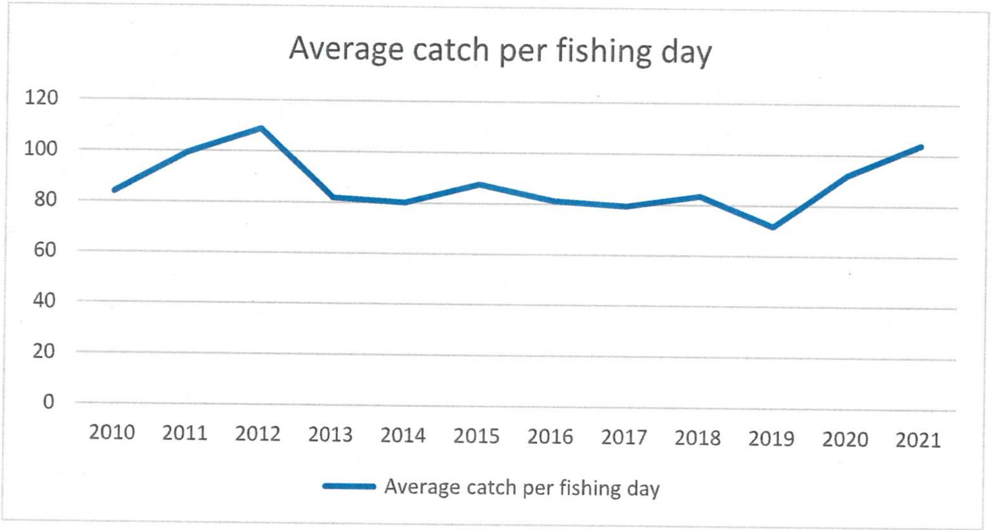
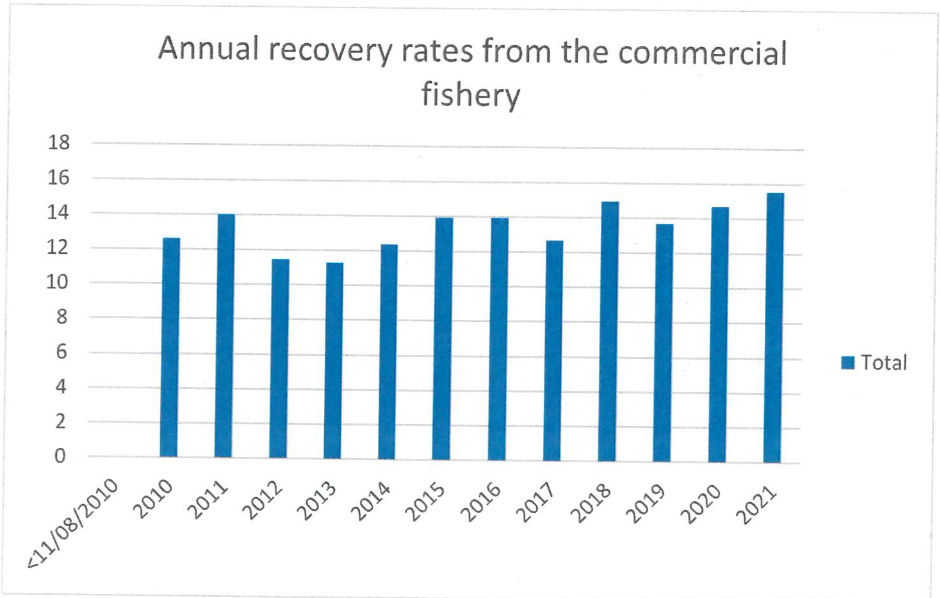
8.4 Appendix 4 Catch per Unit Effort and size composition from CSFA fine-scale reporting areas since 2013



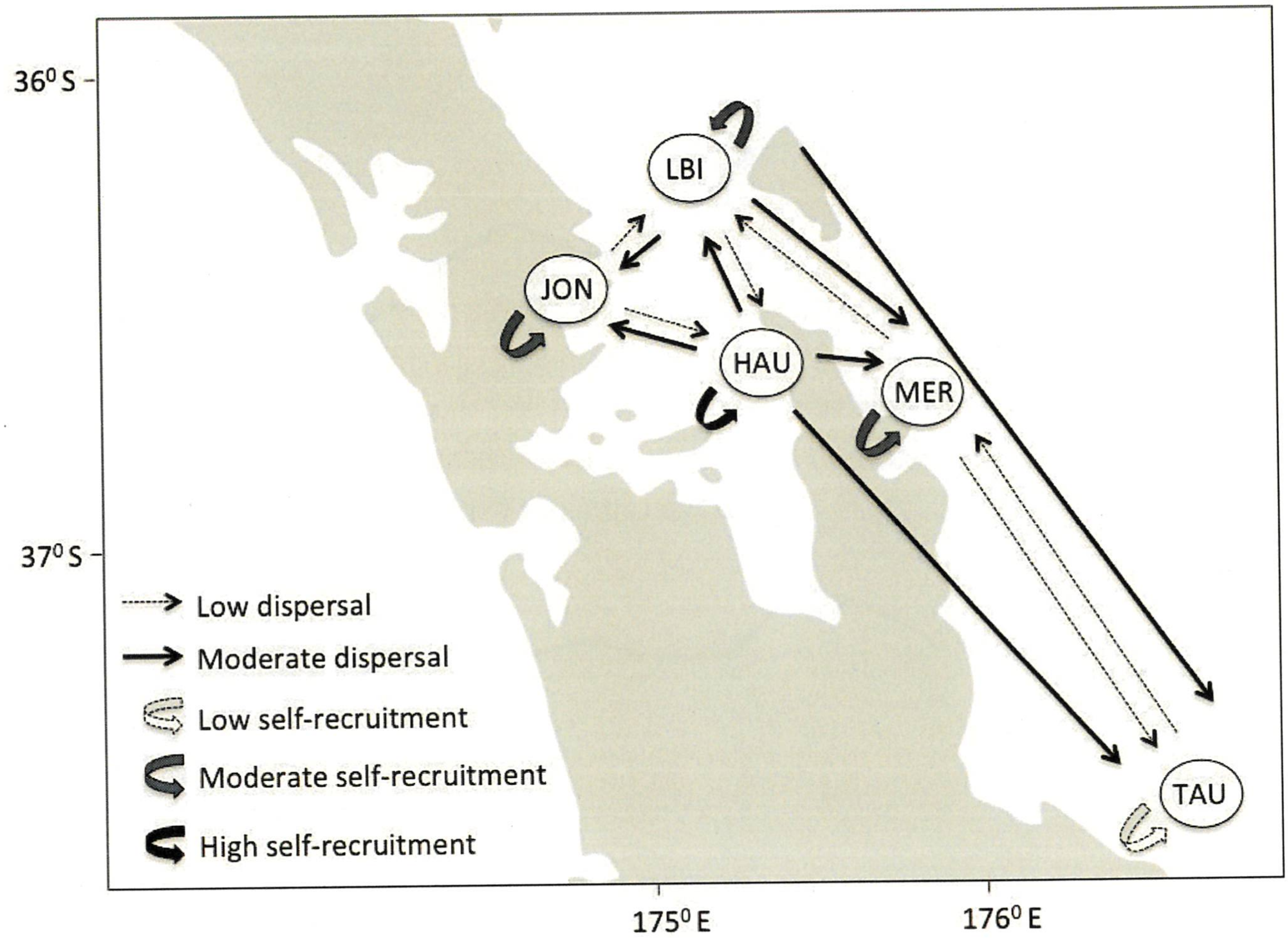
8.5 Appendix 5 Examples of the fishery characterisation data that should be considered to provide context of the status of the fishery (Noting this is best available information)







8.6 Appendix 6 Expected relationships between locations sampled in Coromandel with estimated levels of larval dispersal and self-recruitment (low, moderate and high) indicated by the arrows. Circles are locations sampled (Source: Silva, 2015)



From:	Joe Dennehy
To:	FMSubmissions
Subject:	Scallop review sca 1 and sca cs
Date:	Wednesday, 15 December 2021 3:38:25 PM

I am happy for recreational dredging to be banned providing commercial dredging is banned at the same time.

Mpi in its wisdom saw fit to increase the scallop quota in coromandel and the gulf by ten fold a few years ago, with predictably disastrous consequences.

This is not a shared fishery. The scallops belong to the people of New Zealand, and you should be managing them better.

I support a ban on all dredging commercial and recreational, but not recreational alone.

Yours faithfully

Joe Dennehy

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person: Conor Pullman

Organisation (if applicable):	
Email:	
Fishstock(s) this submission refers to:	Scallops – SCA1 and SCA CS
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	Option 3

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Fisheries New Zealand
Tini a Tangaroa

Submission:[1]

Details supporting your views:

Dredging is very damaging to this fishery and should be prohibited.

Please continue on a separate sheet if required.

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

From:	John Rosser
To:	FMSubmissions
Subject:	Review of sustainability measures – 2022 April round
Date:	Wednesday, 15 December 2021 9:39:56 PM

I have ben diving northland for a long time wall over 400 dives . And mats with alot mor that thay sum in the thosinds .
And sum of the bigist things and ishows we c with seyfood gathering .
Is dreging it braks and damigis alot of scolips aswel as reks the c flor and ther food sorce .
We nead to ban dreging atlest in bays .
Alsow lower the comershil limits or stop the comershil giys gathering all together as thay get them then lokil seasin cums in place and rhay dont get a brake .

Alsow the permits thers alot of people that get permi and go oot over 2 or 3 days and get qwoter ech time that is raping and piliging .
Alsow thers people how go ot stay on ther boats or not stay but get scolips or crays 1 day then the next and agen the next shood be only so menh tims a weak u kan go ott . For them
.

From: Florence Hewitt
To: FMSubmissions
Subject: Sustainability Measures for Scallops
Date: Tuesday, 25 January 2022 3:42:35 PM

Sustainability Measures for Scallops (SCA1 & SCA2) for 2022/23 PDF, 2.9 MB
Discussion Paper No. 2021/30

I would like to support Option 3 - Ban all dredging for scallops.

It seems obvious by your charts and diagrams that commercial dredging in Bream Bay is taking away and destroying the beds which spawn and provide mature scallops closer inshore.
In Smugglers and Urquarts Bay scallops are holding their own which also indicates a lack of commercial dredging. Recreational gatherers have not depleted these areas - but perhaps launches dredging in the B.O.I have destroyed the delicate ecosystems that scallops thrive upon. While there is some sympathy for Commercial fishers - their total haul must be almost uneconomical anyway, add the damage these dredges do - surely their right to take free kaimoana from the seashore must be closed.

It must be remembered that recreational divers (under strict quota limits) provide many family and friends with this delicious food.

The only alternative is that the season should be reduced.

Regards
Peter Hewitt

From: Hanna King
To: FMSubmissions
Subject: Re:
Date: Thursday, 27 January 2022 11:58:46 AM

Sorry it's not working for me lol, I had filled out the form but it all vanished when I sent it, my submission was this.....

What needs to happen is a permanent ban on recreational dredging.
Any form of fishing that drags things along the bottom of the ocean does massive damage to the environment down there.
As a diver I see the damage over and over again. Drag lines everywhere.
Dredging picks up undersized scallops also (along with any other living creature that happens to be in the path, starfish, snails, hermit crabs and horse mussels all get run over) not just the scallops over 100mm.
It also is a large contributing factor to the spread of fan worm and tube worm.
Some people will argue the fact that the damage will repair itself, but the truth is that damage is damage, and damaging an environment is going to have lasting consequences.
If we can repair the environment, life will blossom on all levels.

On Thu, 27 Jan 2022, 11:55 AM Hanna King,

From: Catherine Mcnamara
To: FMSubmissions
Subject: Review of sustainability measures – 2022 April round
Date: Thursday, 27 January 2022 12:32:24 PM

I support option 1 for full protection of scallop fish stock and would be happier if it were to be for an even longer period. I experienced scallops from whangarei harbour in the 70s when origin was more of a mystery. These days they are being extinguished by big business.

Catherine McNamara

Sent from my iPhone

From: Olaf Jones
To: FMSubmissions
Subject: Review of sustainability measures – 2022 April round
Date: Thursday, 27 January 2022 12:45:32 PM

With reference to proposals to review sustainable harvesting of scallops...

Whatever is decided regarding scallop harvesting, it must ban dredging as a method.

I have personally witnessed a commercial scallop dredge in action under water and the utter destruction is hard to appreciate. There was nothing left after its passage but a barren waste. Everything was destroyed.

If we want to have scallops for future generations, this method must be banned and other harvesting methods used instead. Such measures may well result in higher prices but that is no excuse for wanton destruction of an ecosystem.

Regards,
Olaf Jones

From: Rita Gregory
To: FMSubmissions
Subject: Review of sustainability measures – 2022 April round

Review of sustainability measures %2�� 2022 April round

RG Rita Gregory
To FMSubmissions

Thu 3:41 PM

Stop the use of dredging for scallops. These are responsible for killing small/undersized/growing shellfish before they have a chance to mature therefore preventing ongoing growth.

From:	Tony Lenz
To:	FMSubmissions
Subject:	Review of sustainability measures for scallop (SCA 1 and SCA CS) for 2022
Date:	Friday, 28 January 2022 8:55:08 AM

Hi I would support addressing some form of reduction in the scallop allowances and would support:

- Closing the season for a period to rejuvenate and dropping the limit to 20 .
- Dropping the "boat man ' allowance totally
- Banning dredging in all areas as this decimates the beds and other sea life.
- It's been my ancestors custom to harvest food. I do not see why we need a separate Maori quote - from my observation the allowances they have are more often than not abused with access to the "letter of collection" given freely without any checks and balances.This allocation should be dropped totally.
- Drop daily limit to 20

Kind regards
Anthony Lenz

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person: Matt Parkinson	
Organisation (if applicable):	
Email:	
Fishstock(s) this submission refers to:	Scallops – SCA 1 and SCA CS – Northland, Auckland and Coromandel.
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	Other – similar to Option 1 but put an actual time limit on t rather then to de assessed – a 3 year closure to the commercial and recreational harvest of scallops in the SCA 1 and SCA CS fisheries as a sustainability measure under section 11 of the Act.

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Submission:[1]

Details supporting your views:

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

This will protect scallop beds from the direct and indirect impacts of fishing activity.

I am a diver and have dived for many years in the Hauraki Gulf, Northland and Coromandel. Over the years I have noticed a significant reduction in the scallop beds, quality of the scallops and devastation to the seabed from obvious signs of dredging. I know that the current rules will result in the devastating depletion of the Scallop stocks as the are unsustainable. I am thrilled there is a 2 year ban in the Coromandel area and believe this will go some way to meaning the scallop beds will replenish and be available for future generations. Auckland and Northland need to do similar.

Although this ban will mean I cannot gather scallops for some time I believe it is the right thig to do for our fisheries and for future generations.

Please continue on a separate sheet if required.

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person: Matt Parkinson	
Organisation (if applicable):	
Email:	n
Fishstock(s) this submission refers to:	Scallops – SCA 1 and SCA CS – Northland, Auckland and Coromandel.
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	Other – similar to Option 1 but put an actual time limit on t rather then to de assessed – a 3 year closure to the commercial and recreational harvest of scallops in the SCA 1 and SCA CS fisheries as a sustainability measure under section 11 of the Act.

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Fisheries New Zealand
Tini a Tangaroa

Submission:[1]

Details supporting your views:

This will protect scallop beds from the direct and indirect impacts of fishing activity.

I am a diver and have dived for many years in the Hauraki Gulf, Northland and Coromandel. Over the years I have noticed a significant reduction in the scallop beds, quality of the scallops and devastation to the seabed from obvious signs of dredging. I know that the current rules will result in the devastating depletion of the Scallop stocks as the are unsustainable. I am thrilled there is a 2 year ban in the Coromandel area and believe this will go some way to meaning the scallop beds will replenish and be available for future generations. Auckland and Northland need to do similar.

Although this ban will mean I cannot gather scallops for some time I believe it is the right thig to do for our fisheries and for future generations.

Please continue on a separate sheet if required.

[1] Further information can be appended toyour submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person:	Robert Kevin Brown
Organisation (if applicable):	
Email:	
Fishstock(s) this submission refers to:	Scallops – SCA 1 and SCA CS
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	My preffered option is to reduce the co mmercial catch by 75% but also to reduce the recreational catch and restict harvest methods. Please see below.

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Fisheries New Zealand
Tini a Tangaroa

Submission:[1]

Details supporting your views:

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

After diving in the Whangarei Harbour for scallops for the past 20 years I have noticed a gradual but steady decline of the flora and fauna on the sea bed.

After a couple of years of not diving in the Harbour I went in this year in numerous different spots that often had scallops. What I saw left me shocked, sad and angry.

Not only had scallops numbers greatly decreased but also all of the other life on the seabed)benthic epifauna) had disappeared also. The bottom was covered in lifeless white sand when I dived on it this year in numeros places looking for scallops. It reminded me of the dead and lifeless sand of the Mediterranean.

There use to be a great biodiversity of species on the seabed in Whangarei Harbour. In particular horse mussels, sea cucmbers, starfish, seaweed, flat fish, rocks with anemones, limpets, snails, octopus holes Then crabs and fish that would live around all of this on the seabed.

We must stop recreational and commercial dredging as this is what detroys the delicate life on the seabed. Diving both as free divers and tank should be the only gathering system allowed in order to protect all of the flora ond fauna on the seabed. Put a stop to recreational and commercial dredging. It is lazy and is extremely harmful to the future of all the species that rely on the delicate life structures on the seabed.

See info below.

https://www.marine-bio-images.com/blog/lyme-bay-marine-ecology/scallop-dredging-why-is-it-considered-so-damaging-to-reefs/

https://www.fao.org/3/y7135e/y7135e07.htm

https://legasea.co.nz/2021/03/26/its-time-to-ditch-the-dredge/

Please continue on a separate sheet if required.

Vol. 129: 141-150, 1995 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published December 14

The impact of habitat disturbance by scallop dredging on marine benthic communities: what can be predicted from the results of experiments?

Simon F. Thrush[1,*], Judi E. Hewitt[1], Vonda J. Cummings[1], Paul K. Dayton[2]

[1]National Institute of Water and Atmospheric Research, PO Box 11-115, Hamilton, New Zealand
[2]Scripps Institution of Oceanography, University of California San Diego, La Jolla, California 92093-0201, USA

ABSTRACT: Field experiments were conducted on 2 subtidal sandflats to identify the short-term impacts of commercial scallop dredging on macrobenthic communities. The 2 sites (1400 m^2) were situated 14 km apart, both at about 24 m depth, with similar exposure aspects and were characterised by infaunal communities dominated by small and short-lived species. Prior to dredging, preliminary sampling failed to reveal significant differences in the density of common macrofauna within each site, although community composition was distinctly different between sites. The experiment was initiated by using a commercial scallop dredge to dredge half of each study site. Macrofauna samples were collected in both the dredged and adjacent reference plot at each site immediately after dredging and again 3 mo later. The density of common macrofaunal populations at each site decreased as a result of dredging, with some populations still significantly different from the adjacent reference plot after 3 mo. Significant compositional differences in the assemblage structure between dredged and reference plots were also recorded at each site over the course of the experiment. The findings of this experiment are considered a conservative assessment of bottom disturbance by fishing because of the area of seabed used, the types of community present and the intensity of disturbance used in the experiment. The findings of this and similar short-term experiments are discussed in light of the need to predict and assess possible large-scale changes to benthic communities as a result of habitat disturbance by fishing.

KEY WORDS: Fishing impacts · Habitat disturbance · Scallop dredging · Benthic communities · Scaling-up

INTRODUCTION

With the increasing utilisation of fishery resources around the world there is growing concern about the potential for extensive impacts on marine ecosystems. The ecological consequences of a variety of other human activities that modify coastal ecosystems (e.g. urbanisation, reclamation and pollution), although often intense, usually occur on a far more localised scale than the extensive area exploited by commercial fishers. In fact, the spatial and temporal extent of commercial fishing activity has been a major factor limiting our ability to identify interactions between fishing activity and the broad-scale structure and functioning of marine ecosystems. This is unfortunate because the issue of the environmental effects of fishing is important, not solely for conservation, but also because exploited species are integral components of natural systems; any broader effects of their exploitation are likely to have important ramifications for the fishing industry, its management and sustainability.

A number of recent studies have highlighted the variety of effects that can occur as a result of fishing (de Groot 1984, Aronson 1990, Messieh et al. 1991, Jones 1992, Whitman & Sebens 1992, Dayton et al. in press). A potentially important mechanism whereby fishing may influence benthic communities is habitat disturbance by bottom dredging and trawling. Without direct measurements of the spatial distribution and frequency of fishing disturbance, the appropriate scales from which to assess the potential impact have been

*E-mail: thrush@eco.cri.nz

difficult to resolve. However, some studies indicate the potential for long-term ecosystem-wide changes due to bottom disturbance by fishing (e.g. Wadden Sea, Riesen & Reise 1982; English Channel, Holme 1983; Australian North West Shelf, Sainsbury 1988). These studies indicate the need to consider impacts over a variety of spatial and temporal scales, ranging from the immediate effects of short-term differences in and out of individual trawl or dredge tracks, to long-term changes in the structure and functioning of benthic communities in fishing grounds.

In most cases a rigorous assessment of the effects of habitat disturbance by fishing is not possible. The lack of pre-fishing data precludes the use of BACI impact assessment procedures (Green 1979, Stewart-Oaten et al. 1986, Underwood 1992). The large space and time scales over which fishing operates further complicate the situation, making it difficult to identify areas which have not already been modified by previous exploitation and to locate comparable control/impact sites. However, small-scale experiments that focus on effects at the scale of an individual trawl or dredge track are possible; here we present the results of an experiment designed to identify short-term (up to 3 mo) effects of scallop dredging on macrobenthic communities. The problems involved in utilising information gained from small-scale experiments such as this, to predict and test for effects over larger scale, are also discussed.

METHODS

Experiments were conducted in the Mercury Bay area (36° 45′ S, 175° 50′ W) of the Coromandel Peninsula, New Zealand. Two locations were selected for the experiment, these were chosen on the basis of local knowledge of scallop dredging activity, and for similarities in water depth and exposure aspect. The 2 locations selected were about 14 km apart, one in an area regularly exploited by commercial scallop fishers (Opito Bay) and the other in an unexploited area (Hahei).

Based on preliminary diving observations at each location, a representative site (70 × 20 m) was chosen. Sub-surface marker buoys were used to permanently mark the corners of each site and a series of metal stakes were placed down the middle of the site. On each sampling occasion, a transect line marked at 1 m intervals was run along the metal stakes and used to find sampling locations determined by random selection of cartesian coordinates for each side of the transect line.

Prior to the actual experiment, 15 randomly positioned cores (10 cm diameter, 15 cm depth) were collected by SCUBA diving to describe the macrobenthic community and determine any spatial variation within each site. Observations of habitat type and the densities of large epifauna were also made while SCUBA diving. Surface sediment samples (0 to 5 cm depth) were collected haphazardly from each site. For each site, these samples were pooled prior to grain size analysis following the methods described in Folk (1968).

The experiment was initiated in late April 1991, 3 wk after preliminary sampling, by running a commercial scallop dredge through half of each study site. The commercial fishing vessel used a box dredge (about 2.4 m wide) typical of those used by local scallop fishers. This type of dredge is only used in New Zealand and Australia and is similar to that described by McLoughlin et al. (1991). Although the penetration depth of the dredge into the seabed is influenced by a variety of factors, under the conditions used in this experiment we expected the dredge to drag across the sediment. A tooth bar, with teeth about 10 cm long, fitted to the lower leading edge of the dredge, scored the sediment surface. Surface buoys were positioned over the central transect line and 5 parallel dredge tows were made along the long axis of each site, to create a dredged plot and an adjacent reference plot. At both sites core samples were collected by SCUBA diving, within 2 h of dredging and again 3 mo later. On both of these sampling occasions 12 core samples were collected from random locations in each of the dredged and reference plots. Observations of sediment conditions and epifauna were also made.

Macrofaunal core samples were sieved on a 500 µm mesh. The residue from each sample was fixed in 5% formalin and 0.1% Rose Bengal in seawater. In the laboratory macrofauna were sorted, identified to the lowest practical taxonomic level, counted and preserved in 70% isopropanol.

Tests of significant differences between plots and times were conducted on the densities of common taxa (i.e. taxa represented by an average of greater than 2 individuals per core). The significance of differences between dredged and reference plots, between occasions, and their interactive effects were assessed using 2-way ANOVA, with both factors treated as fixed effects. Data from Hahei and Opito Bay were treated separately because the macrobenthic communities at each site were distinctly different. Data were initially analysed to assess normality (Shapiro-Wilk test) and homogeneity of variance (Levene's test). For taxa which could not meet these assumptions, the data were rank transformed prior to ANOVA (Conover & Iman 1981). Statistical significance was attributed to univariate tests at the 10%

level. While this *a priori* decision allows for greater probability of falsely concluding that a significant effect exists (i.e. making a Type I error) than the traditional level of 5%, it is important that due regard also be paid to Type II error (i.e. falsely concluding that no effect exists when there really is one). Type II error is at least as important as Type I error when documenting impacts on the environment and when providing information with implications for resource management (see Eberhardt & Thomas 1991, Fairweather 1991, Peterman & M'Gonigle 1992, Peterson 1993 for further discussion).

The compositional differences between the macrobenthic assemblages found in the dredged and reference plots and through time were assessed using the Bray-Curtis similarity index (Bray & Curtis 1957) followed by multi-dimensional scaling (MDS) ordination (Kruskal & Wish 1978). This technique is frequently used to assess changes in community structure associated with environmental impact (Clarke 1993, Warwick 1993). In all cases MDS ordinations presented are based on untransformed data and had stress levels <0.15. Differences in assemblage composition between plots and times were assessed using ANOSIM, a randomization/permutation procedure that tests for differences in the ranked similarity matrix, both in terms of location and variability (Clarke & Green 1988).

RESULTS

Preliminary sampling

Mean sediment grain size at both sites was characterised as coarse sand (Table 1). Sediments at Hahei were well sorted with a slightly coarse skewed distribution. Observations of the sediment surface at Hahei indicated sediments were homogeneous over the site and composed of small sand ripples (<10 cm high). The sediment surface at the Opito Bay site consisted of an unrippled sandflat with a large fraction of shell hash. This resulted in sediments being characterised as poorly sorted and strongly coarse skewed (Table 1). Common epibenthic animals at both sites were all mobile and included starfish *Astropecten polyacanthus* and *Luidia varia*, hermit crabs *Paguristes setosus* and snails *Cominella adspersa*. Scallops *Pecten novaezelandiae* were only abundant at the Opito Bay site.

Table 1. Near-surface sediment grain size statistics

Site	Mean size (ϕ)	Mean size (mm)	Sorting	Skewness
Hahei	2.590	0.166	0.501	−0.102
Opito Bay	2.150	0.225	1.099	−0.406

Tests on all common taxa, the total number of individuals and number of taxa from the macrofaunal samples collected prior to experimental dredging failed to identify any significant pre-experiment location differences within either of the sites (Table 2) The community composition was distinctly different between the 2 sites, with crustaceans more common at Hahei and polychaetes more common at Opito Bay (Table 3). The MDS ordination (Fig. 1) also demonstrated distinct differences between the 2 sites, with samples from Opito Bay showing higher variability in assemblage composition than those from Hahei. ANOSIM assessment of differences in the ranked similarity matrix revealed an overall significant difference between the 2 sites ($p = 0.002$).

Table 2. Tests for location affects prior to dredging. Data collected from each half of the site were compared using Wilcoxon's rank sum tests ($n = 7$)

Taxa	Probability
Hahei	
Crustaceans	
Ostracods	<0.325
Phoxocephalid complex	<0.772
Tanaidae 1	<0.684
Gynodiastylis laevis	<0.609
Urothoe spp.	<0.561
Pachychelium sp.	<0.639
Polychaetes	
Euchone sp.	<0.602
Aricidea sp.	<0.811
Molluscs	
Felaniella zelandica	<0.859
Total no. of individuals	<0.862
Total no. of taxa	<0.813
Opito Bay	
Crustaceans	
Ostracods	<0.746
Phoxocephalid complex	<0.688
Gynodiastylis laevis	<0.320
Polychaetes	
Polydora sp.	<0.477
Goniadides sp.	<0.865
Euchone sp.	<0.954
Prionospio multicristata	<0.277
Macroclymenella stewartensis	<0.305
Molluscs	
Tawera spissa	<0.836
Total no. of individuals	<0.518
Total no. of taxa	<0.313

Table 3. Initial composition of dominant macrofauna at Hahei and Opito Bay. C: crustacean; P: polychaete; M: mollusc

Taxa	% of individuals
Hahei	
C Ostracods	18.0
P *Euchone* sp.	17.7
C Phoxocephalid complex	12.8
C Tanaidae 1	12.0
C *Gynodiastylis laevis*	6.2
C *Urothoe* spp.	5.2
M *Felaniella zelandica*	3.4
C *Pachychelium* sp.	3.2
P *Aricidae* sp.	2.1
Opito Bay	
P *Polydora* sp.	57.9
C Ostracods	7.1
C Phoxocephalid complex	4.3
P *Goniadides* sp.	4.2
P *Euchone* sp.	3.3
P *Prionospio multicristata*	2.5
P *Gynodiastylis laevis*	2.2
M *Tawera spissa*	2.2
P *Macroclymenella stewartensis*	2.1

Visible effects of dredging

The impacts to the seafloor observed by SCUBA diving immediately after dredging were similar at both sites. The dredge broke down the natural surface features (e.g. emergent tubes, sediment ripples) and the teeth on the front of the dredge created grooves approximately 2 to 3 cm deep. These observations indicated that the dredge had disturbed the dredged plot but not the adjacent reference plot. At both sites, dredge tracks occasionally did not completely overlap, indicating the presence of small undredged patches which could increase the variability of samples from the dredged plots. This did not influence data collected immediately after dredging, when dredge tracks were visible. At both sites undamaged scavenging snails, hermit crabs and starfish were highly active, feeding on damaged and exposed macrofauna. In Opito Bay many damaged scallops were lying on the sediment surface, already being attacked by scavengers.

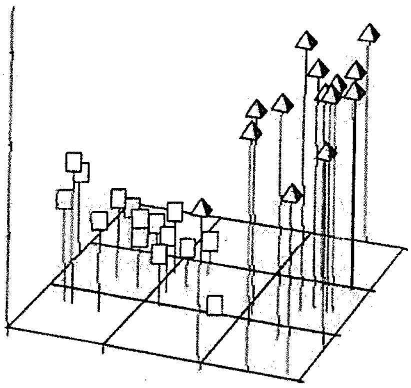


Fig. 1. MDS ordination of data from core samples collected on the preliminary sampling occasions. The ordination recorded a stress level of 0.073. (□) Hahei; (△) Opito Bay

Effects on macrofauna at Hahei

Of the common taxa at Hahei, the crustaceans of the Phoxocephalid complex, Tanaidae 1, and *Urothoe* spp., and the polychaetes *Aricidea* sp., *Onuphis aucklandensis*, and *Prionospio multicristata*, all showed consistent significant differences between the dredged and reference plot, while the crustacean *Pachychelium* sp. and the bivalve *Nucula nitidula* showed significant differences on at least one sampling occasion (Fig. 2, Table 4). For all of these taxa densities were lower in the dredged plot on the first sampling occasion. Three species (the crustacean *Leucon ?latispina*, the polychaete *Euchone* sp., and the bivalve *Felaniella*

Table 4. Significance of 2-way ANOVA on common taxa, total number of individuals and number of taxa from the Hahei experimental site core samples. Degrees of freedom are as follows: Plot 1; Time 1; Interaction 1; Error 44. Probability values above 0.1 are presented as non-significant (ns)

Taxa	Plot	Time	Interaction
Crustaceans			
Gynodiastylis laevis	ns	ns	ns
Leucon ?latispina	ns	0.0001	ns
Ostracods	ns	ns	ns
Pachychelium sp.*	ns	ns	0.0909
Phoxocephalid complex*	0.0551	ns	0.0312
Tanaidae 1*	0.0001	ns	ns
Urothoe spp.	0.0551	ns	ns
Molluscs			
Felaniella zelandica	ns	0.0233	ns
*Nucula nitidula**	ns	ns	0.0113
Polychaetes			
Aricidea sp.*	0.0191	ns	0.0964
Euchone sp.	ns	0.0052	ns
*Onuphis aucklandensis**	0.0622	ns	ns
Prionospio multicristata	0.0543	ns	ns
Total no. of individuals	0.0142	ns	ns
Total no. of taxa	ns	ns	0.0173

*ANOVA based on ranks

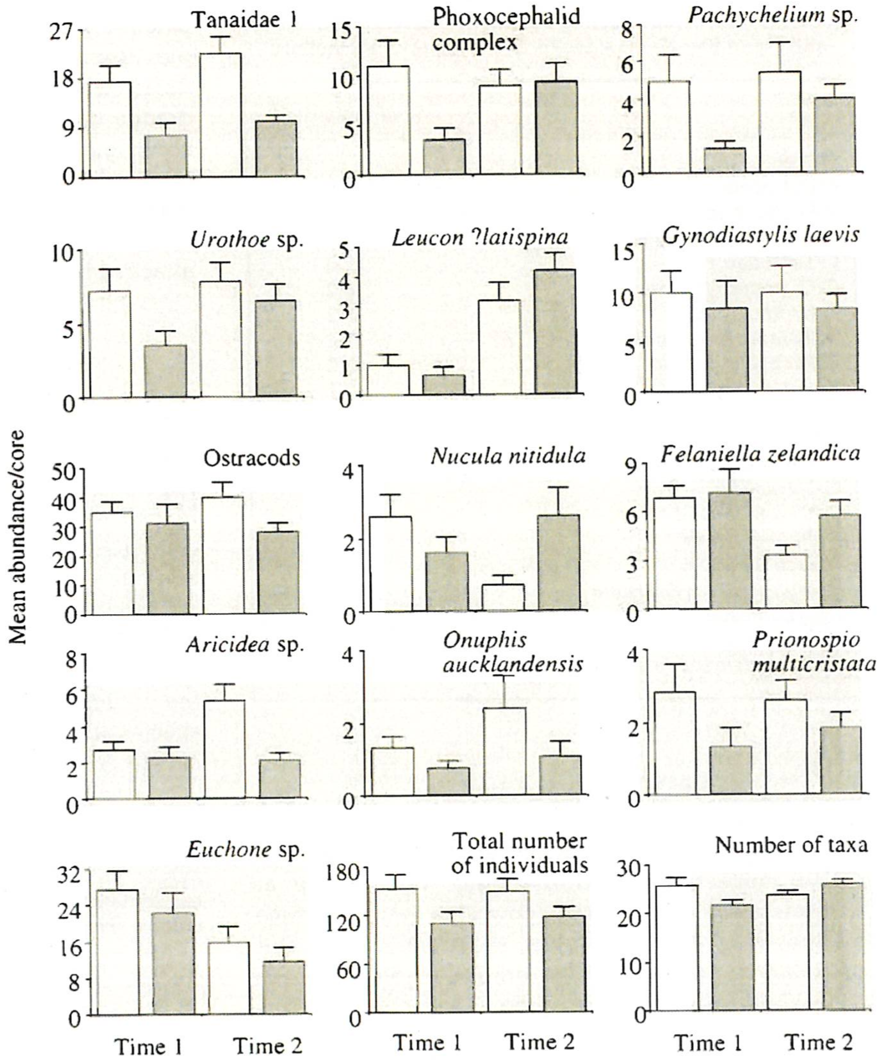


Fig. 2. Mean density (± SE) of common taxa, total number of individuals, number of taxa collected in core samples from dredged (shaded) and reference (unshaded) plots at Hahei

zelandica) showed significant density changes over time. These taxa did not show a significant effect due to dredging. The remaining common taxa were usually those with low and/or variable densities, i.e. the crustaceans *Gynodiastylis laevis* and Ostracods. Although they did not show significant differences, a general pattern of lower mean densities in the dredged plot in comparison to the reference plot is apparent on the first sampling occasion (Fig. 2).

The total number of individuals was significantly lower in the dredged plot on both sampling occasions (Fig. 2, Table 4). The number of taxa was lower in the dredged plot only on the first sampling occasion, accounting for the significant plot × time interaction (Table 4). The MDS ordination from Hahei demonstrated differences in both location and spread of core samples collected in dredged and reference plots over time (Fig. 3). ANOSIM assessment of differences in the ranked similarity matrix demonstrated an overall difference between factors ($p = 0.002$) due to differences between dredged and reference plots on each sampling occasion ($p < 0.05$ respectively). Macrobenthic samples collected on the preliminary sampling occasion and from the reference plot on the other 2 sampling occasions were not significantly different from each other.

Effects on macrofauna at Opito Bay

Temporal changes in the density of resident species appeared to be common at the Opito Bay site over the 3 mo of the experiment. Five taxa (i.e. the crustaceans Gammaridae and Ostracods, the polychaetes *Euchone* sp. and *Macroclymenella stewartensis*, and the bivalve *Felaniella zelandica*) showed significant density changes with time (Table 5). Patterns of density change between the dredged and reference plot were

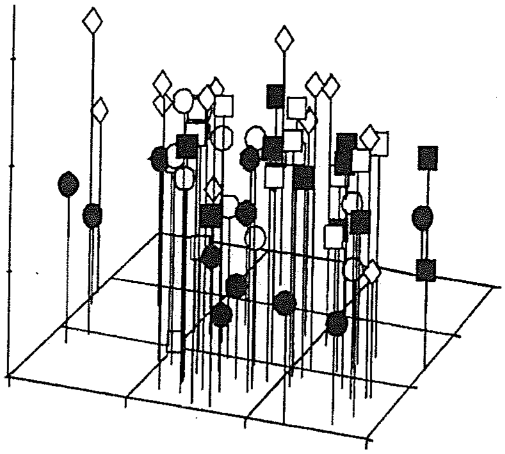


Fig. 3. MDS ordination of core data from the Hahei experimental site. The ordination recorded a stress level of 0.121 (◇) Preliminary samples; (○, ●) Time 1; (□, ■) Time 2. Solid symbols: samples from the dredged plot; open symbols: samples from the reference plot

less clear cut in Opito Bay than at the Hahei site. Only Ostracods and the bivalves *Felaniella zelandica* and *Nucula nitidula* showed consistently lower densities in the dredged plot on both sampling occasions; the polychaete *Polydora* sp. was significantly less abundant in the dredged plot only on the first sampling occasion (Fig. 4). Some taxa, however (i.e. the crustacean *Gynodiastylis laevis*, the polychaetes, *Goniadides* sp. and *Macroclymenella stewartensis*, and the bivalve *Caryocorbula zelandica*), showed a marked increase in density in the dredged plot by the second sampling occasion (Fig. 4). This pattern may result from either preferential settlement into the dredged plot (possibly by *Caryocorbula zelandica* and *Macroclymenella stewartensis*) or colonization by scavenger/predators (e.g. *Goniadides* sp.). As at Hahei, those common taxa exhibiting low and/or variable densities (i.e. the crustacean Phoxocephalid complex, and the polychaete *Prionospio multicristata*) did not show significant differences (Table 5).

Both the total number of individuals and the number of taxa recorded significant site effects (Table 5). The MDS ordination of macrobenthic samples from Opito Bay demonstrate differences in assemblage structure both over time and as a result of dredging (Fig. 5). ANOSIM assessment of differences in the ranked similarity matrix demonstrated an overall difference between factors ($p = 0.002$). Not only are samples from the dredged plot significantly different to those from the reference plot ($p < 0.05$), but samples collected at each time from the reference plot are significantly different from each other ($p < 0.05$) consistant with the strong temporal changes apparent from the univariate analysis at this site.

Table 5. Significance of 2-way ANOVA on common taxa, total number of individuals and number of taxa from the Opito Bay experimental site core samples. Degrees of freedom are as follows: Plot 1; Time 1; Interaction 1; Error 44. Probability values above 0.1 are presented as non-significant (ns)

Taxa	Plot	Time	Interaction
Crustaceans			
Gammaridae	ns	0.0022	ns
*Gynodiastylis laevis**	ns	ns	0.0182
Ostracods	0.001	0.001	0.0211
Phoxocephalid complex*	ns	ns	ns
Molluscs			
Caryocorbula zelandica	0.0743	ns	ns
Felaniella zelandica	0.0037	0.0420	ns
Nucula nitidula	0.0001	ns	ns
Polychaetes			
Euchone sp.	ns	0.0704	ns
Goniadides sp.	ns	ns	0.0417
Macroclymenella stewartensis	0.0437	0.0162	0.0104
Polydora sp.	ns	ns	0.0652
Prionospio multicristata	ns	ns	ns
Nemerteans*	ns	ns	0.0023
Total no. of individuals	0.0566	ns	0.0873
Total no. of taxa	0.0040	0.0407	ns

*ANOVA based on ranks

DISCUSSION

This experiment has demonstrated that macrobenthic community structure in dredged areas differed from undredged areas for at least 3 mo at each study site. At both sites significant differences in community structure and in the densities of common macrofaunal taxa were apparent immediately after dredging. At both sites over 50% of the common taxa showed significant plot effects and/or plot × time interaction effects. The initial responses were all negative, with lower densities in the dredged plot than in the adjacent reference plot. The responses noted 3 mo later were more complex, with differences between the 2 sites. Effects were more pronounced and more often negative at the site that was not commercially exploited (Hahei). Multivariate analysis of community composition also demonstrated differences in assemblage composition between dredged and reference plots at both sites over the course of the study. Differences in the recovery processes at the 2 sites are likely to relate to differences in the initial community composition and to differing environmental characteristics.

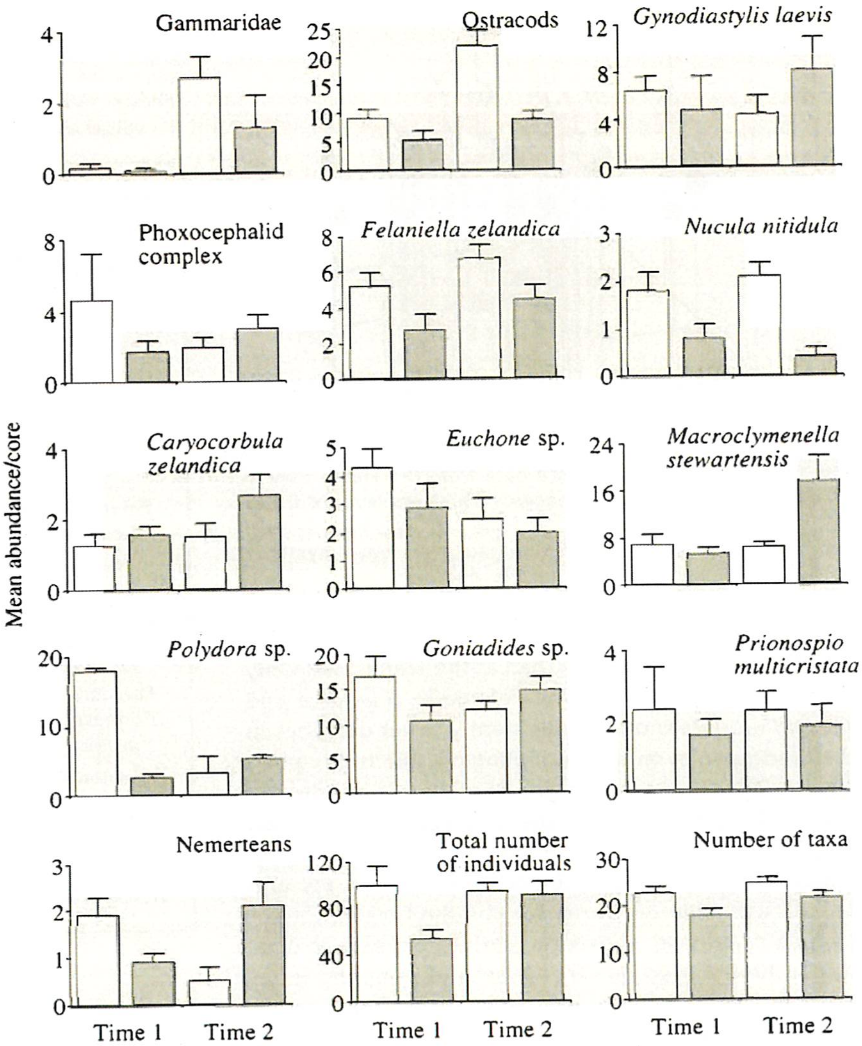


Fig. 4. Mean density (± SE) of common taxa, total number of individuals, number of taxa collected in core samples from dredged (shaded) and reference (unshaded) plots at Opito Bay

As only 1 dredged and 1 reference plot were studied at each site, it is possible that the observed responses were purely location effects (see Underwood 1989 for further discussion of this problem). However, if this was the case we would expect the analysis of preliminary data collected from each site prior to experimental dredging to have suggested significant differences in the density of common taxa between the 2 plots. This was not so and in view of the size (about 700 m^2 each), proximity and similar physical characteristics of the plots, as well as the types of observed response of the macrofauna, we consider such a location effect to be unlikely.

Our experimental assessment of the short-term effects of scallop dredging on macrobenthic communities was quite conservative. Commercial fishers work over much larger areas and repeatedly dredge the same region of the seabed on any one fishing trip,

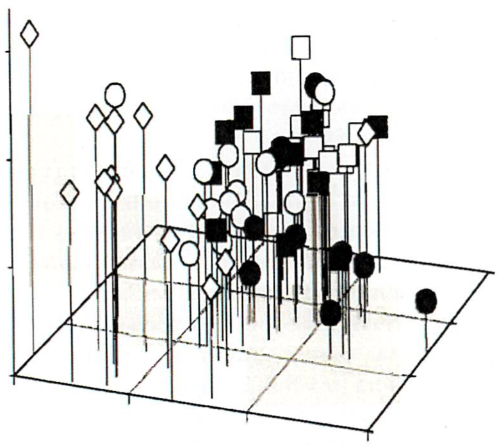


Fig. 5. MDS ordination of core data from the Opito Bay experimental site. The ordination recorded a stress level of 0.138. (◇) Preliminary samples; (○, ●) Time 1; (□, ■) Time 2. Solid symbols: samples from the dredged plot; open symbols: samples from the reference plot

hence resulting in a far higher level of bottom disturbance than that used in our experiment. Furthermore, the macrobenthic communities resident at the experimental sites were composed almost entirely of small, short lived species. Effects on these animals are likely through modifications to their habitat, exposure to predators, and resuspension and subsequent transport in the water column. Only a small proportion are expected to be directly crushed and none removed as by-catch. In many other habitats, extensive and repeated fishing disturbance will remove large and long-lived surface and near surface dwelling sedentary organisms (Sainsbury 1988, Rice et al. 1989, Bergman & Hup 1992, Eleftheriou & Robertson 1992, Dayton et al. in press.) and select for species with a facultative response to disturbance, with communities becoming dominated by juvenile stages, mobile and rapid colonist species. In our 2 study sites the communities were already dominated by small and short-lived species, due to either natural environmental conditions or fishing pressure, and are therefore less likely to show effects than other community types. Larger organisms, particularly starfish, which could not be quantitatively sampled in our experiment, were collected in the by-catch. That the effects on small sediment dwelling animals lasted 3 mo reflects the strength of the benthic community response to this kind of disturbance.

Other experiments on benthic communities have also demonstrated negative effects of habitat disturbance by fishing (Meyer et al. 1981, Peterson et al. 1987, Bergman & Hup 1992, Eleftheriou & Robertson 1992). Modifications to sediment texture and microbial activity (e.g. Churchill 1989, Mayer et al. 1991), or the resuspension of contaminants and increases in benthic/pelagic nutrient fluxes (e.g. Krost 1990) have also been demonstrated. However, fishing effects on macrofaunal communities are not always apparent. Brylinsky et al. (1994) found no significant effects on intertidal macrofauna after flounder trawling, even though physical conditions were visibly impacted for 2 to 7 mo. The lack of significant effects was attributed to the predominance of subsurface feeding polychaetes and the naturally high levels of storm and ice disturbance in the habitat. In addition the power to detect significant effects was not considered by Brylinsky et al. (1994).

While many studies have revealed influences on the structure and function of benthic systems, it is often difficult to assess the generality of their findings and their long-term and large-scale significance. Correlative surveys, feasible over larger spatial and temporal scales, have been used to infer broader changes in the density of long-lived species or the structure of benthic communities (Sainsbury 1988, Hutchings 1990, Langton & Robinson 1990, Witbaard & Klein 1994), but often can not confidently attribute this change to bottom disturbance by fishing activity. The disparity between effects that can be demonstrated by small-scale field experiments and potential larger scale effects is a problem needing to be carefully and explicitly addressed. For example, the removal of large surface dwelling organisms, as well as the homogenisation of sediment characteristics, will reduce the spatial heterogeneity in benthic communities. Heterogeneity is an important component of the function of ecological systems (Kolasa & Pickett 1991, Giller et al. 1994, Legendre 1994), and reductions in heterogeneity over large spatial and temporal scales has implications for the maintenance of diversity and stability at the population, community and ecosystem level (e.g. De Angelis & Waterhouse 1987, Pimm 1991). Theoretical and field based ecological studies of features such as heterogeneity, and processes such as disturbance/recovery can be used to make predictions of potential environmental effects and impacts on the sustainability of fisheries. Such predictions need to take into account the effect of local biotic interactions (e.g. indirect effects on community structure that can occur in response to predator removal; Sih et al. 1985, Kneib 1991) and larger-scale environmental features (e.g. variations in the frequency and intensity of storm disturbance of the seabed; Hall et al. 1990, Brylinsky et al. 1994, Hall 1994) which are likely to influence the identification of any fishing effects. Apart from the influence of physical and biological environmental features, the intensity, frequency and gear used in a particular fishery also needs to be considered in developing hypotheses about potential fishing impacts.

There are a number of approaches that could be taken to provide much needed information on the large-scale changes to natural systems and the sustainable exploitation of resources. Recognition of the possible risks to the environment and the sustainability of resources, through the use of the precautionary principle (Bodansky 1991, Ludwig et al. 1993), by environmental or fisheries managers can, to some extent, overcome the problem of identifying cause and effect relationships over large scales. However, information identifying the degree to which fishing alters marine ecosystems over large spatial and temporal scales will still be useful in providing advice on sustainable exploitation of resources to managers. Adaptive management strategies (Walters & Holling 1990) could be used as the basis of large experiments, to test predictions of ecological effects and gain much needed information on large-scale effects (Hilborn & Walters 1981). Marine protected areas (Agardy 1994) may provide suitable controls against which to assess fishing impacts. But, as well as the need for adequate control and replication, these approaches also require a commitment to the sustained collection of appropriate data to identify ecological changes, as currently little information is available to specify appropriate time scales over which to assess change. The most straightforward and readily applicable approach is to conduct surveys over appropriately large scales to test *a priori* predictions gained from theoretical and small-scale field studies. A variety of design and analytical techniques exist that not only enable differences in abundance to be identified from survey data but also indicate why such differences exist (Eberhardt & Thomas 1991, Legendre 1994).

The experiment presented here described short-term changes in macrobenthic community structure, associated with bottom disturbance from commercial fishing. As pronounced changes can be identified for a 3 mo period after a single disturbance event in a small area dominated by small and short-lived species, there is the potential for much longer lasting changes to ecosystem structure and function as a result of commercial fishing practices. However, assessing possible large-scale changes is difficult and predicting their effect on ecosystem function and sustainability of fish resources is even more problematic. If studies such as this are integrated with large-scale surveys, designed to test appropriately constrained predictions concerning differences in habitat heterogeneity, biodiversity, life history characteristics of resident species, densities of epifauna and effects on harvestable species, this should provide a practical mechanism to assess the large-scale consequences of fishing within marine ecosystems (Eberhardt & Thomas 1991). This approach should be particularly effective in providing an appropriate balance between confidence in results and the generality of the findings.

Acknowledgements. We thank Rod Budd, Peter Carter, Rex George, Helen Neil, Rick Thorpe, Theo Stephens, Kerry Hogan, Craig Meiklen and John Nagels for their help with the field work and Richard Ford, Helen Neil, Susan Hasler and Delwyn Hudson for their help with sample processing. We also thank Theo Stephens, Martin Cryer, Rick Pridmore and 3 anonymous reviewers for comments on earlier drafts. Fieldwork was funded by DoC (3.12/518), while manuscript preparation was funded by FRST (CO 1429).

LITERATURE CITED

Agardy MT (1994) Advances in marine conservation: the role of marine protected areas. TREE 9:267–270
Aronson RB (1990) Onshore-offshore patterns of human fishing activity. Palaios 5:88–93
Bergman MJN, Hup M (1992) Direct effects of beam trawling in macrofauna in a sandy sediment in the southern North Sea. ICES J mar Sci 49:5–11
Bodansky D (1991) Law: scientific uncertainty and the precautionary principle. Environment 33:43–44
Bray JR, Curtis JT (1957) An ordination of the upland forest communities of Southern Wisconsin. Ecol Monogr 27: 325–349
Brylinsky M, Gibson J, Gordon DC Jr (1994) Impacts of flounder trawls on the intertidal habitat and community of the Minas Basin, Bay of Fundy. Can J Fish Aquat Sci 51: 650–661
Churchill JH (1989) The effect of commercial trawling on sediment resuspension and transport over the middle Atlantic Bight Continental Shelf. Cont Shelf Res 9:841–864
Clarke KR (1993) Non-parametric multivariate analyses of changes in community structure. Aust J Ecol 18:117–143
Clarke KR, Green RH (1988) Statistical design and analysis for a 'biological effects' study. Mar Ecol Prog Ser 46: 213–226
Conover WJ, Iman RL (1981) Rank transformations as a bridge between parametric and nonparametric statistics. Am Stat 35:124–133
Dayton PK, Thrush SF, Agardy MT, Hofman RJ (in press) Environmental effects of fishing. Aquat Conserv 5
De Angelis DL, Waterhouse JC (1987) Equilibrium and non-equilibrium concepts in ecological models Ecol Monogr 57:1–21
de Groot SJ (1984) The impact of bottom trawling on benthic fauna of the North Sea. Ocean Mgmt 9:177–190
Eberhardt LL, Thomas JM (1991) Designing environmental field studies. Ecol Monogr 61:53–73
Eleftheriou A, Robertson MR (1992) The effects of experimental scallop dredging on the fauna and physical environment of a shallow sandy community. Neth J Sea Res 30: 289–299
Fairweather PG (1991) Statistical power and design requirements for environmental monitoring. Aust J mar Freshwat Res 42:555–567
Folk RL (1968) Petrology of sedimentary rocks. Hemphilis, Austin, TX
Giller PS, Hildrew AG, Raffaelli D (1994) Aquatic ecology: scale, pattern and process. Blackwell Scientific, Oxford
Green RH (1979) Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York
Hall SJ (1994) Physical disturbance and marine benthic communities: life in unconsolidated sediments. Oceanogr Mar Biol Ann Rev 32:179–239
Hall SJ, Basford DJ, Robertson MR (1990) The impacts of hydraulic dredging for razor clams *Ensis* sp. on an infaunal community. Neth J Sea Res 27:119–125
Hilborn R, Walters CJ (1981) Pitfalls of environmental baseline and process studies. Env Impact Ass Rev 2:265–278
Holme NA (1983) Fluctuations in the benthos of the western Channel. Oceanologica Acta, Proc 17th European Marine Biological Symposium, p 121–124
Hutchings P (1990) Review of the effects of trawling on macrobenthic epifaunal communities. Aust J mar Freshwat Res 41:111–120
Jones JB (1992) Environmental impact of trawling on the seabed: a review. NZ J mar Freshwat Res 26:59–67
Kolasa J, Pickett STA (1991) Ecological heterogeneity. Springer-Verlag, New York
Kneib RT (1991) Indirect effects in experimental studies of marine soft-sediment communities. Am Zool 31:874–885
Krost P (1990) The impact of otter-trawl fishery on nutrient release from the sediment and macrofauna of Kieler Bucht (Western Baltic). Ber Inst Meeresk 200
Kruskal JB, Wish M (1978) Multidimentional scaling. Sage Publications, Beverley Hills, CA

Langton RW, Robinson WE (1990) Faunal association on scallop grounds in the western Gulf of Maine. J exp mar Biol Ecol 144:157-171
Legendre P (1994) Spatial autocorrelation: trouble or new paradigm? Ecology 74:1659-1673
Ludwig D, Hilborn R, Walters C (1993) Uncertainty, resource exploitation, and conservation: lessons from history. Science 260 (2):17-36
Mayer LM, Schick DF, Findlay RH, Rice DL (1991) Effects of commercial dragging on sedimentary organic matter. Mar environ Res 31:249-261
Messieh SN, Rowell TW, Peer DL, Cranford PJ (1991) The effects of trawling, dredging, and ocean dumping on the Eastern Canadian Continental Shelf seabed. Cont Shelf Res 11:1237-1263
Meyer TL, Cooper RA, Pecci KJ (1981) The performance and environmental effects of a hydraulic clam dredge. Mar Fish Rev 43:14-22
McLoughlin RJ, Young PC, Martin RB, Parslow J (1991) The Australian scallop dredge: estimates of catching efficiency and associated indirect fishing mortality. Fish Res 11:1-24
Peterman R, M'Gonigle M (1992) Statistical power analysis and the precautionary principle. Mar Pollut Bull 24:231-234
Peterson CH (1993) Improvement of environmental impact analysis by application of principles derived from manipulative ecology: lessons from coastal marine case histories. Aust J Ecol 18:21-52
Peterson CH, Summerson HC, Fegley SR (1987) Ecological consequences of mechanical harvesting of clams. Fish Bull US 85:281-298
Pimm SL (1991) The balance of nature: ecological issues in the conservation of species and communities. University of Chicago Press, Chicago
Rice MA, Hickox C, Zehra I (1989) Effects of intensive fishing effort on the population structure of Quahogs, *Mercenaria mercenaria* (Linnaeus 1758), in Narragansett Bay. J Shellfish Res 8:345-354
Riesen W, Reise K (1982) Macrobenthos of the subtidal Wadden Sea: revisited after 55 years. Helgoländer Meeresunters 35:409-423
Sainsbury KJ (1988) The ecological basis of multispecies fisheries and management of a demersal fishery in tropical Australia. In: Gulland JA (ed) Fish population dynamics, 2nd edn. Wiley, Chichester, p 349-382
Sih A, Crowley P, McPeek M, Petranka J, Strohmeier K (1985) Predation, competition, and prey communities: a review of field experiments. A Rev Ecol Syst 16:269-311
Stewart-Oaten A, Murdoch WM, Parker KR (1986) Environmental impact assessment: pseudoreplication in time? Ecology 67:929-940
Underwood AJ (1989) The analysis of stress in natural populations. Biol J Linn Soc 37:51-78
Underwood AJ (1992) Beyond BACI: The detection of environmental impact on populations in the real, but variable, world. J exp mar Biol Ecol 161:145-178
Walters CJ, Holling CS (1990) Large-scale management experiments and learning by doing. Ecology 71:2060-2068
Warwick RM (1993) Environmental impact studies on marine communities: pragmatical considerations. Aust J Ecol 18: 63-80
Whitman JD, Sebens KP (1992) Regional variation in fish predation intensity: a historical perspective in the Gulf of Maine. Oecologia 90:305-315
Witbaard R, Klein R (1994) Long-term trends on the effects of the southern North Sea beam trawl fishery on the bivalve mollusc *Arctica islandica* L. (Mollusca, bivalvia). ICES J mar Sci 51:99-105

This article was presented by D. C. Schneider (Senior Editorial Advisor), St. John's, Newfoundland, Canada

Manuscript first received: March 2, 1995
Revised version accepted: June 20, 1995

Vol. 134: 131–150, 1996 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published April 25

Effects of scallop dredging on a soft sediment community: a large-scale experimental study

David R. Currie, Gregory D. Parry*

Victorian Fisheries Research Institute, PO Box 114, Queenscliff, Victoria 3225, Australia

ABSTRACT: Changes to benthic infauna caused by scallop dredging at a site in Port Phillip Bay, southeastern Australia, were examined experimentally using a BACI (before, after, control, impact) design. The experimental dredging was undertaken by commercial fishermen and was typical of normal commercial operations in its spatial extent, intensity and duration. Changes to benthic community structure following dredging were monitored using grab samples taken on 3 occasions pre-dredging and 6 occasions post-dredging. The significance of changes was assessed using ANOVA for the more abundant species and, for pooled groups of species, Bray-Curtis community dissimilarities and multidimensional scaling (MDS). The abundance of 7 of the 10 most common species changed significantly (ANOVA $p < 0.10$) after dredging; 6 species decreased in abundance while 1 species increased. The size and persistence of dredging impacts varied between species, but most species decreased in abundance by 20 to 30%. Dredging impacts became undetectable for most species following their next recruitment. Most species recruited within 6 mo of the dredging impact, but a small number of species still had not recruited after 14 mo. These latter species appeared to cause a persistent change in community structure which was still detectable after 14 mo using Bray-Curtis dissimilarities. MDS ordination indicated that changes to community structure caused by dredging were smaller than those that occur between seasons and years.

KEY WORDS: BACI · Benthic community · Environmental impact · Scallop dredging · Fishing impact

INTRODUCTION

The impact of commercial fishing on the marine environment has been a matter of concern since at least the 14th century (de Groot 1984). Different groups of fishermen have often raised this issue, particularly when they find themselves in competition (de Groot 1984, Jamieson & Campbell 1985, Scarratt 1972, 1975 cited in Messieh et al. 1991). More recently the world-wide increase in environmental awareness has resulted in further concern as ever heavier fishing gear is towed by larger and more powerful vessels (Hall 1994). But few impacts of fishing have been well-documented and biological impacts are particularly difficult to investigate because of the complexity of benthic communities and our limited knowledge of its natural variability (Messieh et al. 1991, Gislason 1994).

*E-mail: g.parry@msl.oz.au

The impacts of trawls and dredges are often considered to be similar as both are towed across the surface sediments where they are likely to damage organisms near the surface. Several studies (Caddy 1973, de Groot 1984) have described changes to the topography of the sea bed caused by fishing gear, and these suggest that fishing gear penetrates 10 to 30 mm into the sediment depending upon the weight of the gear and the softness of the sediments (de Groot 1984). Typically, dredges (Caddy 1973) and to a lesser degree trawl nets (Krost et al. 1990) flatten existing topographic features while trawl doors dig 2·deep furrows up to 30 cm deep (Jones 1992). These topographic changes persist longer in deeper and more sheltered waters less exposed to wave action (de Groot 1984, Thiel & Schriever 1990, Jones 1992).

Where trawls and dredges operate in areas with large amounts of epifauna or epiflora it is clear that they will dislodge or uproot much of this biota (e.g. Hutchings 1990). Trawl nets typically catch much more bycatch than target species and most is returned to the sea dead (Andrew & Pepperell 1992). Fragile epifauna such as razor shells, *Tubularia* beds, and *Sabellaria* reefs in the North Sea have been severely damaged by trawling (de Groot 1984). Sponge and bryozoan communities are also vulnerable to trawling, and changes caused to these communities result in changes to fish communities dependent on these habitats (Bradstock & Gordon 1983, Sainsbury 1988). In contrast shellfish dredging often appears to occur in localities where the target species is the dominant species of epibiota (e.g. Caddy 1973, Butcher et al. 1981), so the proportion of non-target species in the catch is low. But where shellfish dredging occurs at sites with significant amounts of epibiota most will be removed. Dredging reduces seagrass abundance and may cause seagrass habitats to be replaced by unvegetated sand flats (Peterson et al. 1987). Few indirect effects of dredging and trawling have been documented but benthic animals exposed or damaged by fishing attract predators (Arntz & Weber 1970, Caddy 1973), and where large amounts of bycatch are discarded scavenger populations may increase (e.g. Wassenberg & Hill 1990, Britton & Morton 1994).

Unfortunately previous studies of impacts of commercial trawling and dredging are either qualitative (Caddy 1973, Butcher et al. 1981) or involve the disturbance of such small experimental areas (e.g. McShane 1981, Eleftheriou & Robertson 1992) that extrapolating the results to the scale of the commercial fishery is uncertain. Even the largest controlled experimental study of impacts due to shellfish dredging (Peterson et al. 1987) involved simulated dredging ('kicking') of 12 experimental plots only 1225 m^2. In this experimental study changes were measured on a 360000 m^2 plot subject to supervised dredging by commercial scallop vessels. Thus we measured changes to the benthic community caused by dredging on a scale directly relevant to the impact of a commercial fishery.

The expense of sorting and identifying benthic animals has both limited the number of experimental studies of the impact of fishing, and necessitated some compromises in their design. Control sites have often not been sampled (McShane 1981, Bergman & Hup 1992) and sampling intensities are usually low so that only a large impact would be detected (e.g. McShane 1981, Peterson et al. 1987, Eleftheriou & Robertson 1992). In this study much smaller changes were detectable, as the total number of organisms identified in this study (>100000 individuals) was an order of magnitude greater than in previous studies. Even small changes measured at an experimental site may be important if they lead to changes throughout an extensive fished area, especially since tests of low power could lead to an incorrect conclusion of no impact.

The scallop industry in Port Phillip Bay is a valuable commercial fishery in southeastern Australia and has produced up to 2000 t, worth approximately $20 million, annually. Dredging for scallops *Pecten fumatus* in Port Phillip Bay is also widely regarded by the local community as environmentally damaging. Many changes to the ecology of Port Phillip Bay noted by fishermen and others have been attributed (rightly or wrongly) to scallop dredging. In response to these concerns, a series of linked biological and physical studies were initiated in 1991 to provide information on the extent of impacts due to scallop dredging. Experimental studies were undertaken in 3 large areas (30 to 40 km^2) of Port Phillip Bay (Fig. 1) which was closed to all scallop dredging throughout 1991 (see Parry & Currie 1992). Dredging-related changes to the abundance and diversity of benthic animals were examined using a BACI (before, after, control, impact) experimental design (see Stewart-Oaten et al. 1986). This design involves simultaneous sampling of 2 plots (1 'control' and 1 'dredge') on a number of occasions, both before and after experimentally dredging 1 plot. The magnitude and duration of changes to the soft bottom community near St. Leonards (Fig. 1) are described. The expense of this large-scale experiment (see Warwick 1993) meant that at the other 2 study areas, Dromana and Portarlington (Fig. 1), only short-term changes to benthic communities following dredging could be monitored (Currie & Parry unpubl.). The effects of changes to benthic communities on fish communities following dredging were monitored for several months at St. Leonards and for shorter periods at Dromana and Portarlington (Parry & Currie unpubl.). At all 3 areas the effect of dredging on turbidity and sedimentation rates were also monitored (Black & Parry 1994).

METHODS

Study area. The Port Phillip Bay scallop fishery commenced in 1963, and catches and dredging intensity increased dramatically until the fishery collapsed in 1968 (Gwyther & McShane 1988). The total number of hours dredging is now much lower than in the early years of the fishery (Currie & Parry unpubl.), but there are still 84 vessels licensed to dredge for scallops in Port Phillip Bay. Since 1963 all but the shallowest regions of the Bay have been dredged, but with varying intensities. Most scallop dredging occurs in depths between 10 and 20 m, and since 1985 dredging has been illegal in areas shallower than 10 m in the east and shallower than 5 m in the west of the Bay.

The intensity with which different areas of Port Phillip Bay have been dredged historically was calcu-

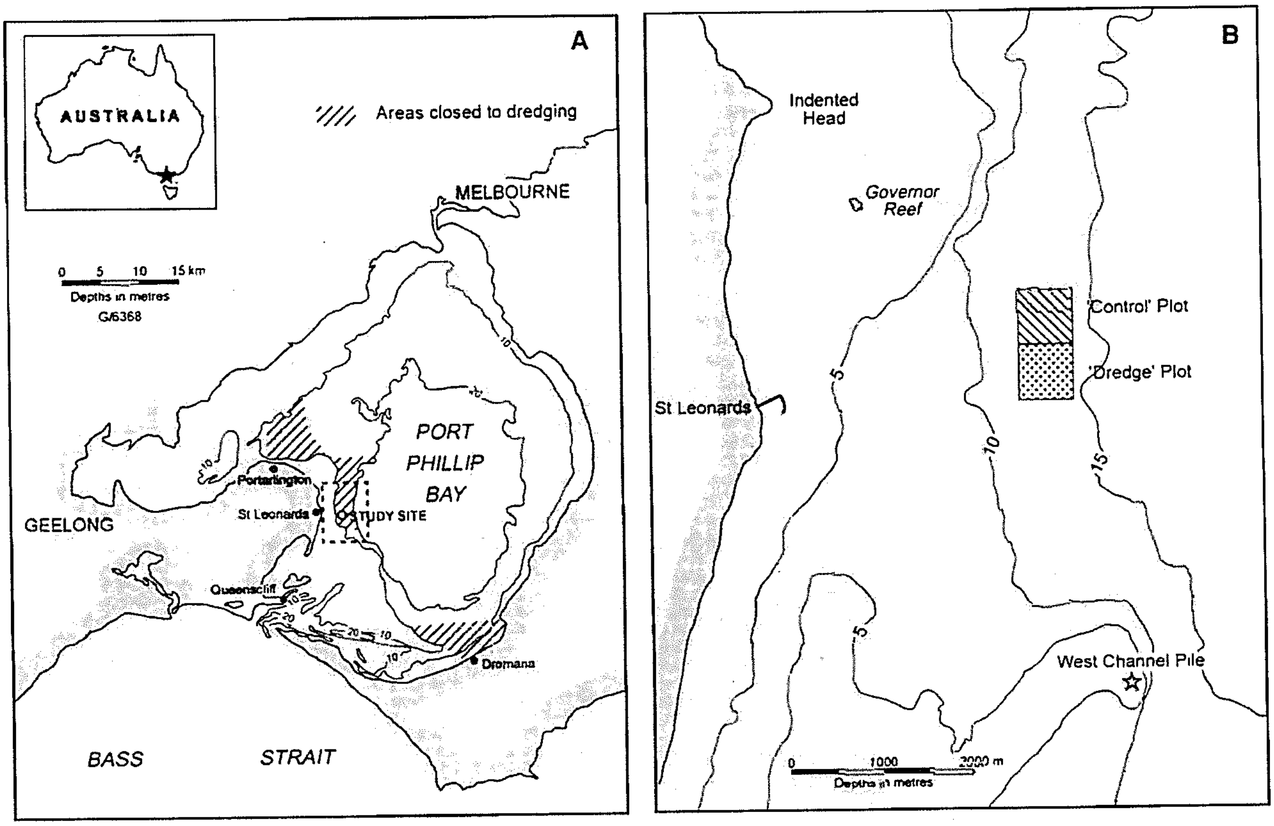


Fig. 1. (A) Location of study site. Hatched areas were closed to all but experimental scallop dredging during this study. Rectangle is fishing sector 43. (B) Location of study plots

lated to determine the appropriate intensity of experimental dredging to use in our study. For the period 1980 to 1990 the annual number of hours fished in each of 70 reporting sectors (each 2 to 44 km^2 in area) was estimated from fishing effort information (hours fished per month per fisherman) provided by fishermen and summarised in the Victorian Fisheries Catch and Effort Database (Australia). The annual intensity of dredging in each sector was estimated from the total fishing time in the sector, the total area deeper than 5 or 10 m that could be dredged legally in the sector, the proportion of fishing time that involved dredging on the sea floor (40 min dredging in 60 min fishing, Gwyther & Parry pers. obs.), the average vessel speed (5 knots) and the dredge width (3.0 m). Within each sector the undredged area, the area passed over once by a dredge (1×, dredging intensity), the area passed over twice by a dredge (2×, dredging intensity), etc. was estimated using a Poisson distribution:

$$\text{Area}(n) = A \times e^{-I} \times I^{n}/n! \quad (1)$$

where Area(n) is the area passed over n times by a dredge, A is the area of the sector, and I is the average intensity with which the sector is dredged.

Estimates for each sector were summed to estimate the total area of Port Phillip Bay dredged with each intensity (Table 1A). These estimates are only approximate and will overestimate the area dredged with low intensity and underestimate the area dredged with high intensity where dredging is concentrated in only part of a sector. The historical intensity of dredging in Sector 43, which included the St. Leonards study area (Fig. 1A), is shown in Table 1B.

Study design and statistical analysis. Typically, commercial scallop vessels in Port Phillip Bay work close together in groups of 5 to 50 vessels. Within each group dredges are dragged in the same direction for 500 to 2000 m before they are emptied and dragged in the opposite direction. Fishermen usually target a region until the catch rate there becomes low and they do not usually return to the same region until the following year. The experimental study was designed to closely duplicate normal fishing practice. A single large plot was dredged because this created an impact similar in scale to that caused by commercial scallop fishermen over a 2 to 3 d period. The large size of the plots also enabled changes to fish populations within the plots to be monitored using a large trawl net (Parry & Currie

Table 1. Percentage of total area dredged with different intensities between 1980 and 1990 in: (A) Port Phillip Bay (area 1920 km^2), which was used to determine appropriate intensity for experimental dredging; and (B) St. Leonards, Sector 43 (Fig. 1, area 44.1 km^2) which documents the historical intensity of dredging in the study area. Dredging intensity is the number of times an area is traversed by a dredge: ×1 = area traversed once by dredge, ×2 = area traversed twice by dredge, etc.

Dredging intensity	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Average 1980–1990	(area km^2)
(A) Port Phillip Bay													
Undredged	80.4	81.9	71.9	80.5	81.3	78.6	89.3	82.4	99.8	100	100	86.0	
×1	14.3	12.0	18.0	14.5	13.4	14.7	9.0	12.7	0.2			9.9	(190)
×2	3.6	3.5	6.6	3.8	3.7	4.0	1.4	3.4				2.7	(52)
×3	1.1	1.4	2.3	0.9	1.0	1.5	0.2	1.0				0.9	(17)
> ×3	0.5	1.1	1.2	0.3	0.4	1.2		0.5				0.5	(10)
Total dredged	19.6	18.1	28.1	19.5	18.7	21.4	10.7	17.6	0.2	0.0	0.0	14.0	(269)
(B) St. Leonards, Sector 43													
Undredged	85.5	90.6	83.9	84.6	90.6	80.7	85.0	75.9	99.8	100	100	88.8	
×1	13.4	9.0	14.8	14.2	8.9	17.3	13.8	20.9	0.2			10.2	
×2	1.1	0.4	1.3	1.2	0.4	1.9	1.1	2.9				0.9	
×3	0.1		0.1	0.1		0.1	0.1	0.3				0.1	
> ×3													
Total dredged	14.5	9.4	16.1	15.4	9.4	19.3	15.0	24.1	0.2	0.0	0.0	11.2	

unpubl.). However, their large sizes made replication of the control plot prohibitively expensive and limited replication of the dredge plots to uncontrolled before-after comparisons at the other experimental sites (Currie & Parry unpubl.). These pragmatic considerations meant that there was only limited spatial replication (Hurlbert 1987, Underwood 1991).

Two adjacent 600 × 600 m experimental plots were located in 12 to 15 m of water, approximately 2 km offshore from St. Leonards. The southern plot was experimentally dredged by commercial vessels ('dredge' plot) and the northern plot was left undredged ('control' plot) (Fig. 1B). The dredge plot was dredged over 3 d (16 to 18 July 1991) by a fleet of 6 commercial scallop vessels, using 3 m wide 'Peninsula' dredges fitted with scraper/cutter bars that did not extend below the level of the skids (see diagram in Hughes 1973). Dredging was conducted for a maximum of only 3 h d^{-1} and coincided with periods in which there was a strong southerly tidal current that carried dredging-related sediment away from the adjacent control site. Dredging was continued until the entire plot had, on average, been passed over twice by a scallop dredge. This intensity of dredging (2×; Table 1A) was consistent with a moderately high fishing intensity based on historical levels in Port Phillip Bay. During the 1980s an average of 52 km^2 of Port Phillip Bay was dredged with this intensity annually, and the maximum area dredged with this intensity was 127 km^2 in 1982 (Table 1A). A lower level of dredging would also have made detection of impacts more difficult as much of the 'dredged' plot would have remained undredged. At the 2× dredging intensity used in this experiment it was estimated, using Eq. (1), that 13% of the plot remained undredged.

On the first morning of the experimental dredging the plot to be dredged was marked with 4 equidistant buoys along each side of the 600 × 600 m plot using a Furuno GP 500 GPS Navigator connected to a colour video plotter. This GPS provides an accuracy of 15 to 25 m in 95% of fixes. Where inaccuracy exceeded 25 m due to intentional degradation of the system (selective availability) this was obvious on the plotter. The buoys marked out three 200 × 600 m lanes directed east-west. Scallop vessels dredged these lanes sequentially and fishermen were encouraged to dredge the whole area as evenly as possible. On the second and third days of dredging the buoys marking the lane boundaries were moved 50 m north and south of their initial positions to minimise any undredged 'shadows' resulting from vessels not dredging near buoys.

To assess visually apparent changes caused by dredging, diver-operated video recordings were taken of the sea bed on both plots 3 mo before dredging (11 April 1991), 8 d after dredging (25 July 1991), 6 mo after dredging (23 January 1992) and 11 mo after dredging (19 June 1992).

The depth of bed sediment disturbed by dredges was determined using 32 sets of colour-coded 'depth rings', which were inserted 20, 40, 60 and 80 mm into the sediment within the dredge plot before dredging commenced. During the experimental dredging observers on each vessel identified each ring and therefore were able to determine the depth from which it was collected (Black & Parry 1994).

The vertical distribution of the fauna in the sediment was sampled on the control plot on 11 April 1994 by divers using four 120 mm diameter cores. Cores were taken haphazardly within a 50 × 50 m area and separated into 3 strata: surface to 5 cm, 5 to 10 cm, and 10 to 20 cm, and the number of animals in each stratum was counted.

To determine the abundance and size of callianassid mounds, divers counted and measured the height of all mounds in two 50 × 1 m transects on the control plot on 16 August 1992. A ruler was inserted into each mound to determine its height.

To determine how selectively benthic organisms were dislodged from the sediment by dredging, a specially designed 'plankton' net (1 mm mesh, 300 mm mouth diameter, 900 mm length) was attached to the upper rear section of a scallop dredge to sample animals thrown up in the sediment plume during the experimental dredging. A net sample was collected approximately every 10th drag for the first 2 d of dredging. The 5 net samples collected were subdivided using a plankton splitter and all organisms in $\frac{1}{16}$ to $\frac{1}{4}$ of a sample were identified and counted. For the 30 most common species differences between their relative abundance in the net and their relative abundance in the benthos immediately before dredging (2 July 1991) were tested using a χ^2 test. The significance of progressive changes in species composition in the net during the dredging was determined for the 10 most common species from regressions of relative abundance versus time from the commencement of dredging (see Fig. 3).

The distribution and abundance of infauna at each plot were determined from replicate 0.1 m^2 Smith-McIntyre grab samples. Fifteen samples were taken from each plot on 3 sampling dates before and 6 after the experimental dredging (i.e. a total of 270 grabs). Samples were taken 3 mo before dredging (8 April 1991), 2 mo before dredging (13 May 1991), 2 wk before dredging (2 July 1991), immediately after dredging (18 July 1991), 3 wk after dredging (9 August 1991), 3.5 mo after dredging (31 October 1991), 5 mo after dredging (16 December 1991), 8 mo after dredging (25 March 1992), and 14 mo after dredging (23 September 1992). Plots were sampled using a mixture of stratified random and random sampling. Each plot was subdivided into 12 equal sectors and one grab was taken at random from within each sector and the remaining 3 grab samples were taken at random across the plot. Samples were drained, weighed and a 70 ml subsample retained for sediment analysis. All animals retained on a 1.0 mm sieve were sorted to the lowest practical taxonomic level (generally species) under a dissecting microscope before being counted.

Changes to benthic communities following dredging were assessed using Bray-Curtis (B-C) dissimilarity measures (Bray & Curtis 1957) and multidimensional scaling (MDS). Analysis of variance (ANOVA) was used to determine the significance of changes to the more common species following dredging. ANOVA was also used to determine whether there were any common features to species which were impacted by dredging. The significance of changes to the abundance of species groupings based on their taxonomic affinity, feeding type, depth of occurrence in the substrate, and rarity were all tested. The percentage change experienced by different species and species groupings following dredging was also documented to determine the extent to which they were impacted by dredging.

Differences between the control and dredge plots on each sampling date were examined using B-C dissimilarity measures. This measure was chosen because it is not affected by joint absences, it gives more weighting to abundant than rare species, and it has consistently performed well in preserving 'ecological distance' in a variety of simulations on different types of data (Field et al. 1982, Faith et al. 1987). For each sampling date, data from the 15 replicate grabs on each plot were pooled giving the total number of individuals found on that plot. Before calculating the B-C dissimilarity measures, square root, double square root, and presence/absence transformations were applied to the number of individuals of each species. These progressively more severe transformations prevent abundant species from influencing the B-C dissimilarity excessively (e.g. Clarke & Green 1988, Clarke 1993). For each transformation, 9 pairwise B-C dissimilarity measures comprising all control plot versus dredge plot comparisons for the 9 sampling dates (3 pre-dredging and 6 post-dredging) were used in the BACI analysis as proposed by Faith et al. (1991). To estimate the duration of the impact, *t*-tests were calculated using all pre-dredging dissimilarity measures and with progressively 3, 4, 5, and 6 post-dredging dissimilarity measures.

Temporal and dredging-related changes on the study plots were mapped using MDS. MDS plots a measure of similarity between objects into 2 or more dimensional space so that distances between objects correspond closely to their input similarities. While the computational algorithm for MDS is complex, the graphical representation is easily communicated (Clarke 1993), and ecologically meaningful patterns become more apparent (Gamito & Raffaelli 1992). The PATN computer package (Belbin 1990) was employed for the non-metric MDS ordinations used in this study. MDS plots were calculated using the triangular matrix of dissimilarities generated from B-C dissimilarity measures calculated for all 18 plot × date combinations (2 plots × 9 dates), using double square root transformed data.

Marked differences between communities on the eastern and western halves of the experimental plots were found. Consequently separate MDS plots were also calculated using B-C dissimilarities based on the double square root of the total number of individuals of each species found on each half of the plots for the 9 dates sampled. MDS plots were also used to summarise differences between both halves of the plots. Following double square root transformations of all abundance data, B-C dissimilarities of all grab samples taken on the east and west of the control plot were incorporated into an MDS plot, as were the B-C dissimilarities of all grab samples taken on the east and west of the control and dredge plots in the pre-dredging period.

For the 10 most abundant species, differences between the number of individuals found on each plot (and each half plot) before and after dredging were examined using a BACI experimental design (see Stewart-Oaten et al. 1986). Statistical significance of the dredging impact was tested using nested analysis of variance (ANOVA) in which plot × time interactions were tested against the mean square for the plot × date(time) term. This test is equivalent (Underwood 1991, his Table 2c) to the *t*-test recommended by Stewart-Oaten et al. (1986). An additional analysis, similar to that described in Underwood (1991), but including a sediment covariate (% sediment <63 µm), was undertaken for those species for which this covariate was significant, after a preliminary ANOVA demonstrated that dredging caused no significant change to sediment type on the plots ($p = 0.75$ for plot × time interaction). Homogeneity of variance was examined using Cochran's test and heterogeneity removed by $\log_{10}(n+1)$ and $1/(n+1)$ transformations. To provide an objective test of the persistence of dredging impacts ANOVAs were performed progressively with 3, 4, 5, and 6 post-impact sampling dates.

To determine whether different categories of species were more or less vulnerable to dredging, species were grouped by taxonomic affinity, feeding type, their proximity to the sediment surface and their rarity. ANOVAs of these different groupings were undertaken using data for the entire plots and 3 post-dredging dates. Three post-dredging dates were included as fewer dates had less power, and more dates provided too much time for recovery. A sediment covariate (% sediment <63 µm) was included in the statistical model, although in most cases inclusion of this variable had a minimal effect on significance levels. Cochran's test was used to ensure that a $\log_{10}(n+1)$ transformation removed significant heterogeneity from variances of all species groups, but it was necessary to exclude 2 very contagiously distributed species, the bivalve *Theora* cf. *lubrica* (Sp. rank 17) and the scavenging ostracod *Empoulsenia* sp. 1 (Sp. rank 27) from these analyses.

Species were grouped by phylum and class to test for any influence of taxonomic affinity. Species were also divided into 4 feeding types: deposit feeders, predators, scavengers and suspension feeders. Feeding categories of molluscs were based on Poore & Rainer (1974), while feeding categories of other taxa were slightly modified from those used by Wilson et al. (1993), which were themselves based on Brusca & Brusca (1990) and Fauchald & Jumars (1979). There were no direct data on the microdistribution of species in the top 5 cm of surface sediments most disturbed by dredges (Black & Parry 1994); consequently, depth-related groupings were based on the degree to which 27 of the 30 most common species were over- or under-represented in net samples taken in the dredge plume. Three species of mysids found amongst these 30 species were not included in this analysis as they do not occur in the sediment. Four categories of 'depth within the sediment' were based on ratios of relative abundance of species netted in the dredge plume versus their abundance in the benthos: ratio >1.0 = surface layer; 0.5 < ratio < 1.0 = near surface layer; 0.1 < ratio < 0.5 = below surface; and ratio < 0.1 = well below surface layer. To assess whether rare and abundant taxa were impacted similarly, all species were ranked by their abundance during the 17 mo of the study and grouped into 5 abundance classes: Sp. 1–10, Sp. 11–20, Sp. 21–30, Sp. 31–50, Sp. 51–247.

As a final step, where there was no significant change in abundance of individual species or a group of species, 2 power values were calculated, the first to detect a decrease (or increase) of 30% and the second to detect a decrease of 50% following dredging. These power values were calculated using the *t*-test equivalent of the ANOVA method used elsewhere in this paper. Thus no provision was made for the inclusion of the sediment covariate in these power calculations.

Estimates of the percentage change in the abundance of individual species and of different species groupings were calculated using the 3 pre-dredging samplings and the first 3 post-dredging samplings. Percentage change was estimated from the difference between ratios of the sum of individuals on plots before and after dredging:

$$\%\ \text{Difference} = [(n_{da} - n_{ca}/n_{ca}) - (n_{db} - n_{cb}/n_{cb})] \times 100$$

where n is the sum of the number of individuals in the 3 sampling times either before or after dredging, and the subscripts are as follows: c is control plot; d is dredge plot; a is after dredging; b is before dredging.

Conventionally the null hypothesis is rejected (a result is considered 'statistically significant') if the probability of the null hypothesis being true is less than 1 in 20 ($p < 0.05$). In this study a result is considered 'significant' if $p < 0.10$. This convention was adopted because in this study the cost of making a Type II error was considered as important as making a Type I error. Failure to detect a real change due to dredging (Type II error) was considered as serious a problem as identifying a change due to dredging when none had occurred (Type I error) (Cohen 1988, Peterman 1990, Peterson 1993).

RESULTS

Physical changes to sea floor

Before the experimental dredging, bedforms within the control and dredge plots were dominated by low-relief mounds and depressions formed by callianassids. The cone shaped mounds of sediment excavated by these shrimps were up to 100 mm high and 230 mm in diameter, but averaged 42 mm in height, 152 mm in diameter and had an average density of 1.2 m^{-2} (Table 2). Adjacent pits and depressions often trapped detached seagrasses and algae. Epifauna was sparse and dominated by 40 to 80 mm scallops.

Observations made 8 d after the experimental dredging indicated that only the dredge plot had changed markedly. Most of the sea floor within the dredge plot was very flat. Dredges had a grader-like impact, callianassid mounds were removed and depressions filled, but most callianassids appeared to have survived. There were many callianassid mounds being rebuilt (cf. Peterson 1977) and the density of callianassids taken in grabs on the dredge plot did not change significantly in the 3 mo following dredging. The density of *Callianassa arenosa* was 0.13 (±0.05 SE) before and 0.11 (±0.05 SE) in the 3.5 mo after dredging and the density of *Upogebia dromana* was 0.09 (±0.07 SE) and 0.02 (±0.02 SE) after dredging. Narrow undredged strips occupied approximately 10% of the area of the dredge plot. Parallel tracks from dredge skids (up to 25 mm deep) were observed throughout the flattened regions of the plot and drifting seaweed was no longer apparent. The number of large scallops within the dredge plot was reduced although small scallops remained plentiful. Small numbers of the ascidian *Pyura stolonifera* were observed on the surface of the sediments where they had been discarded from dredges and a small number of dead pebble crabs *Philyra undecimspinosa* were found.

One month after the experimental dredging, the sea floor within the dredged plot remained flat, and dredge tracks could still be distinguished. Six months after dredging, dredge tracks were no longer visible, and callianassid mounds were abundant and appeared similar in size to those which had been present before dredging. Depressions had reformed throughout the plot and now contained scallops and detached weed. However, while the dredged plot resembled its pre-dredging appearance, flat areas were still visible between adjacent mounds and pits. Eleven months after dredging, the callianassid mounds appeared similar on the control and dredge plots and any differences in topography between the plots were no longer distinguishable by a diver.

Colour-coded depth rings recovered by dredges indicated that dredges typically disturbed the top 20 mm of sediment but could penetrate up to 60 mm into the sediments (see Black & Parry 1994 for details).

Depth distribution of infauna prior to dredging

Most (68%) organisms occurred in the top 5 cm of sediment, a further 22% occurred at a depth of between 5 to 10 cm, and only 9% occurred in sediments deeper than 10 cm (Table 3).

Infauna dredged from sediments

Comparison of the relative abundance of species netted in the sediment plume with their relative abundance in the benthos immediately before dredging (2 July 1991) indicated that many species were netted significantly [$\chi^2(28) = 14646$, $p \ll 0.01$] more or less frequently than expected (Fig. 2). Ratios of the relative abundance of each taxon in the net compared to its relative abun-

Table 2. Density and size of callianassid mounds on two 50 × 1 m transects on the control plot on 16 August 1992

Transect	Density (no. m^{-2})	Mean height (mm)	Mean diameter (mm)
1	1.00	33	169
2	1.43	51	135
Mean	1.22	42	152

Table 3. Number of organisms in different depth strata of sediment cores taken within a 2500 m^2 area on the control plot at St. Leonards on 11 April 1994

Depth stratum (mm)	Core A	B	C	D	Total
Top 50	24	6	21	38	89 (68%)
50–100	3	12	6	8	29 (22%)
100–200	1	4	1	6	12 (9%)
Total	28	22	28	52	130

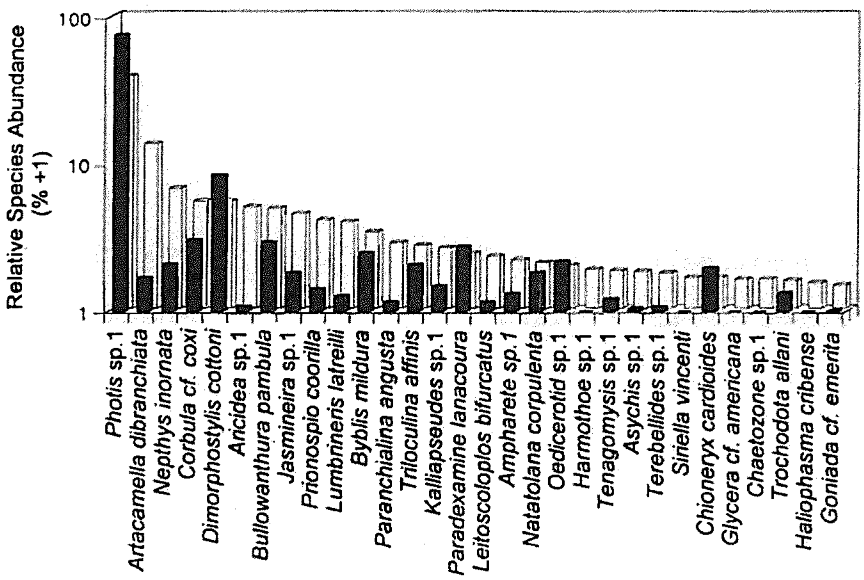


Fig. 2. Relative abundances of the 30 most abundant species taken in a net in the dredge plume (black) and in the benthos immediately before the experimental dredging (white). To enable use of a logarithmic scale, 1 was added to all percentages

dance in the benthos (Fig. 2) were used to subdivide species into 4 categories: 'over-represented' (ratio > 1.0), 'probably over-represented' (0.5 < ratio < 1.0), 'probably under-represented' (0.1 < ratio < 0.5) and 'under-represented' (ratio < 0.1). *Photis* sp. 1, *Dimorphostylis cottoni*, *Paradexamine lanacoura*, *Oedicerotid* sp. 1, *and Chioneryx cardioides* were 'over-represented' in the net; *Bullowanthura pambula*, *Byblis mildura*, *Triloculina affinis*, *Natatolana corpulenta* and *Trochodota allani* were 'probably over-represented', whereas *Nephtys inornata*, *Corbula* cf. *coxi*, *Jasminiera* sp. 1, *Prionospio coorilla*, *Kalliapseudes* sp. 1, *Leitoscolopolos bifurcatus*, *Ampharete* sp. 1, *Tenagomysis* sp. 1 and *Terebellides* sp. 1 were 'probably under-represented'; *Artacamella dibranchiata*, *Aricidea* sp. 1, *Lumbrinereis* cf. *latreilli*, *Paranchialina angusta*, *Harmothoe* sp. 1, *Asychis* sp. 1, *Siriella vincenti*, *Glycera cf. americana*, *Chaetozone* sp. 1, *Haliophasma cribense* and *Goniada* cf. *emerita* were 'under-represented'. The relative abundance of 5 of the 10 most common species caught in the net changed significantly during the first 2 d (5 h) dredging (Fig. 3). *Photis* sp. 1 was significantly more abundant during the early drags whereas in late drags *A. dibranchiata*, *B. pambula*, *Jasminiera* sp. 1 and *N. inornata* became significantly more abundant (Fig. 3).

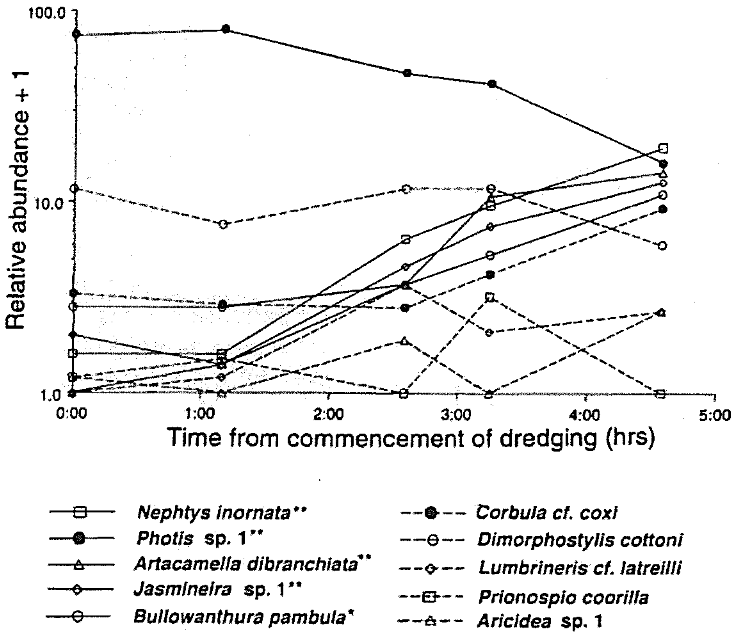


Fig. 3. Relative abundances of the 10 most abundant species taken in a net in the dredge plume at different times during experimental dredging. Species whose relative abundance changed significantly during dredging are indicated: *p < 0.10, **p < 0.05

Photis sp. 1, a tube-building amphipod, and *Dimorphostylis cottoni*, a cumacean, both occur in the surface sediments and were 'over-represented' in net samples (Fig. 2) particularly during the early drags (Fig. 3). Other species which appeared to be 'over-represented' in net samples were 3 amphipods *Byblis mildura*, *Paradexamine lanacoura*, *Oedicerotid* sp. 1, an isopod *Natatolana corpulenta*, a holothurian *Trochodota allani*, a foram *Triloculina affinis*, a bivalve *Chioneryx cardoides*, and a paranthurid isopod *Bullowanthura pambula* (Fig. 2). The first 4 of these are actively swimming crustaceans likely to occur in the surface sediments, while *T. allani* is frequently found adhering to divers' wet suits, indicating that this species too is abundant in the surface sediments. The foram *T. affinis* probably occurs in surface sediments but the distributions of *C. cardoides* and *B. pambula* are unknown. Species which appeared to be 'under-represented' in net samples were predominantly polychaetes (14 spp.) most of which occur in burrows: 3 were mysids, *Tenagomysis* sp. 1, *Paranchialina angusta*, and *Siriella vincenti*, and the remaining species were a tanaid, *Kalliapseudes* sp. 1, an anthurid isopod, *Haliophasma cribense*, and a bivalve, *Corbula cf. coxi*. The burrowing polychaetes *Artacamella dibranchiata*, *Nephtys inornata*, *Aricidea* sp. 1, *Jasmineira* sp. 1, and *Lumbnrinereis* cf. *latreilli* were all more abundant in late drags (Fig. 3); these burrowing species appear to become progressively more vulnerable as the surface sediments are removed. Mysids do not occur in the sediment and may be able to avoid the net. The depth distributions of the isopods and the bivalve which appeared to be under-represented are unknown.

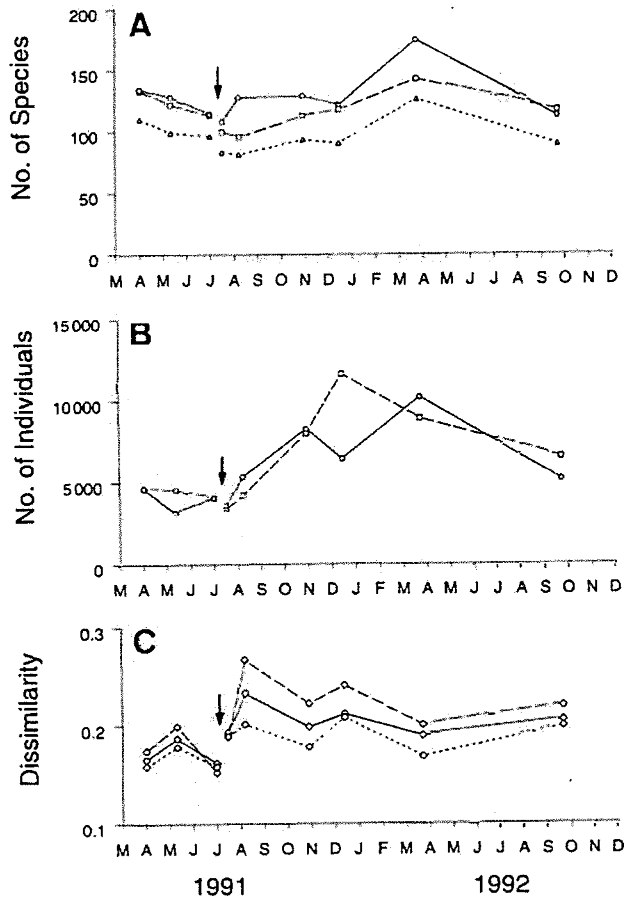


Fig. 4. Differences between control and dredge plots before and after dredging. (A) Changes in number of species on (o) control plot, (□) dredge plot, (Δ) both plots; (B) changes in number of individuals on (o) control plot, (□) dredge plot; (C) Bray-Curtis dissimilarity between plots, using the following transformations: (— —) presence/absence; (——) double square root; (-----) square root. Arrows indicate time of dredging

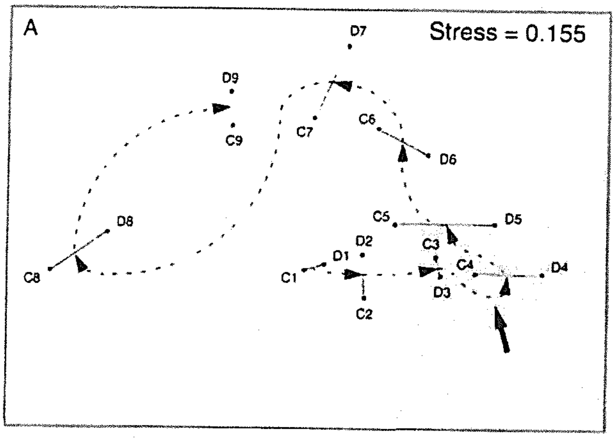
Changes to benthic community structure

A total of 247 invertebrate species (see Currie & Parry 1994 for a species list) and 107 518 individuals were collected at the 2 St. Leonards plots during this study. There were 99 (40%) crustaceans collected, 60 (24%) polychaetes, 46 (19%) molluscs, and 42 (17%) members of other phyla. The amphipod *Photis* sp. 1 was the most abundant species and contributed 22% of the animals collected.

Before the experimental dredging, the numbers of species on the control and dredge plots were very similar (Fig. 4A; 135 vs 134 on 8 April 1991, 128 vs 122 on 13 May 1991, and 115 vs 114 on 2 July 1991), but following the experimental dredging there was a significant decrease in the number of species on the dredge plot which persisted for 14 mo (non-independent ANOVAs including 3, 4, 5, and 6 post-dredging sampling dates, $0.03 < p < 0.08$). After 14 mo the number of species on the dredge plot slightly exceeded the number on the control plot (Fig. 4A), but the number of species shared between both plots (Fig. 4A) was reduced following dredging (111, 100 and 97 species before vs 84, 82, 94, 91, 129 and 90 species after dredging). Over the period of the study a total of 60 species were always found on the control plot, while only 53 were always found on the dredge plot.

The total number of individuals of all species sampled at both plots remained relatively constant before dredging, although there were slightly fewer animals collected on the control plot 2 mo before dredging (Fig. 4B). The number of individuals on both plots more than doubled in the 5 to 8 mo following the experimental dredging and then decreased again over the following 6 to 9 mo. The increases in abundance following dredging are largely the result of recruitment of juveniles, particularly *Photis* sp. 1 and *Jasmineira* sp. 1. Differences between the total number of individuals on the control and dredge plots did not change significantly in the 3.5 mo following dredging or thereafter (ANOVAs, $\log(n_c - n_d)$ for 3 pre-dredging and 3, 4, 5, and 6 post-dredging dates, $p > 0.10$).

B-C dissimilarities calculated using 3 different data transformations (square root, double square root and presence/absence; Fig. 4C) all increased significantly following experimental dredging and persisted for 14 mo, the duration of the study (ANOVAs including 3, 4, 5, and 6 post-dredging sampling dates, $0.007 < p < 0.03$). In the post-dredging period, except with the square root data transformation, the 2 plots were most different 3 wk after dredging (Fig. 4C).



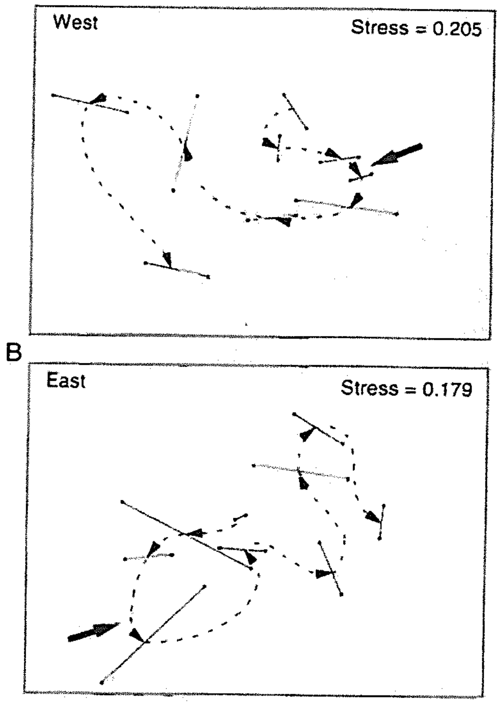


Fig. 5. MDS ordinations of grab samples on (**A**) the control (C) and dredge (D) plots on each sampling date (1 to 9) and (**B**) the western and eastern halves of the plots on each sampling date. Solid lines measure the dissimilarity between control and dredge plots at each sampling date. Broken arrow line shows the temporal sequence of sampling; large arrow indicates time of experimental dredging

Multidimensional scaling

The MDS ordination (Fig 5A) maps the spatial and temporal changes in benthic community structure on the control and dredge plots before and after dredging. The stress coefficient of 0.155 indicates that the ordination is not unduly distorted (Clarke 1993) and is a fair representation of the input dissimilarities in 2 dimensions.

The MDS ordination summarises many of the changes on the control and dredge plots noted above. The lengths of the lines C–D in Fig. 5A provide a measure of the dissimilarity between the dredge and control plots through time. Short lines connect the control and dredge plots for the 3 pre-dredging sampling dates (C1–D1, C2–D2 and C3–D3). But immediately following dredging, the lengths of the C–D lines increase until they reach a maximum 3 wk after dredging (C5–D5) when the plots are at their most different. Subsequent changes to the lengths of the C–D lines indicate that the plots gradually become more similar. The broken line in Fig. 5A indicates that both the control and dredge plots follow a similar temporal trajectory representing seasonal and interannual changes on both plots. Temporal changes occurred progressively over the 17 mo of the study and there was little evidence of cyclical seasonal changes. Previous studies of benthos in Port Phillip Bay (Poore & Rainer 1979) also found that interannual changes were greater than seasonal changes. The second to the last last sampling date was the most divergent as a result of recruitment of many species at this time (see Fig. 4A).

The western and eastern halves of the study plots show patterns of change similar to those of the whole plots (Fig. 5A, B). The maximum difference between the control and dredge plots occurred 3 wk after dredging on both the entire plots and the western halves. In contrast the maximum difference between the eastern halves of the control and dredge plots occurred immediately after dredging. It is not clear whether this indicates that impacts were noticed more quickly in the softer sediments on the eastern half of the dredge plot or merely that the changes observed on the eastern halves are less reliable as these half plots straddled a large environmental gradient (see Figs. 6 & 7).

Spatial variation across the study plots

A pronounced ecological gradient was detected between the eastern and western edges of both the control and dredge plots (Fig. 6). There were more species (Fig. 6A) and individuals (Fig. 6B) on the western than on the eastern sides of both plots. These differences were also seen in the distribution of many species, most of which were much more abundant on the western than on the eastern halves of the plots.

The gradient in abundance and number of species across the plots parallelled physical changes across the plots. Depth increased from west to east across the plots, although the recorded gradient from 12 m on the west to 15 m on the east (Fig. 6C) was greater than the actual change in depth, as recorded values were not corrected for a 1 m tidal variation. The amount of mud (sediment fraction <63 µm) in the sediment increased from 10% in the west to 30% in the east (Fig. 6D).

Most of the variation across the 600 m width of the study plots occurred across the eastern halves of the plots; there was little or no gradient across the western half of either plot. This was particularly evident with the change in mud content, which varied little across the western halves of both plots but changed markedly across the eastern halves (Fig. 6D). Gradients in species number and total number of individuals were also sharper in the eastern half than in the western half of each plot (Fig. 6A, B).

This east-west gradient was clearly seen from the distribution of many individual species across the plots and from MDS ordination of communities taken in grabs on the eastern and western halves of each plot. All grab samples taken on the western half of the control plot were very similar, whereas there was

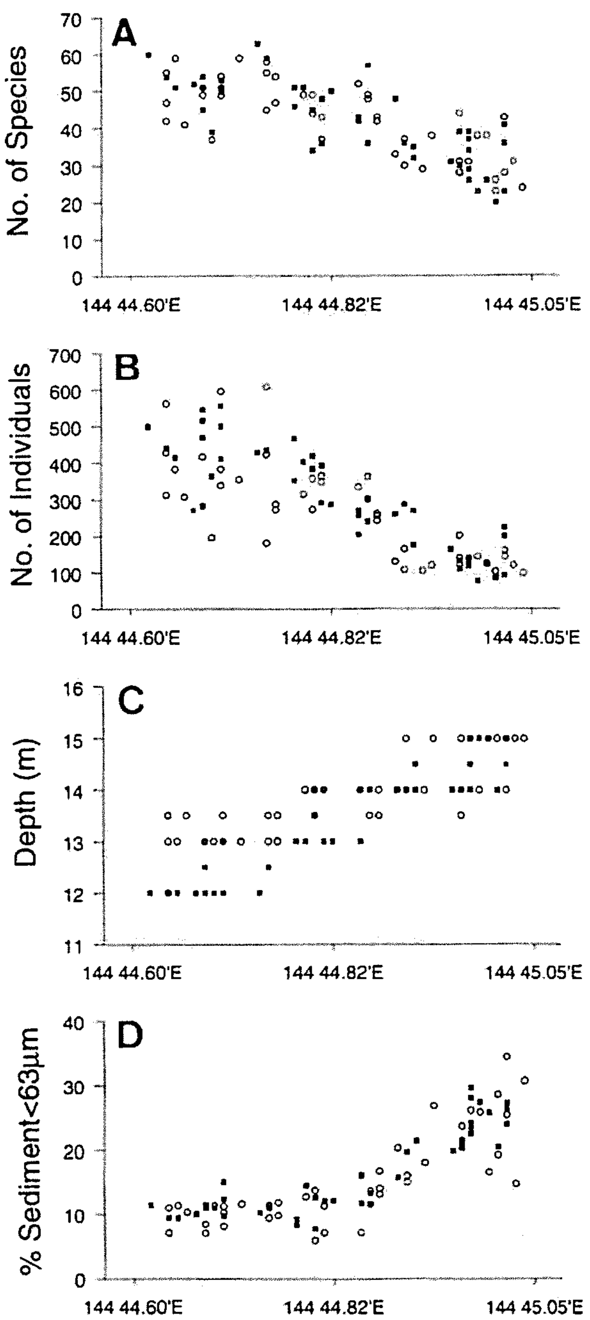


Fig. 6. East-west gradients across the control (o) and dredge (■) plots. (A) number of species; (B) number of individuals; (C) depth; (D) sediment type

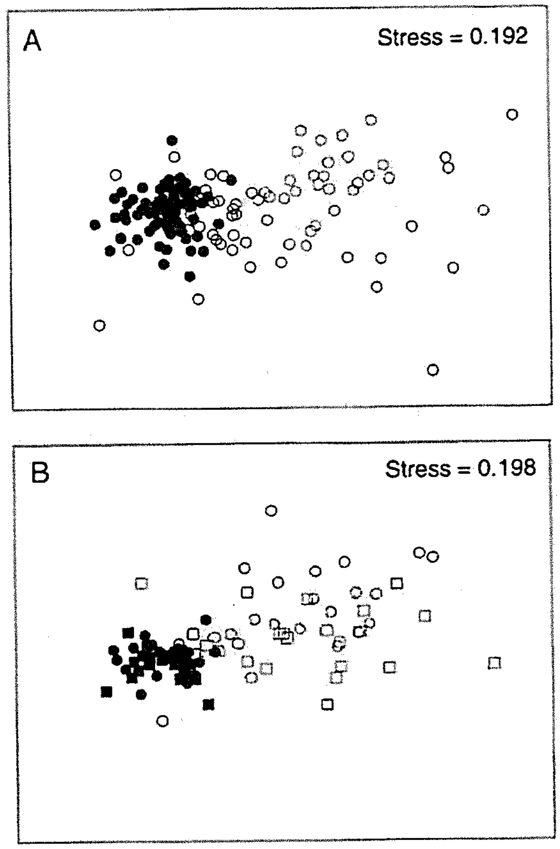


Fig. 7 MDS ordinations of (A) all grab samples taken on the western (●) and eastern (O) halves of the control plot; (B) grab samples taken during the pre-dredging period on the western (●) and eastern (O) halves of the control plot and the western (■) and eastern (□) halves of the dredge plot

much greater variation in grab samples taken on the eastern half (Fig 7A). A similar pattern was apparent using MDS ordination of all grab samples taken on the 3 pre-dredging sampling dates. Grab samples taken on the western halves of the control and dredge plots were very similar, whereas grabs taken in the eastern halves were much more variable (Fig 7B).

The gradient across both the control and dredge plots was similar for all the parameters discussed above, indicating that the experimental plots were well-matched. However, the marked east-west gradient across both plots led to separate statistical analyses being undertaken for the eastern and western halves of the plots as well as for the entire plots.

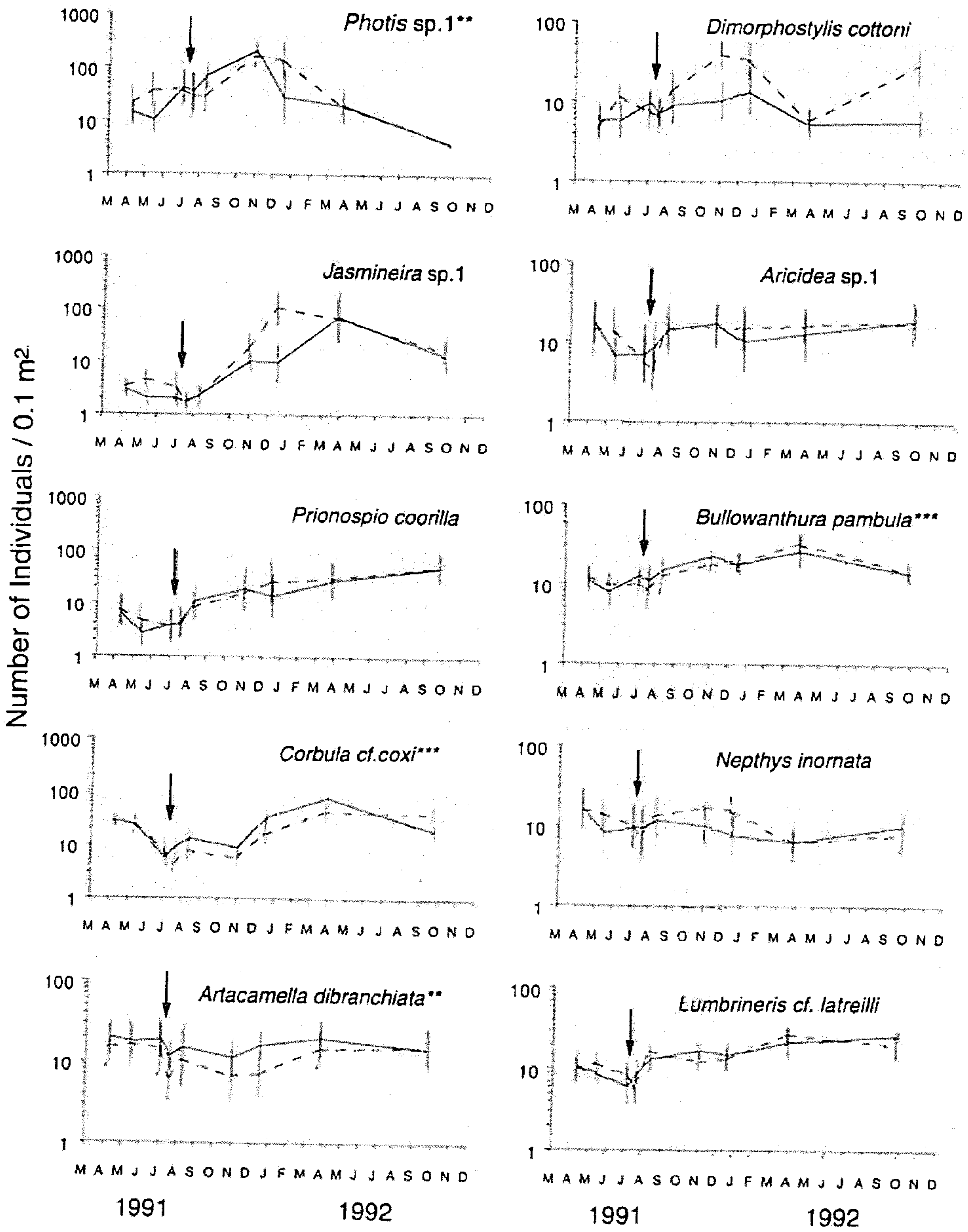


Fig. 8. Change in abundance of the 10 most common species on the control (——) and dredge (- - -) plots before and after dredging. Error bars show SE. Arrows indicate time of experimental dredging. Species that changed in abundance significantly across the entire plots in the 3.5 mo following dredging are marked **$p < 0.05$, ***$p < 0.01$

Changes in abundance of individual species

Changes to the abundance of the 10 most common species found during the 17 mo of the study were considered in detail. These species in order of abundance were: *Photis* sp. 1 (corophid amphipod), *Jasmineira* sp. 1. (sabellid polychaete), *Prionospio coorilla* (spionid polychaete), *Corbula* cf. *coxi* (corbulid mollusc), *Artacamella dibranchiata* (terebellid polychaete), *Dimorphostylis cottoni* (diastylid cumacean), *Aricidea* sp. 1 (paraonid polychaete), *Bullowanthura pambula* (paranthurid isopod), *Nephtys inornata* (nephtyid polychaete), and *Lumbrineris* cf. *latreilli* (lumbrinerid polychaete). Changes in abundance of these 10 species on the control and dredge plots throughout the 17 mo of the study are shown in Fig. 8. Significance levels for plot × period interactions for ANOVAs including the 3 pre-dredging sampling dates and 3 post-dredging sampling dates (3.5 mo) are shown in Table 4. Estimates of the percentage change in the mean abundance of each species over the same period are shown in Table 5. The duration of dredging impacts on these species was determined from the number of post-dredging sampling dates that resulted in significant interactions beyond the initial 3.5 mo post-dredging period and are shown in Table 6.

The likelihood of detecting significant changes in the abundance of a species following dredging depends on

Table 4. Probability levels for ANOVAs for 12 common species including 3 sampling dates before and 3 sampling dates after dredging for plot × time interactions tested against plot × date(time) terms. Separate analyses are provided for entire plots and eastern and western halves, in all cases with and without a covariate (percentage of sediment <63 µm) and for the covariate itself. All abundance data were transformed using $\log_{10}(n+1)$, except for *Jasmineira* sp. 1 where a $1/(n+1)$ transformation was used

Species	Rank	Entire plot			Western half			Eastern half		
		−Cov	+Cov	Cov	−Cov	+Cov	Cov	−Cov	+Cov	Cov
Photis sp. 1	1	0.1038	0.0338	0.0001	0.1287	0.1514	0.2246	0.0793	0.0370	0.0001
Jasmineira sp. 1	2	0.1515	0.1288	0.0001	0.5013	0.4936	0.7336	0.0696	0.1057	0.0008
Prionospio coorilla	3	0.1750	0.1646	0.0001	0.0344	0.0502	0.0023	0.9592	0.7336	0.0001
Corbula cf. *coxi*	4	0.0091	0.0093	0.8839	0.0045	0.0057	0.3443	0.0360	0.0544	0.0001
Artacamella dibranchiata	5	0.0479	0.4388	0.0001	0.7571	0.8616	0.1952	0.0702	0.0681	0.8367
Dimorphostylis cottoni	6	0.3937	0.3818	0.0001	0.0635	0.0544	0.0515	0.9115	0.9616	0.0001
Aricidea sp. 1	7	0.3593	0.2085	0.0001	0.0477	0.0419	0.7894	0.8847	0.7007	0.0001
Bullowanthura pambula	8	0.1750	0.0045	0.0001	0.7909	0.8048	0.4375	0.2290	0.0965	0.0001
Nephtys inornata	9	0.9185	0.6730	0.0001	0.1794	0.1754	0.1020	0.0891	0.9982	0.0001
Lumbrineris cf. *latreilli*	10	0.2083	0.2240	0.0001	0.1074	0.1069	0.6922	0.2431	0.2860	0.0001
Natatolana corpulenta	14	0.3411	0.3509	0.1979	0.2120	0.2465	0.4570	0.7586	0.7698	0.2313
Oedicerotid sp. 1	16	0.0760	0.1651	0.0001	0.0484	0.0515	0.8557	0.2863	0.2398	0.0001

Table 5. Pre-dredging differences between dredge and control sites and % change in abundance in the 3.5 mo following dredging for 12 common species. Changes are shown for entire plots and their western and eastern halves. Significant changes are shown: *p < 0.10, **p < 0.05, ***p < 0.01. Power to detect changes of 30 and 50% shown where changes were non-significant (ns)

Species	Rank	% Difference pre-dredging	% Change post-dredging			Power, α = 0.10: 30% decrease or (increase)			Power, α = 0.10: 50% decrease or (increase)		
		Entire	Entire	West	East	Entire	West	East	Entire	West	East
Photis sp. 1	1	+68	−79**	ns	−99**	–	0.16	–	–	0.37	–
Jasmineira sp. 1	2	+179	−71	ns	ns	0.30	0.14	0.06	0.69	0.25	0.10
Prionospio coorilla	3	+34	−60	−78**	ns	0.11	–	0.22	0.86	–	0.49
Corbula cf. *coxi*	4	+19	−66***			–			–		
Artacamella dibranchiata	5	+6	−28**	ns	−36*	–	0.64	–	–	0.98	–
Dimorphostylis cottoni	6	+1	+119	+141*	ns	(0.13)	–	(0.11)	(0.17)	–	(0.13)
Aricidea sp. 1	7	+4	−26	−41**	ns	0.22	–	0.15	0.50	–	0.30
Bullowanthura pambula	8	−6	−0.4***	ns	−32*	–	0.33	–	–	0.74	–
Nephtys inornata	9	+7	−3	ns	ns	0.29	0.71	0.14	0.66	0.99	0.25
Lumbrineris cf. *latreilli*	10	+3	−18	ns	ns	0.40	0.94	0.22	0.84	0.99	0.50
Natatolana corpulenta	14	+21	+23			(0.47)			(0.78)		
Oedicerotid sp. 1	16	+11	+71	+44**	ns	(0.43)	–	0.12	(0.73)	–	(0.21)

Table 6. Statistical significance of the effect of dredging on abundance [$\log_{10} n+1$, except for *Jasminiera* sp. 1 where $1/(n+1)$ transformation was used] of 12 common species when 3, 4, 5 and 6 post-dredging dates are included in ANOVAs for each species. Probability values are derived from ANOVAs including a sediment covariate, except for *Artacamella dibranchiata*, *Corbula* cf. *coxi* and *Natatolana corpulenta*, where there was no clear correlation with sediment type (Table 3). Significant changes are shown: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. For *Lumbrineris* cf. *latreilli* the percentage change during the 5 mo following dredging is shown

Species	Rank	Plot	Number of post-dredging dates included in ANOVA (time after experimental dredging)			
			3 (3.5 mo)	4 (5 mo)	5 (8 mo)	6 (14 mo)
Photis sp. 1	1	Entire	**			
		West				
		East	**			
Jasmineira sp. 1	2	Entire				
		West				
		East				
Prionospio coorilla	3	Entire				
		West	**	*	**	**
		East				
Corbula cf. *coxi*	4	Entire	***	***	***	
Artacamella dibranchiata	5	Entire	**	**	**	
		West				
		East	**	**	**	
Dimorphostylis cottoni	6	Entire				
		West	*	**		
		East				
Aricidea sp. 1	7	Entire				
		West	**	**	**	**
		East				
Bullowanthura pambula	8	Entire	***	*		
		West				
		East	*			
Nephtys inornata	9	Entire				
		West				
		East				
Lumbrineris cf. *latreilli*	10	Entire				
		West		*(−25%)		
		East				
Natatolana corpulenta	14	Entire				
Oedicerotid sp. 1	16	Entire		*	*	*
		West	*	*	**	**
		East				

the size of the impact in relation to the background spatial and temporal variability of that species. The distinct east-west gradient across the plots resulted in the abundance of 9 of the 10 most abundant species correlating significantly with the change in sediment type across the plots (Table 4) All species were more abundant in the sandier sediments on the west of the plots, except for *Artacamella dibranchiata* which was more abundant on the east of the plots and *Corbula* cf. *coxi* which showed no gradient across the plots. Consequently, except for *C.* cf. *coxi*, separate ANOVAs were calculated comparing changes in abundance following dredging between the 2 eastern halves and between the 2 western halves. This approach reduced variability caused by low abundances in only one half, but caused some loss in statistical power as the number of grab samples used in each ANOVA cell decreased from 15 for the entire plots to 7 for half plots.

For all abundant species, except *Corbula* cf. *coxi* and *Artacamella dibranchiata*, significance tests of the impact of dredging (Tables 4 & 5) were based on ANOVAs which included a sediment covariate. A sediment covariate was not included in the ANOVA model used to test the significance of changes to the abundance of *A. dibranchiata* because its abundance did not clearly correlate with sediment type in either the eastern or western halves of the plots (Table 4). The east-west gradient in its abundance appeared to be correlated with another factor (e.g. depth) which was itself correlated with sediment type.

For 12 common species, including the 10 most abundant, heterogeneity of variance was examined using

Cochran's test and removed by $\log_{10}(n+1)$ for 9 of these species. A $1/n+1$ transformation effectively removed significant heterogeneity of variance from *Jasminiera* sp. 1 while no transformations could remove the heterogeneous variances from *Photis* sp. 1 and *Bullowanthura pambula*. Consequently the significance of changes to the abundance of *Photis* sp. 1 and *B. pambula* need to be interpreted cautiously. The heterogeneous variance for *Photis* sp. 1 was due to high variances on the control plot immediately following recruitment (Fig. 8) and may be due to patchier recruitment/survival on the more topographically variable control plot. In contrast, high variances with *B. pambula* occurred on the dredge plot during the first 2 post-dredging samplings (Fig. 8). This increase in variance probably resulted from a temporary redistribution of this species following dredging, when a high proportion of the population may have become concentrated in small undredged regions. The very small but 'significant' change across the entire plots for *B. pambula* (Tables 4 & 5) results from the high variances on the dredge plot which cause a minimal change in the arithmetic mean on the dredge plot but a decrease in the mean of log transformed data used in the ANOVA and plotted in Fig 8.

In the 3.5 mo following dredging, 6 of the 10 most abundant species showed a significant decrease in relative abundance of 28 to 79% on at least the eastern or western halves of the study plots, and 1 species showed a significant increase of 141% (Table 5). Across the entire plots, 4 species decreased in relative abundance (*Photis* sp. 1, *Jasminiera* sp. 1, *Prionospio coorilla*, and *Corbula* cf. *coxi*) between 60 and 79%, although only 2 of these changes were significant. These relatively large decreases may result from undersampling of the plots in the pre-dredging period, as measured densities of these species were between 19 and 179% higher on the control plot than on the dredge plot in the pre-impact period (Table 5). Consequently, if the pre-dredging abundances of these species were actually similar on the control and dredge plots (which seems likely as the plots were well-matched ecologically), the estimated change following dredging would have been exaggerated by 19 to 179%, and the actual changes in abundance of these species would have been −11%, −26%, and −37% for *Photis* sp. 1, *P. coorilla* and *C.* cf. *coxi* respectively and the abundance of *Jasmineira* sp. 1 would have increased rather than decreased.

The duration of detectable impacts varied between species. No significant changes in abundance were found with *Jasmineira* sp. 1 or *Nephtys inornata* over any time period (Table 6) The low power of statistical tests (Table 5) to detect changes in the abundance of *Jasmineira* sp. 1, an uncommon species during the first 7 mo of the study (Fig. 8), indicates that the impact of dredging on this species is uncertain. In contrast, the high power of statistical tests (Table 5) to detect changes in the abundance of *N. inornata* indicates that this species decreased in abundance by less than 30% following dredging (Fig 8). The similarly high power of statistical tests to detect changes in the abundance of *Lumbrineris* cf. *latreilli* (Table 5) suggests that decreases in the abundance of this species were also less than 30%. Inclusion of 4 post-dredging dates in the ANOVA for *L.* cf. *latreilli* resulted in a significant decrease of 25% in the 5 mo following dredging (Table 6). Of the 7 species (Table 5) whose abundance changed significantly over the first 3.5 mo, *Bullowanthura pambula* and *Photis* sp. 1 were affected for 3.5 mo (Table 6, Fig. 8), *Dimorphostylis cottoni* for 5 mo, *Corbula* cf. *coxi* and *Artacamella dibranchiata* for 8 mo, and *Prionospio coorilla* and *Aricidea* sp. 1 for 14 mo (Table 6). As noted above, changes to the abundance of *B. pambula* appear to result from their redistribution rather than a decrease in their abundance; changes do not persist beyond 3.5 mo and indeed the high variances associated with dredging appear to last only 3 wk (Fig. 8). The decreases in populations of *Photis* sp. 1, *C.* cf. *coxi* and *A. dibranchiata* lasted 1 sampling date beyond the period of recruitment of juveniles. Following recruitment of each of these species, relatively high mortalities on the control plot resulted in convergence of abundances on both plots (Table 6, Fig. 8). The shorter duration of impact with *Photis* sp. 1 (3.5 mo) compared to *C.* cf. *coxi* and *A. dibranchiata* (8 mo) probably reflected the shorter interval between the dredging impact and the annual recruitment for *Photis* sp. 1 The abundance of *D. cottoni* increased for 5 mo, after which its abundance on the dredge plot decreased again (Table 6, Fig. 8). The extended persistence of the dredging-related decrease in the abundance of *Aricidea* sp. 1 on the western side of the dredge plot was probably due to the minimal recruitment of this species in the 14 mo following dredging. In contrast the impact on *P. coorilla* appeared persistent despite significant recruitment on both plots; this may be the result of inadequate sampling in the pre-dredging period. For both *Aricidea* sp. 1 and *P. coorilla*, densities on the dredge and control plots were indistinguishable after 14 mo (Fig. 8), but in the pre-dredging period densities were higher on the dredge plot.

Changes in abundance of species groupings

Taxonomic groups share many morphological and other features that may influence their susceptiblity or resistance to dredging impacts. The abundance of annelids, crustaceans, molluscs and nemerteans de-

Table 7. Pre-dredging abundance and percentage change in abundance in the 3.5 mo following dredging of species groupings based on (A) taxonomic affinity, (B) feeding types, (C) probable depth of occurrence in sediment, (D) rarity. Significant changes are shown: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$ Power to detect changes of 30% and 50% is shown where changes were non-significant. Only those groupings with a pre-impact density >1.0 m^{-2} are shown. Suspension-feeding bivalve *Theora* cf. *lubrica* (Sp. rank 17) and the scavenging ostracod *Empoulsenia* sp. 1 (Sp. rank 27) have not been included in the analyses as both had exceedingly contagious distributions

Phylum	Class	Pre-dredging density (No. 0.10 m^{-2})	% Change following dredging	Power, $\alpha = 0.10$ 30% decrease or (increase)	50% decrease or (increase)
(A) Taxonomic affinity					
Annelida		110.4	-23*		
	Polychaete	110.4	-23*		
Crustacea		108.6	-35 (-6)[1,2]	0.21	0.58
	Amphipoda	73.8	-62** (-7)[1]		
	Brachyura	2.2	-31	0.20	0.56
	Cumacea	10.3	+108 (-24)[2]	(0.09)	(0.19)
	Isopoda	13.8	0	0.75	0.99
	Mysidacea	4.4	+78	(0.16)	(0.45)
	Tanaidacea	2.6	-20	0.32	0.80
Echinodermata		5.3	+4	0.24	0.68
	Holothuroidea	2.5	-16	0.15	0.40
	Ophiuriodea	2.0	+19	0.37	0.86
Mollusca		31.0	-50*** (-17**)[3]		
	Bivalvia	28.3	-53** (-13)[3]		
	Gastropoda	2.7	-22*		
Nemertea		2.4	-68**		
(B) Feeding types					
Deposit feeder		183.5	-39*** (-17)[1]		
Predator		28.5	-12	0.38	0.88
Scavenger		5.5	-21	0.57	0.98
Suspension-feeder		46.8	+26 (-15)[2]	0.15	0.40
(C) Probable depth of occurrence					
Surface layer		76.2	-50* (+81)[1](+29)[1,2]		
Near surface layer		32.8	+11	0.44	0.93
Below surface		65.7	-26	0.36	0.85
Well below surface		61.9	-24	0.34	0.83
(D) Rarity					
Sp. 1-10		184.5	-30** (-5)[1]		
Sp. 11-20		33.6	-6	0.27	0.72
Sp. 21-30		21.3	-22	0.66	0.99
Sp. 31-50		16.2	-23	0.99	0.99
Sp. 50-247		16.1	-28**		

% change for groups excluding [1]*Photis* sp. 1, [2]*Dimorphostylis cottoni*, [1,2]both, or [3]*Corbula* cf. *coxi* shown in parentheses

creased significantly following dredging while there was no significant decrease in the abundance of echinoderms (Table 7A). This difference largely reflects the paucity of echinoderms and the low power of analyses with this phyla (Table 7A). Where phyla could be subdivided into classes it was clear that the component classes were often affected differently by dredging (Table 7A). Similarly where abundant species (e.g. *Photis* sp. 1, *Dimorphostylis cottoni*, *Corbula* cf. *coxi*) could be identified within a class, these species were often affected differently from the remainder of their class. Thus there was little evidence for a consistent level of impact within a taxonomic group at the level of phylum or class. However, the abundance of nemerteans was decreased 68% by dredging (Table 7A) and the fragility of this group may make them unusually susceptible to dredging.

Deposit-feeding animals were the best represented trophic group at St. Leonards and accounted for 43% of the total species. Other groups were less well represented: suspension feeders (22%), predators (19%), scavengers (14%) and grazers (2%). Deposit feeders appeared to be more susceptible than predators and scavengers, and suspension feeders became more abundant after dredging (Table 7B). But these patterns were strongly influenced by *Photis* sp. 1, the most abundant deposit-feeding species, and *Dimorphostylis cottoni*, the most abundant suspension-feeding species (Table 7B). If these 2 species were excluded, then feeding type had no clear influence on the susceptibility of species to dredging impacts (Table 7B).

It seemed likely that species that occurred nearest the sediment surface would be the most susceptible to dredging Unexpectedly, however, except for the amphipod *Photis* sp. 1, which builds its tube on the sediment surface and whose abundance was reduced by dredging (Table 5), most species that occurred on or near the sediment surface appeared to increase in abundance compared to those which occurred deeper in the sediments (Table 7C).

Changes to the abundance of species grouped on the basis of their rank abundance indicated that 4 of the 5 species groups decreased in abundance by 20 to 30%, and 2 of these decreases (Sp. 1–10, and Sp. 51–247) were statistically significant (Table 7D). The relatively small decrease of 6% observed with the Sp. 11–21 grouping compared to other species groupings (Table 7D) resulted largely from an increase in abundance of *Natatolana corpulenta* and a significant ($p = 0.07$) increase in the abundance of *Oedicerotid* sp. 1 (Tables 4 & 5). The increase in abundance of *Oedicerotid* sp. 1 remained significant ($0.01 < p < 0.04$) for the 14 mo of the study. The abundance of *N. corpulenta* on the dredge plot decreased immediately following the dredging, then increased and remained consistently higher on the dredge plot for 8 mo. Thus there was no evidence that rare species were more or less likely to be impacted by dredging than were abundant species.

DISCUSSION

The design of dredges and the appearance of their tracks indicate that dredges have a grader-like impact on the sea floor. Scallop dredging markedly changed the topography of the experimental dredge plot by flattening callianassid mounds and filling adjacent pits and depressions. Bioturbation caused by *Callianassa* is a major ecological disturbance in many soft sediment communities (Branch & Pringle 1987, Griffis & Suchanek 1991) and is known to reduce the abundance of a range of species including bivalves (Peterson 1977, Murphy 1985), tube-dwelling spionids and amphipods (Posey 1986) and meiofauna (Branch & Pringle 1987). However, while dredging removed callianassid mounds, it did not significantly reduce the density of callianassids themselves, and it seems unlikely to have reduced bioturbation significantly. Mounds were rebuilt immediately following dredging, although they took 6 to 11 mo to attain their former size. Thus it appears that changes to bioturbation caused by dredging are minimal and similar to those noted following a cyclone which removed *Callianassa* mounds but did not kill the *Callianassa* themselves (Riddle 1988).

Sediment cores taken within the study plots at St. Leonards indicated that the majority of organisms (68%) were concentrated in the top 5 cm of sediment, and 91% in the top 10 cm of sediment, although some burrowing species (e.g *Callianassa*) extend well below this depth. The range of species collected in nets placed behind dredges confirmed that much of the infauna was dislodged from the sediment and passed through the dredge cage mesh. When dredging commenced 2 species that occurred in the surface layer *Photis* sp. 1 and *Dimorphostylis cottoni* were thrown up in the sediment plume, but as dredging continued deeper sediments were disturbed and more burrowing species, especially polychaetes, were dislodged. The medium-term impact of dredging on 2 surface-dwelling species differed markedly, the abundance of the tube-dwelling amphipod *Photis* sp. 1 decreased while the cumacean *D. cottoni* increased in abundance following dredging. Unexpectedly, species abundant in net samples, and hence probably over-represented in the surface layer, increased rather than decreased in abundance (Table 7C) in the 3.5 mo following dredging. Most of these species were mobile crustaceans (*D. cottoni, Paradexamine lanacoura, Oedicerotid* sp. 1, *Byblis mildura*, and *Natatolana corpulenta*), and their mobility may enable them to migrate opportunistically into disturbed areas with fewer competitors. Alternatively, their mobility may make them less susceptible to dredge-related sedimentation (Brenchley 1981) or more susceptible to being netted. There were few other consistent patterns of susceptibility to dredging between groups of species. Except for nemerteans, which are probably an unusually fragile group, there was no evidence that dredging impacted species from the same phylum or class in a consistent manner. Similarly, susceptibility to dredging was not correlated with feeding type or rarity.

The near absence of general patterns in susceptibility of species groups to dredging is not surprising when the range of possible mechanisms causing mortality or increased migration into a disturbed area are considered. General patterns will probably not emerge until we have a better understanding of the causes of fishing-induced mortality. A number of species, especially burrowing polychaetes and fragile groups such as nemerteans (Table 7A), were probably cut and killed by the passing dredge. Others may have been affected by high turbidity, high rates of sedimentation, or were buried when depressions were filled. Turbidity immediately behind dredges was 2 to 3 orders of magnitude greater than occurs during storms (Black & Parry

1994). Laboratory experiments indicate that mortality occurs when invertebrates are exposed to sediment concentrations of 2 to 20 g l^{-1} over 21 d (e.g. McFarland & Peddicord 1980 cited in Engler et al. 1991). These high concentrations are similar to those that occur immediately behind scallop dredges but such levels last for only a few minutes (Black & Parry 1994). High rates of sedimentation and burial may also cause some mortality. Species differ greatly in their tolerance of burial (e.g. Maurer et al. 1982), but suspension feeding bivalves, such as *Corbula* cf. *coxi*, are generally unable to escape burial of more than 5 cm (Kranz 1974) and also appear sensitive to high rates of sedimentation (e.g. Howell & Shelton 1970).

Two species, the cumacean *Dimorphostylis cottoni* and the amphipod *Oedicerotid* sp. 1, increased in abundance significantly following dredging. The cirolanid isopod *Natatolana corpulenta* showed a sharp decrease in abundance immediately following dredging and then its abundance increased and was consistently higher on the dredge plot for 8 mo. Two of these species are known to swim actively at night, and *Oedicerotid* sp. 1 has a large median eye, suggesting that it may also be active nocturnally. The significant reduction in the abundance of many species by dredging may have increased the amount of food available on the plot and attracted some of the more mobile and opportunistic species. For example, *N. corpulenta* may have been attracted to the dredge plot by a greater accessibility of invertebrate prey following dredging. Baited traps deployed in the region at night caught large numbers of *N. corpulenta*, *Empoulsenia* sp. 1 and smaller numbers of *Lysiannasid* sp. 1 (Parry pers. ob.). While cirolanids and lysianassids are both well-known scavengers of large carcasses they may have other roles. For example, Oliver & Slattery (1985) found lysianassids were important predators of invertebrates injured and dislodged from sediments by feeding grey whales, and suggested that small invertebrates may be the most important source of food for lysianassids in other environments.

That the maximum impact does not occur immediately after dredging (Figs. 4 & 5A) suggests that indirect ecological changes may also follow dredging. Organisms uncovered by dredging may become more vulnerable to predation by invertebrate predators and demersal fish. The increase in the abundance of the scavenger/predator *Natatolana corpulenta* following dredging was noted earlier and may contribute to a higher mortality of its prey. Changes to the abundance of demersal fish and their diets were monitored during this study and will be described elsewhere (Parry & Currie unpubl.).

The magnitude and duration of dredging impacts varied between species. In the 3.5 mo following dredging, 6 of the 10 most abundant species showed a significant decrease in abundance of 28 to 79% on at least one half of the study plots, and 1 species showed a significant increase of 141% (Table 5) in the 3.5 mo following dredging. But most species decreased in abundance by 20 to 30% (Tables 5, 6 & 7D). Of the 7 species which changed significantly following dredging, differences persisted for 3 wk (*Bullowanthura pambula*), 3.5 mo (*Photis* sp. 1), 5 mo (*Dimorphostylis cottoni*), 8 mo (*Corbula* cf. *coxi* and *Artacamella dibranchiata*) and 14 mo (*Prionospio coorilla* and *Aricidea* sp. 1) post-dredging. However, the apparent persistent differences with *P. coorilla* and *Aricidea* sp. 1 may be due to undersampling in the pre-impact period, as the densities of these species were indistinguishable on the control and dredge plots after 14 mo (Fig. 8).

Our most sensitive measure of change following dredging was the B-C dissimilarity between the dredge and the control plots (Fig. 4C). For 14 mo following dredging, the dissimilarity between plots remained higher than during the pre-dredging period for all data transformations (Fig. 4C). But the more persistent differences with double square root and presence/absence transformed data suggests that these differences were due mostly to fewer rare species being shared between plots following dredging. There were 11 species found on the dredge plot before dredging that were not found again after dredging, although 5 of these were found on the control plot after dredging. Some of these 11 uncommon species may be very susceptible to dredging, but it appears more likely that dredging reduced densities of most rare species by 20 to 30% (Table 7D) so that each rare species was less likely to be sampled. The particular species not found again on the dredge plot following dredging were probably those that experienced a year of low recruitment and did not recruit to either plot in 1991/92. Thus a similar number of missing species may have been found had the experiment been conducted in another year but the missing species would probably have been different. Most of the 11 species (3 bivalves, 2 burrowing polychaetes, 2 burrowing crustaceans, 3 gastropods and 1 squid) found only on the dredge plot before it was dredged are sedentary and so were unable to re-establish on the dredge plot except by larval recruitment.

This study documented the size and duration of scallop dredging impacts on a soft sediment community. Reductions in density caused by dredging were usually small compared to annual changes in population density. The significance of changes to community structure following dredging can also be assessed by comparison with temporal changes in community structure using MDS. Seasonal and particularly interannual changes (see also Poore & Rainer 1979) were greater than those caused by dredging (Fig. 5). However further studies are required to establish that the results of this study are representative of scallop grounds throughout Port Phillip Bay (Currie & Parry unpubl.) and to determine whether changes to the benthos cause other ecological consequences, particularly to demersal fish populations (Parry & Currie unpubl.).

This study is the first to have undertaken a controlled experiment to assess the impact of commercial fishing at a spatial scale similar to that of commercial activities. The appropriate temporal scale for such an experimental study is more difficult to determine. While 14 mo was long enough for the dredged plot to recover almost completely, the difference between the 'recovered' community and the 'never-dredged' community that occurred on this site 30 yr earlier remains uncertain. The long-term effects of dredging may differ from the short- to medium-term changes described here. In particular, after 3 decades of dredging, species that were very vulnerable to dredging may now be too rare in Port Phillip Bay to be adequately sampled. In practice the only species that seem likely to be have been that vulnerable to dredging are long-lived and slowly recruiting epifaunal species such as sponges and ascidians. Ascidians *Pyura stolonifera* and *Herdmania momus* remain common at St. Leonards but sponges are not. However, considering the low levels of dredging at St. Leonards over recent years it seems more likely that these slowly recruiting taxa were never common at St. Leonards, unless they are unexpectedly sensitive to dredging. The sector in which the study plots were located was virtually undredged for 3 yr preceding the experimental dredging and in the preceding 8 yr only 9 to 24% of the sector was dredged annually (Table 1B). But in the absence of quantitative data on completely unimpacted sites, long-term effects can be determined with certainty only with a long-term study in which changes to regions from which the impact is removed are monitored for many years (Gislason 1994). Such recovery studies need proper controls (i.e. sites in which the impact is continued) but their required duration is difficult to predict. A reasonable duration would appear to be the longevity of the longest-lived component species, but frequently this is also unknown.

Acknowledgements. The field program and the laboratory identifications were efficiently coordinated by Ross Haughton and Arnold Jahnecke respectively. Special thanks are due to Rhonda Flint, Anna Bos, Matt Hoskins and Mike Forsyth who contributed in the field and the laboratory and to VFRI operations staff especially John Barry, Dave Byer (skipper) and Bob Metcalf (engineer) of RV 'Sarda'. Thanks also to the following staff directly involved in laboratory analysis: Melinda Miller, Steve Frlan, Bruce Waters and Di Crookes and the many (23) staff members at VFRI directly involved in the dredging experiment. The support of the Victorian scallop industry is gratefully acknowledged. We thank specially Melita Proebstl and Gordon Milliken, who coordinated the trials, and the skippers and crews of the following vessels that took part in the experimental dredging: 'AB Hunter', 'AB Venture', 'Conquest', 'Grace', 'Jennann', 'Marie Lizette', 'Nephelle', 'Nimrod', 'Pegasus', 'Saint', 'Sandgroper', 'Tingara' and 'Trinity'. Statistical support was provided by Anne Gason and Nik Dow. Mick Keogh (University of Melbourne) provided valued advice on experimental design. Gary Poore, Robin Wilson and Sue Boyd (Museum of Victoria) checked identifications of all specimens in our reference collection.

LITERATURE CITED

Andrew NL, Pepperell JG (1992) The by-catch of shrimp trawl fisheries. Oceanogr Mar Biol A Rev 30:527–565

Arntz WE, Weber W (1970) *Cyprina islandica* L. (Mollusca, Bivalvia) als Nahrung von Dorsch und Kliesche in der Kieler Bucht. Ber Dt Wiss Kommn Meeresforsch 21S: 193–209

Belbin L (1990) PATN technical reference manual. CSIRO Division of Wildlife and Ecology, Canberra

Bergman MJN, Hup M (1992) Direct effects of beamtrawling on macrofauna in a sandy sediment in the southern North Sea. ICES J Mar Sci 49:5–11

Black KP, Parry GD (1994) Sediment transport rates and sediment disturbance due to scallop dredging in Port Phillip Bay. Mem Queensl Mus 36:327–341

Bradstock M, Gordon DP (1983) Coral-like bryzoan growths in Tasman Bay, and their protection to conserve commercial fish stocks. NZ J Mar Freshwater Res 17:159–163

Branch GM, Pringle A (1987) The impact of the sand prawn *Callianassa kraussi* Stebbing on the impact on sediment turnover and on bacteria, meiofauna, and benthic microflora. J Exp Mar Biol Ecol 107:219–235

Bray JR, Curtis JT (1957) An ordination of the upland forest communities of southern Wisconsin. Ecol Monogr 27: 325–349

Brenchley GA (1981) Disturbance and community structure: an experimental study of bioturbation in marine soft-bottom environments. J Mar Res 39:767–790

Britton JC, Morton B (1994) Marine carrion and scavengers. Oceanogr Mar Biol A Rev 32:369–434

Brusca RC, Brusca GJ (1990) Invertebrates. Sinauer Associates, Sunderland, MA

Butcher T, Matthews J, Glaister J, Hamer G (1981) Study suggests scallop dredges causing few problems in Jervis Bay. Aust Fish 40 (9):9–12

Caddy JF (1973) Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. J Fish Res Bd Can 30:173–180

Clarke KR (1993) Non-parametric multivariate analyses of changes in community structure. Aust J Ecol 18:117–143

Clarke KR, Green RH (1988) Statistical design and analysis for a 'biological effects' study. Mar Ecol Prog Ser 46:213–226

Cohen J (1988) Statistical power analysis for the behavioural sciences, 2nd edn. L Erlbaum Associates, Hillsdale, NJ, p 1–567

Currie DR, Parry GD (1994) The impact of scallop dredging on a soft sediment community using multvariate techniques. Mem Queensl Mus 36:316–326

de Groot (1984) The impact of bottom trawling on benthic fauna of the North Sea. Ocean Manage 9:177–190

Eleftheriou A, Robertson MR (1992) The effects of experimental scallop dredging on the fauna and physical environment of a shallow sandy community. Neth J Sea Res 30: 289–299

Engler R, Saunders L, Wright T (1991) Environmental effects of aquatic disposal of dredged material. Environ Prof 13: 317-325
Faith DP, Humphrey CL, Dostine PL (1991) Statistical power and BACI designs in biological monitoring: comparative evaluation of measures of community dissimilarity based on benthic macro invertebrate communities in Rockhole Mine Creek, Northern Territory, Australia. Aust J Mar Freshwat Res 42:589-602
Faith DP, Minchin PR, Belbin L (1987) Compositional dissimilarity as a robust measure of ecological distance. Vegetatio 69:57-68
Fauchald K, Jumars PA (1979) The diet of worms: a study of polychaete feeding guilds. Oceanogr Mar Biol A Rev 17: 193-284
Field JG, Clarke KR, Warwick RM (1982) A practical strategy for analysing multispecies distribution patterns. Mar Ecol Prog Ser 8:37-52
Gamito S, Raffaelli D (1992) The sensitivity of several ordination methods to sample replication in benthic surveys. J Exp Mar Biol Ecol 164:221-232
Gislason H (1994) Ecosystem effects of fishing activities in the North Sea. Mar Pollut Bull 29:520-527
Griffis RB, Suchanek TH (1991) A model of burrow architecture and trophic modes in thalassinidean shrimp (Decapoda: Thalassinidea). Mar Ecol Prog Ser 79:171-183
Gwyther D, McShane PE (1988) Growth rate and natural mortality of the scallop *Pecten alba* Tate in Port Phillip Bay, Australia, and evidence for changes in growth rate after a 20-year period. Fish Res 6:347-361
Hall SJ (1994) Physical disturbance and marine benthic communities: life in unconsolidated sediments. Oceanogr Mar Biol A Rev 32:179-239
Howell BR, Shelton RGJ (1970) The effect of china clay waste on the bottom fauna of St Austell and Mevagissey Bays. J Mar Biol Assoc UK 50:593-607
Hughes WD (1973) Operational tests of Victorian scallop boats. Aust Fish 33(5):14-16
Hurlbert SH (1987) Pseudoreplication and the design of ecological field experiments. Ecol Monogr 54:187-211
Hutchings P (1990) Review of the effects of trawling on macrobenthic epifaunal communities. Aust J Mar Freshwat Res 41:111-120
Jamieson GS, Campbell A (1985) Sea scallop fishing impact on American lobsters in the Gulf of St. Lawrence. Fish Bull US 83:575-586
Jones JB (1992) Environmental impact of trawling on the seabed: a review. NZ J Mar Freshwater Res 26:59-67
Kranz PM (1974) The anastrophic burial of bivalves and its paleological significance. J Geol 82:237-265
Krost P, Bernhard M, Werner F, Hukriede W (1990) Otter trawl tracks in Kiel Bay (Western Baltic) mapped by side scan sonar. Meeresforsch 32:344-353
Maurer D, Keck RT, Tinsman JC, Leathem WA (1982) Vertical migration and mortality of benthos in dredged material: Part III. Polychaeta. Mar Environ Res 6:49-68
McFarland VA, Peddicord RK (1978) Lethality of a suspended clay to diverse selection of marine and estuarine macrofauna. Arch Environ Contam 9:733-741
McShane P (1981) The effect of scallop dredging on the macrobenthos of a muddy environment in Port Phillip Bay. Marine Science Laboratories, Queenscliff Tech Rep 4:1-16
Messieh SN, Rowell TW, Peer DL, Cranford PJ (1991) The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. Cont Shelf Res 11:1237-1263
Murphy RC (1985) Factors affecting the distribution of the introduced bivalve, *Mercenaria mercenaria*, in a California lagoon — the importance of bioturbation. J Mar Res 43:673-692
Oliver JS, Slattery PN (1985) Destruction and opportunity on the sea floor: effects of gray whale feeding. Ecology 66: 1965-1975
Parry GD, Currie DR (1992) Interim report on the effects of scallop dredging on Port Phillip Bay. Marine Science Laboratories, Queenscliff, Internal Rep 193:1-67
Peterman RM (1990) Statistical power analysis can improve fisheries research and management. Can J Fish Aquat Sci 47:2-15
Peterson CH (1977) Competitive organisation of the soft-bottom macrobenthic communities of Southern California lagoons. Mar Biol 43:343-359
Peterson CH (1993) Improvement of environmental impact analysis by application of principles derived from manipulative ecology: lessons from coastal marine case histories. Aust J Ecol 18:21-52
Peterson CH, Summerson HC, Fegley SR (1987) Ecological consequences of mechanical harvesting of clams. Fish Bull US 85:281-298
Poore GCB, Rainer S (1974) Distribution and abundance of soft-bottom molluscs in Port Phillip Bay, Victoria, Australia. Aust J Mar Freshwat Res 25:371-411
Poore GCB, Rainer S (1979) A three-year study of benthos of muddy environments in Port Phillip Bay, Victoria. Estuar Coast Mar Sci 9:477-497
Posey MH (1986) Changes in a benthic community associated with dense beds of burrowing deposit feeder, *Callianassa californiensis*. Mar Ecol Prog Ser 31:15-22
Riddle MJ (1988) Cyclone and bioturbation effects on sediments from coral reef lagoons. Estuar Coast Shelf Sci 27: 687-695
Sainsbury KJ (1988) The ecological basis of multispecies fisheries, and management of a demersal fishery in tropical Australia. In: Gulland JA (1988) Fish population dynamics, 2nd edn. John Wiley, London, p 349-382
Scarrat DJ (1972) Investigations into the effects on lobsters of raking Irish Moss, 1970-1971 Fish Res Bd Can Tech Rep No. 329
Scarrat DJ (1975) Observations on lobsters and scallops near Pictou N.S. Fish Mar Serv Tech Rep No. 532
Stewart-Oaten A, Murdoch WM, Parker KR (1986) Environmental impact assessment: 'pseudoreplication' in time? Ecology 67:929-940
Thiel H, Schriever G (1990) Deep-sea mining, environmental impact and the DISCOL project. Ambio 19:245-250
Underwood AJ (1991) Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations. Aust J Mar Freshwat Res 42: 569-587
Warwick RM (1993) Environmental impact studies on marine communities: pragmatical considerations. Aust J Ecol 18: 63-80
Wassenberg TJ, Hill BJ (1990) Partitioning of material discarded from prawn trawlers in Moreton Bay. Aust J Mar Freshwat Res 41:27-36
Wilson RS, Cohen BF, Poore GCB (1993) The role of suspension-feeding and deposit-feeding benthic macroinvertebrates in nutrient cycling in Port Phillip Bay. CSIRO Port Phillip Bay Environmental Study Technical Report No. 10: 1-41. CSIRO, Melbourne

This article was presented by C. H. Peterson (Senior Editorial Advisor), Morehead City, North Carolina, USA

Manuscript first received: June 27, 1994
Revised version accepted: October 4, 1995

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person:	Samuel Michael Henehan
Organisation (if applicable):	
Email:	
Fishstock(s) this submission refers to:	Scallops – SCA 1 and SCA CS
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	SCA 1 Option One

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Fisheries New Zealand
Tini a Tangaroa

Submission:[1]

Details supporting your views: My whanau have a tradition of collecting scollops for Xmas lunch every year. After 4 hours free diving I could only find 9 scollops. It has become increasingly difficult over the last 15 years. I support closing the gathering of scollops for both commercial and all recreational gathers for no less than 3 years. In the hope this will allows stop ks to recover to a point where some recreational gathering can continue. When this does happen I would like to see the recreational gathering of scollops restricted to free diving only as this will also increase the sustainability of the Taonga

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

Please continue on a separate sheet if required.

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person:	**Paul Ganley**
Organisation (if applicable):	N/A
Email:	
Fishstock(s) this submission refers to:	SCA 1 and SCA CS
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	Option 2

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Fisheries New Zealand

Tini a Tangaroa

Submission:[1]

Details supporting your views:

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

To whom it may concern

I would like to submit the following submission on the proposed Review of Sustainability Measures for New Zealand scallops (SCA 1 & SCA CS) for 2022/23

As a fifth-generation Whangārei resident and frequent user of the Whangārei harbour, my family and I have noticed a gradual and continual decline in the fish and shellfish stocks within the harbour and surrounding areas.

There is now the seventh generation of our family taking to the water to experience and enjoy what nature has provided, and I am greatly concerned and saddened that this generation and future ones will not be able to enjoy these treasures.

There are some questions that need answers too.

Why has this situation come about?

Why has this situation been allowed to get into the current state it is in now?

Why has Fisheries New Zealand and preceding government departments done nothing about it before?

Why does it take so long for anything to be accomplished for the better good of the environment and the general public?

These questions are only a few of the many that will be asked in the coming weeks and months.

The general public knows that there is not a government department that can take the initiative and be proactive, rather than reactive, in anything that they do.

There is a common thread among upper and top-level management that "shutting the gate after the horse has bolted", is the generic thing to do. "If I don't make a decision then I can't be held accountable", is the thought process that comes to mind.

It appears to myself and the general public that at this level, management is not capable of running a bath, let alone a government department.

The art of Procrastination seems to have been perfected at this high level of management and it gets even better and more refined as time goes on.

There is now an opportunity for Fisheries New Zealand to break this government's mindset way of thinking take the initiative and be proactive.

With more community involvement, suggestions can be sought and ideas noted, so a plan of action can be put in place, sooner rather than later.

My submission has some points that I believe will benefit both the sustainability and future welfare of the scallops as well as the public interest.

My points are as follows:

- An initial temporary closure of 2 years on all taking of scallops, effective immediately. This will help enable the existing scallop stocks to recover to sustainable numbers.
- Ban recreational dredging.
- Reduce the season from 6 months, (1st September – 31st March), to 2 months, (1st December – 31st January).

- Reduce the daily catch limit for boats to 80 scallops maximum, regardless of the number of people on board. The daily catch limit still remains at 20 scallops per person, i.e 20 scallops per diver either on scuba or free diving and 20 scallops each for the 2 safety watches.
- Government-funded research to be provided to help monitor the health of the scallop beds in the affected areas.

The points noted above are not the only points to be considered, but when added to the "Think Tank" of other ideas, will give more options to choose from.

Other submissions will have valid points which when compiled together, can give some direction in what steps should be taken to preserve the future scallop numbers.

There is an opportunity for Fisheries New Zealand to take proactive steps and to do something now to preserve the scallop fishery for current and future generations.

Be the first government department to break the mould and be proactive in resolving a problem.

You now have the chance to do the right thing.

What you decide to Do, or Not Do, as a government department, will have implications for future generations. In the future scallops may still be around in sustainable numbers for all to enjoy, OR they will be relegated to the past as a memory and as pictures in a book.

Do the right thing and don't Fuck it up.

Yours sincerely

Paul Ganley

Please continue on a separate sheet if required.

Submission to Fisheries New Zealand on the review of sustainability measures for New Zealand scallops: (SCA 1 & SCA CS) for 2022/23

Introduction

I have gathered scallops by hand while snorkelling or scuba diving regularly since 1987 in various New Zealand locations including the Bay of Plenty, Tasman District, Marlborough Sounds, and Northland. In Northland most of my scallop gathering has taken place in the Bay of Islands where I have lived since 2006. I have also gathered scallops elsewhere in Northland including Whangarei Harbour. I have witnessed the collapse of Bay of Islands' scallop beds. I have not harvested any scallops from this area for several years now due to the extremely low densities of harvestable scallops now present.

I have a PhD in environmental science and policy. My 2011 PhD thesis developed quantitative methodology for measuring coastal (aquatic and terrestrial) natural character/ environmental naturalness. I have carried out marine ecological assessment and monitoring in a variety of locations including various Northland locations such as the Bay of Islands. I am writing a book about New Zealand marine environment history.

Preferred option

Given the declines in New Zealand scallop stocks shown in the 2021 discussion paper, Fisheries New Zealand identifies three options for the future management of New Zealand scallops for SCA 1 and SCA CS.

Option 1 proposes a full closure of the scallop beds in SCA 1 and SCA CS. This is strongly supported. It is proposed that new information be sought within three years, although I note that there was a fourteen year gap between data collections for the Bay of Islands while the stock continued to decline significantly to a state of collapse. There needs to be considerable caution before opening the beds, particularly in the Bay of Islands. To this end a strategy should be prepared specifying density thresholds for different size classes and recruitment rates. In the Bay of Islands it is highly likely that a longer closure time would be needed.

Option 2 proposes a partial closure, prohibition of recreational dredging and reductions to the TAC, recreational take and TACC (with no commercial harvest). In Northland, Smugglers Bay and Urquarts Bay on Whangarei Harbour would remain open, although I note that this is not supported by tangata whenua (Te Renga Paroa (Whangarei Harbour)). In Coromandel, recreational gathering would be permitted in the scallop beds to the southwestern of Little Barrier Island/ Te Hauturu-o Toi and in Colville Channel. All other scallop beds would remain closed to recreational gathering, with a three yearly data collection proposal as for Option 1. My comments on this in relation to Option 1 also apply to Option 2.

Option 3 proposes that the TACC for both SCA1 and SCA CS be set at zero and that there be a pre-season survey and CAY estimate which may result in an in-season increase (above zero) for that season. Commercial collection dredges would still be allowed, in spite of the environmental damaged caused. There would be a prohibition on recreational dredges.

My position is that my strongest support is for Option 1. I would also support Option 2 as this provides for recreational gathering at only a few locations which appear to have reasonable stocks at this stage. I do not support Option 3 as this would not sufficiently protect and restore severely damaged or collapsed scallop beds such as those in the Bay of Islands.

Other matters relating to the proposal

1. When depicting the boundaries of the closed area in the Bay of Islands, I strongly recommend that all of the Bay of Islands is included. Scallops have been gathered in more areas than those shown in the Discussion Document Figure A1. Given the collapse of the scallop beds in the Bay of Islands, I recommend that all the Bay of Islands should be closed to recreational scallop gathering. This is necessary to improve the chance for recovery of the currently collapsed Bay of Islands scallop beds.
2. As the recruitment sources are not fully understood a full ban on scallop gathering or "fishing" is probably needed to maximise recovery chances for the scallop beds in Northland, Auckland and Coromandel.
3. Given the damage to benthic habitats caused by scallop dredging (outlined in the discussion document and elsewhere), a ban on recreational dredges in SCA 1 and SCA CS is supported. This is proposed in Options 2 and 3, but not in Option 1 given the proposed prohibition on all harvest. The use of recreational dredges for collecting sea food should be prohibited for all options.
4. The prohibition on the use of recreational dredges would prevent benthic habitat damage from that source. It could also help to prevent damage to the limited remaining soft sediment subtidal beds of green-shell mussel and horse mussels. Wild green-shelled mussels on soft-sediments in the Hauraki Gulf are very much reduced following the overharvesting in the first half of the twentieth century. In spite of considerable research, success in re-establishing these beds has been patchy with most relocated mussels[1] failing to thrive/ survive. Intact horse mussels are an important biogenic habitat that is prone to damage from dredging. The extent of heathy examples of this biogenic habitat is much reduced.
5. Moves to reduce the use of dredges by commercial fishers are supported. Scuba or UBA diving should cause much less habitat damage although there would be a need to ensure that heavy bags of scallops are not dragged along the sea bed.
6. A strategy for rebuilding scallop stocks should be prepared to provide more clarity on what conditions need to be met before beds are reopened for gathering scallops. This strategy should specify abundance levels for different size classes and recruitment rates. Any reopening should be done extremely cautiously to prevent a short term intensive gathering boom that crashes the scallop populations again.
7. The recreational scallop harvest season needs to be reviewed. It is my observation that shifting the start of the season from 15 July to 1 September and extending the season by six weeks at the far end, led to notably greater levels of scallop collection activity. Relatively few people gathered scallops from 15 July to 1 September given the cooler water temperatures, reduced scallop quality and less boating activity. The six weeks from 15 February to 31 March appears to have resulted in a higher scallop take because waters are warmer, scallops are in better condition and people are undertaking more boating activity. I recommend that when the recreational scallop beds are reopened for the collection of scallops, that the collection season be shortened.

Scallop beds in Spirits and Tom Bowling Bays

I recommend that given the outstanding ecological values of the unique benthic communities and the history of rapid scallop decline, that this commercial scallop bed be permanently closed. In

[1] Usually small mussels from mussel farms)

addition, given the ecological values of these benthic communities, the benthic protection area established in 1999 should be extended to include a greater extent of this special environment. The reasons for this are documented below:

"The area between North Cape and Cape Reinga is unique and of national importance for its exceptionally high diversity and high rate of local and regional endemism" (p.9, Tuck et al 2010). For example, Tuck et al. documented that existing studies had recorded 310 sponge species. *"Of these, 87 (28%) are known from Spirits Bay only. An additional 95 (31%) are known from the Spirits Bay region only. Of the 117 genera represented, within New Zealand, 38 (32%) are only found in the Spirits Bay region, and 5 are unique globally to the Spirits Bay region. Two genera (Crambe and Lithoplocamia) are found elsewhere only in fossil taxa". "The genus and species diversity of marine sponges in the Spirits Bay region is unprecedented in New Zealand, as it is known at present ..."*

During the 1990's the commercial scallop fishery in this area had a large and unusual bycatch of sponges, bryozoans and hydroids. In 1997 local fishers instituted a voluntary closure. NIWA research (Cryer et al 2000), funded by the Ministry of Fisheries, examined the nature and extent of the benthic communities and identified a probable link between dredging for scallops and a decline in the quality of the unique benthic communities. A regulated closure of some of the area was introduced in 1999. Tuck et al (2010) reported that the specific area sampled by Cryer et al. (2000) supported high biomass scallop harvests for several years following its discovery, but by the time of sampling in January 1999, few adult scallops were found, and no scallop spat.

Tuck et al. (2010) reported *"Significant differences were identified between the "voluntary" (closed since 1997), "regulated" (closed since 1999), and "open to fishing" areas, and species contributing to differences in communities included those previously identified as being most vulnerable to the effects of fishing. However, the community differences could not be attributed specifically to fishing, owing to environmental gradients and uncertainty over the history of fishing impacts in the area. No significant differences were identified within areas between 1999 and 2006, suggesting there has been no detectable change (impact in fished areas, or recovery in closed areas) over this time."* The characteristics of many of the species found in these benthic communities are such that more time would be needed before there would be notable recovery

Bay of Islands scallops

While there have been a number of informal anecdotal reports of declining scallop numbers and abundance in the Bay of Islands for about five years, there was no formal monitoring of the scallop beds between 2007 and 2020. Earlier and more-timely monitoring and an appropriate management response may have prevented the collapse of the Bay of Islands scallop beds.

I began snorkelling for scallops in the eastern Bay of Islands before 2000. It was easy to collect scallops by swimming out from the southern shore of Urupukapuka. When I moved to the Bay of Islands in 2006, shore-based snorkelling was not so practical. Scuba diving was relatively shallow and focused on areas north and south-west of Poroporo Island. Over time different areas were popular –including sites closer to Rawhiti and various locations around several of the Ipipiri Islands. In later years deeper dives were required. From late 2016 it consistently became much more difficult to find legal scallops. After several years with very low scallop numbers early in the season I stopped looking to collect scallops. I have more detailed information about scallop locations and abundance changes since 2006.

Victoria Froude

6 February 2022

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person: Nicolas Somerhayes	
Organisation (if applicable):	
Email:	
Fishstock(s) this submission refers to:	SCA 1 & SCA CS
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	Option 1

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Fisheries New Zealand
Tini a Tangaroa

Submission:[1]

Details supporting your views:

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

Fisheries New Zealand
Tini a Tangaroa

I have been a recreational diver who has collected Scallops in Taurikura Bay for the past 7 years.

During the past 3 years I have noticed a gradual decline in Scallop numbers however this current season I was alarmed by how low the scallops stocks were.

I would support the total closure of the beds until stock return ton a sustainable level, I would also support reduced catch numbers when the beds reopen to prevent this from happening again.

One suggestion I would like to make is an overall boat limit. For the below example I have used 100 scallops as an overall boat limit.

A boat with 3 dives, skipper and a safety person can collect up to 100 scallops.

If that same boat has 4 divers, skipper and a safety person they would still be limited to up to 100.

If they only had 2 divers, skipper and safety person they would be limited to 80 scallops

Please continue on a separate sheet if required.

Fisheries New Zealand
Tini a Tangaroa

Please continue on a separate sheet if required.

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person: Alicia King	
Organisation (if applicable):	
Email:	
Fishstock(s) this submission refers to:	New Zealand scallops (SCA 1 & SCA CS)
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	Option 1: Full closure

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Fisheries New Zealand

Tini a Tangaroa

Submission:[1]

Details supporting your views:

As a recreational diver and local resident of Whangarei Heads, I am concerned about the decline in scallops we have noticed over the last 12 months. The Whangarei Harbour has experienced a rapid decline in number and the overall size of the scallops present in the main beds that we dive on including McLeod Bay, Urquharts and Taurikura.

It is also evident that the seabed is changing due to excess sediment run-off from the land.

I feel that a full closure now, will give a much better chance for us to see what is causing the major decline in scallop numbers and to allow us to better mitigate and manage the impact.

I would also like to see recreational dredging of scallops banned within the Whangarei Harbour for the foreseeable future due to the detrimental impacts it has on the scallops and the seabed.

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

Please continue on a separate sheet if required.

From:	Andrew Wiseman
To:	FMSubmissions
Subject:	Review of sustainability measures for NZ scallops – 2022 ; submission by Andrew Wiseman
Date:	Tuesday, 8 February 2022 1:05:39 PM

I own a property at Urquharts Bay at the entrance of Whangarei Harbour. I have regularly dived for scallops in Whangarei Harbour for 39 years. My experience has provided an opportunity to observe how scallops are taken, who takes them and the effects on scallop beds. My comments are: **Comment on Whangarei scallop situation**

- Pressure on scallop beds around Whangarei increases as locations becomes known. Knowledge is bed locations is now publicised on media such as facebook and snap chat, and is circulated quicker and more widely than it was previously. We can't change that. Despite good spots being more widely known, an advantage of the entire harbour being available is that it spreads the load. There are always divers going somewhere else, for example Takahiwai, Parua Bay, McLeods Bay and Taurikura. Over time, people also move around and pressure on each area is relaxed, allowing recovery. A legislative change focussing every diver on Urquharts and Smugglers would be an absolute disaster in my opinion, and a death knell for scallops there.
- Urquharts Bay and Smugglers Bay are examples of how incredible pressure by recreational divers can be sustained by scallop beds if take limits are maintained and the load is spread by allowing divers to also dive elsewhere. Unfortunately at Smugglers Bay after many years of excellent diving the scallop beds disappeared overnight several years ago. The suddenness of the change suggested by illegal and systematic GPS commercial dredging. I did observe dredge marks at the time. Similarly Urquharts Bay has sustained extreme diver pressure for several years. However at the start of the 2021/22 season I observed the best scallop numbers there that I've ever seen. Then, three months into the season the bigger scallops disappeared almost overnight. It is currently so hard to find a legal sized scallop, that I no longer dive in Urquharts Bay. In my opinion the dramatic change was caused by scallop smuggling, or customary take, both of which remove thousands of scallops at once. *Smugglers Bay and Urquharts Bay illustrate that bulk gathering techniques such as commercial dredging and customary take can be unsustainable techniques that tip over the scallop beds and ruin it for everybody.*

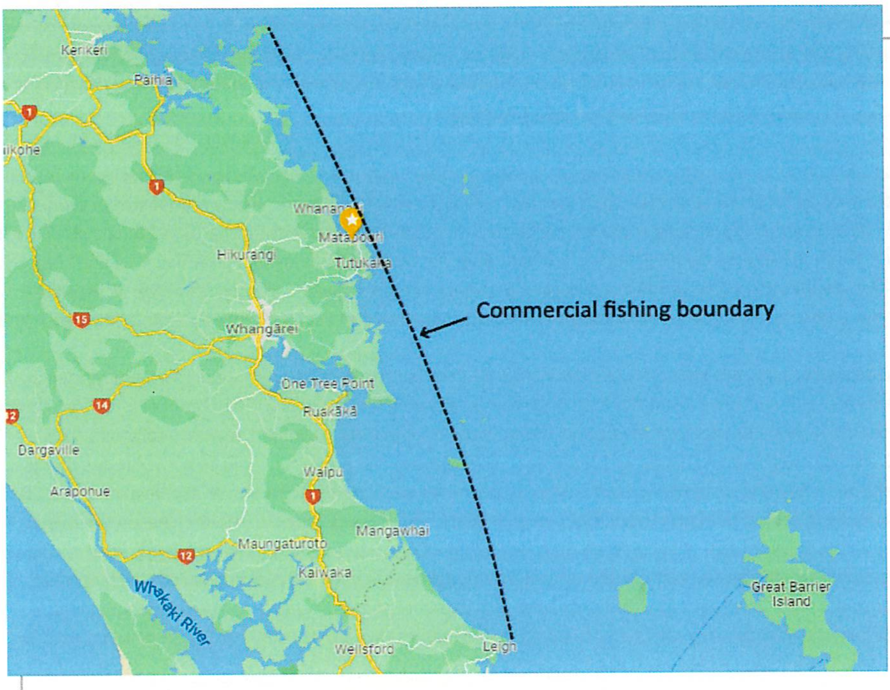
Customary permits

- Scallop smuggling and customary take are both widespread in Whangarei. Loss of scallops in Bay of Islands and Doubtless Bay has resulted in increasing pressure on Whangarei Harbour scallops. Bulk gathering techniques can only be dealt with by logical rules and active policing. Arguably customary divers from outside Whangarei are not mana whenua and should have no customary rights. It is disappointing that Whangarei iwi seems to have so little control.
- After decades of customary permits there appears to be no documentary evidence of how many permits have issued, who they issued to and what take was permitted. Paragraph 91 of the review states that , *While scallops are a common species for which customary authorisations are issued, there is limited quantitative information available on the level of customary take of scallops from both SCA 1 and SCA CS.* The review options relating to iwi take have been created without a fundamental basis. In effect there is no restriction or limit on customary take either in place or proposed, in numbers or size.
- Customary permits need to be structured and organised to control the effect on total take. Irrespective of treaty provisions, if Te Renga Paraoa wants to be remembered positively for it's role a kaitiaki, then self imposed permit rules would be helpful eg:
  - Permits in the Whangarei rohe should be issued by an authorised kamatua of Te Renga Paraoa.
  - Permits can only be issued to local applicants eg Whangarei iwi/hapu members (other iwi have recreational rights)
  - Iwi needs to deliberate on what qualifies as an acceptable reason for issue of a customary permit, recognising that applicants already have recreational rights. For example Tangi, but not birthdays or homecomings.
  - Permits must issue to a person, not a group, with proof of identity recorded by the kamatua eg license, passport.
  - Permits should be electronic and tamperproof
  - Permit details could be recorded and submitted to Fisheries NZ on the day of issue, preferably automatically
  - Permits could impose the same size limits as for recreational take eg scallops 100mm. Currently they don't, resulting in undersized scallops being taken.
  - Customary take could be restricted to reflect iwi's understanding of declining numbers eg 200(?) scallops.

Commercial

- Existing commercial fisherman have a right to fish. Removing their right as proposed is for the community good. Accordingly fishermen deserve to be compensated for their loss. This cost should be met by the community (Govt) which receives the benefit. The approach for calculating compensation could be modelled on taking of land pursuant to the Public Works Act ie market value of the interest lost.

  Bream Bay and Whangarei Harbour provide a breeding for the entire food chain, as does much of the coastal area. Protection from commercial fishing is the single most effective change that could be made. A simple suggestion is a total ban on commercial fishing inside a line from Leigh to Cape Brett, including the Hen and Chicken Islands. This could be linked with changes to commercial fishing in Hauraki gulf. Recent commercial restrictions in Hauraki Gulf have simply encouraged fishmen to come north to Bream Bay, which has increased overfishing already occurring.



Proposed changes to TAC, TACC

- I disagree with all three options. Providing 3 options in a review should not prevent other more practical options being considered and adopted, particularly if all three option presented are inappropriate or unacceptable.
- None of the three options reflect any change on customary take. Acknowledging that Fisheries NZ has consulted with Iwi in preparation of the report and that Iwi recognises there is a problem with sustainability, it would appear shameful on iwi that no change is proposed to customary take, while at the same time it proposes that commercial take should be discontinued completely, and that recreation take should be allocated to a small number of locations which will result in a concentration of divers that will quickly decimate the resource, and effectively discontinue the availability of recreational scallop diving also. In my view Iwi needs to come to the table and show some mana by restricting customary take by 50%, while structuring the consent process as suggested above..
- The incidence of private dredging in my experience is so low that it is inconsequential, particularly when compared to smuggling, commercial dredging and customary take. I've seen dredges go past while diving. They typically move slowly and push scallops out of the way, or scoop them up depending on size. The incidence of dredging and effect of dredging on the resource seems so small, that banning dredging is unjustified. People that do dredge usually have no alternative option. They only dredge because they have to. Removing this right is unreasonable, based on the sketchy information provided by the review.
- Concentration of recreational diving on a small number of specific areas will wipe out legal scallops very quickly. It removes the natural advantage to both scallops and divers of leaving divers free to move around as they please, which reduces the concentration of divers on key areas, and provides relief to overfished areas when divers move on.
- Altering fishing rules is an obvious approach to reducing overall take, without undue hardship. One obvious suggestions is a boat limit of say 50. Scallops per diver could also be reduced.
- I agree that TACC should be discontinued, provided fishermen are compensated.
- ***My suggestions for a fourth option to reduce SCACS TAC by 43% from 30 to 13 are:***
  Reduce TACC from 10 to 0. Compensation required.
  Reduce customary Maori from 7.5 to 4.0 by imposition of structure to the consent and recording process, and application of iwi led rules (see above – Customary Permits).
  Reduce recreational take from 7.5 to 4.0 by imposition of a boat restriction of 50 scallops maximum and reduction in take from 20 to 15 per diver (25%)
- ***I would be grateful for confirmation that my submission has been received and considered. Thank you.***
- ***Regards, Andrew Wiseman***

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person: Matthew Conmee	
Organisation (if applicable):	N/A
Email:	
Fishstock(s) this submission refers to:	SCA 1 and SCA CS Scallop management area
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	Option 1

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Submission:[1]

Details supporting your views:

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

I have dived the Northland area for over forty years and in that time I have not seen such a depletion of the scallop resource, particularly in Whangarei harbour. I think resting the resource from all exploitation would be part of the best option for the future.

I note with interest that local Tangata Whenua have already taken the step to put a Rahui on the resource, it therefore seems logical to follow suit. If we are not all on the same page then we are lost.

Closing the resource to all will also make it a far easier policing activity for MPI and their associated Tangata whenua agencies.

Fisheries New Zealand

Tini a Tangaroa

Please continue on a separate sheet if required.

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person:	**Chris Wade and Shirley Wills**
Organisation (if applicable):	
Email:	
Fishstock(s) this submission refers to:	Scallops
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	Option 2 (including a Section 186a Closure)

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Submission:[1]

As Urquharts Bay residents we have observed over the last few years how overwhelmingly popular the Bay has become for Scallop gatherers. At any one time we could count up to 75 recreational boats in the bay, notwithstanding all the shore divers.

We would really support a Section 186a temporary closure of two years for Urquharts Bay and Smugglers Bay with even a Radui also put in place for the same period of time.

This valuable resource needs time to recover and then kept under constant review.

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

Fisheries New Zealand

Tini a Tangaroa

Please continue on a separate sheet if required.

From: Z Tisot
To: FMSubmissions
Subject: Review of sustainability measures – 2022 April round - Review of Sustainability Measures for New Zealand scallops (SCA 1 & SCA CS) for 2022/23
Date: Monday, 7 February 2022 11:53:20 AM

Submission on Review of Sustainability Measures for New Zealand scallops (SCA 1 & SCA CS) for 2022/23

Submitter Details:

Tony & Joanne Tisot

PH:

I support the following changes to the SCA 1 & SCA CS areas; Option 3
I also have the following comments and recommendations;
The NZ Fisheries are an asset that should be conserved for all new Zealanders to enjoy and not primarily by a select few for commercial purposes, after all the fisheries belongs to all New Zealanders.

Statistics clearly show the commercial catch has the most significant affect on reducing stocks and causing damage to the seabed.

The primary objective should be to protect our fisheries for future generations to enjoy. Export revenue should not be a part of our dwindling natural resource.

The commercial revenue with a ban on these 2 areas from commercial harvest is less than $1M per annum, yet would make a significant impact on stock recovery.

A very small commercial loss of revenue to protect our Scallop stocks for the future.

Recommendations:

1. Ban all dredging (commercial & recreational) to protect the seabed and reduce the destruction of fish stocks.
2. Ban all commercial Scallop harvesting.
3. Increase the number of Marine Reserve areas to allow greater stock recovery.

We live at Omaha beach, Warkworth and our community values the sea and enjoy harvesting a variety of seafood for our families.

It's noticeable over the last 30 years that harvesting has become more difficult with continuously reducing stocks of all the sea life that was at one time abundant.

Since the closure of the Coromandel Scallop area, late in 2021 we have seen commercial scallop boats within the Omaha beach prohibited commercial fishing zone dredging through our small beds, particularly during the evening when it's impossible to identify the ship. The Omaha Beach Scallop stocks were completely annihilated by commercial dredging many years ago and have managed to slowly recover, however it only takes a single commercial dredge ship to devastate the beds and the seafloor.
Kind regards
Tony & Joanne Tisot
Sent from Mail for Windows

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person:	
Organisation (if applicable):	
Email:	
Fishstock(s) this submission refers to:	Scallops – SCA 1 and SCA CS Northland, Auckland and Coromandel
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	I want recreational dredging banned and the commercial quota reduced significantly. A ban on all scollop gathering needs to be implemented immediately until the beds rejuvenate.

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Submission:[1]

D
I have been diving recreationally for scollops in SCA 1 and SCA CS for over 30 years and have never seen the scallop beds so empty. This happened within two years of the last significant increase in commercial quota. I have also witnessed many more dredging markings in our scollop bedded areas. I would like to see our beds return to their former biomass or even healthier to have a sustainable fishery for future generations. It saddens me that my friends and family can not dive and collect a meal because the commercial quota was increased to a proven unsustainable amount.

Thank you for reading my submission.

Ross Christensen.

etails supporting your views:

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

Please continue on a separate sheet if required.

Fisheries New Zealand
Tini a Tangaroa

Submission Form

Review of sustainability measures for 1 April 2022

Once you have completed this form

Email to: FMsubmissions@mpi.govt.nz

While we prefer email, you can also post your submission to:

2022 Sustainability Review, Fisheries Management, Fisheries New Zealand, PO Box 2526, Wellington 6140, New Zealand.

Submissions must be received no later than 5pm on Tuesday 8 February 2022.

Anyone may make a submission, either as an individual or on behalf of an organisation. Please ensure all sections of this form are completed. You may either use this form or prepare your own but if preparing your own please use the same headings as used in this form.

Submitter details:

Name of submitter or contact person: Graham Brough	
Organisation (if applicable):	
Email:	
Fishstock(s) this submission refers to: Scallops – SCA 1 and SCA CS My experience of over 50 years observing this fishery makes me believe it's in a perilous state and needs to be significantly reduced with urgency And although not asked for here, a blind man can see that our inshore fisheries are severely depleted and need urgent protection. An immediate ban on ALL bottom trawling is required along with more areas being converted to marine reseves which will help most species in their recovery	

Fisheries New Zealand
Tini a Tangaroa

As a	
Your preferred option as detailed in the discussion paper (write "other" if you do not agree with any of the options presented):	

Official Information Act 1982

Note, that your submission is public information. Submissions may be the subject of requests for information under the Official Information Act 1982 (OIA). The OIA specifies that information is to be made available to requesters unless there are sufficient grounds for withholding it, as set out in the OIA. Submitters may wish to indicate grounds for withholding specific information contained in their submission, such as the information is commercially sensitive or they wish personal information to be withheld. Any decision to withhold information requested under the OIA is reviewable by the Ombudsman.

Submission:[1]

Details supporting your views:

[1] Further information can be appended to your submission. If you are sending this submission electronically we accept the following formats – Microsoft Word, Text, PDF and JPG.

Please continue on a separate sheet if required.

From: John Beu
To: FMSubmissions
Subject: Review of Sustainability Measures for New Zealand scallops (SCA 1 & SCA CS) for 2022/23
Date: Tuesday, 8 February 2022 8:52:40 AM

Good morning

I support option 3 of Review of Sustainability Measures for New Zealand scallops (SCA 1 & SCA CS) for 2022/23.

Sincerely
John Beu

From: Sue Beu
To: FMSubmissions
Subject: Review of Sustainability Measures for New Zealand scallops (SCA 1 & SCA CS) for 2022/23
Date: Tuesday, 8 February 2022 8:54:21 AM

Good morning

I support option 3 of Review of Sustainability Measures for New Zealand scallops (SCA 1 & SCA CS) for 2022/23.

Sincerely
Susan Beu