SIPF C0083 - Effects of electrofishing for *Ensis* spp. on benthic macrofauna, epifauna and fish species

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Effects of electrofishing for *Ensis spp.* on benthic macrofauna, epifauna and fish species.

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Acknowledgements

The current report presents and analyses the data produced by a number of different workers involved in the "*Design and Trials of Electrofishing System for Razorclams – FIFG 57437*" project. Stephen Thompson was project officer responsible for managing the project, carrying out the developmental field work and macrofaunal grab sampling. Dive surveys were undertaken by divers from MarineSeen, Francies Bunker, Jon Moore, Lou Luddington and Jen Jones. Divers from Kaymac Marine Ltd. provided vital observations and video footage during experimental stages of the project. Barry Thomas skipper of *MV Shield*, and Tony Walker skipper of *FV About Time*, provided vessels for experimental and sampling work.

Executive Summary

This report summarises the results of experimental work carried out as part of "*Design and Trials of Electrofishing System for Razorclams – FIFG 57437*". The aim of the project was to design and trial methods of harvesting *Ensis spp.* using electrical stimulus with the intention of providing a more environmentally benign alternative to existing hydraulic and toothed dredges.

The simple electrofishing gear used in this projected employed a voltage of 30 v DC with a current of 140 A. This produced a maximum electrical field strength of 50 vm^{-1} between the electrodes; a voltage at which guidelines consider it is safe for divers to come into direct contact with the electrodes.

A field experiment was developed and implemented to determine negative effects on non-target invertebrate macrofauna, and epifauna including fish species. A modified BACI (before-after-control-impact) design established a series of four 200 m x 100 m experimental areas containing 50 m x 100 m fished (treatment) or control sectors in Carmarthen Bay south Wales. The electrofising gear was used in the in the 'treatment' areas by fly dragging in order to simulate a commercial fishing operation.

In order to determine whether the electrofising gear had negative effects on non-target macrofauna a series of macrofaunal grab samples were collected from each sample sub-sector before fishing, and then variously at intervals up to 28 days post-fishing. Epifaunal species were sampled by divers surveying transects before and after electrofishing treatments. Throughout the experimental work commercial divers recorded observations and video footage was reviewed for visual effects on species and changes in behaviour.

Multi- and uni-variate analyses, supported by behavioural observations, resulted in the following conclusions:

Short-term effects on macrofauna: Analysis (ANOSIM) of macrofaunal samples 1 day post-fishing determined that there was no significant effect between fished and control treatments. This result confirms that any short-term effects of the electrical field on the macrofaunal species are not fatal and are resolved in 24 hours.

Long-term effects on macrofauna: Analysis (ANOSIM) of macrofaunal samples found no significant changes in the community or relative species abundance over the 28 days post fishing. The post-fishing univariate analysis (REML) of individual species, which included commonly occurring representatives from the polychaetes, crustacean and molluscs, found that there were no long-term effects to abundance.

Short-term effects on epifauna and fish: Observations recorded by divers and review of video footage revealed that the short-term effects on epifauna and fish were predominantly stupefaction and disorientation suggesting an effect of the electrical field on the nervous system of these animals. These effects were observed to be temporary and short-term; of the 4 species of crustaceans, 6 species of molluscs, 3 species of echinoderms and 3 fish species observed only *E. siliqua* was recorded to take more than 5 minutes to resume normal behaviour.

Long-term effects on epifauna and fish: Analysis (ANOSIM) of epifauna dive survey data no significant changes in the epifaunal community over the 28 days post fishing. The long-term effects on fish remains undescribed although the escape response of fish to disturbance provides an effective natural protection from any unreported negative effects of the gear and is considered as of low risk.

Conclusions: The results of this study demonstrate that the effects of electrofishing gear employing relatively low DC voltage and amperage can be effectively used in the harvest of *Ensis spp*. without serious negative effects on the epifaunal and macrofaunal benthic community. Given the commonly reported negative effects of alternative approaches such as hydraulic and toothed dredges the results of this study suggest that further development work is warranted in order to develop less disturbing fishing gears, both for *Ensis spp.* and for other species.

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1.0 Introduction

South and West Wales Fishing Communities Ltd (SWWFC) has identified a global market for live and processed razorfish (*Ensis spp.*) exists and that stocks of these are widely distributed around the South Wales's coast. These stocks are believed to hold sufficient biomass to establish a sustainable fishery with significant socio-economic benefit for local communities. Given the negative environmental and commercial issues associated with existing harvest methods such as hydraulic and toothed dredges (see below) SWWFC has wished to develop a more environmentally benign harvest method. To this end the current study was developed to examine the utility of using electrical stimulation to trigger the *Ensis spp.* emergence and escape response in the harvest process therefore avoiding the need for disturbing seabed penetrating gears.

Although the use of electricity for fishing is prohibited in the EU under Article 31 of EU Regulation 850/98, which addresses the use of unconventional fishing methods, it has been reported that electricity, if used appropriately, could reduce seabed impacts and reduce bycatch from mobile fishing gears (ICES, 2010). The aim of the "*Design and Trials of Electrofishing System for Razorclams – FIFG 57437*" project was to develop and trial, in commercial conditions, a system for the electrofishing of *Ensis spp.*

This report presents and reviews the ecological sampling results and outputs of the project.

1.1 Review of Current *Ensis spp.* Harvest Methods

Ensis spp. are currently harvested in Europe using a number of alternative methods which range from small scale hand collection to relatively large scale operations employing sizable vessels and fishing equipment. Table 2 presents an overview of commercial and ecological constraints, requirements for existing *Ensis spp.* harvest methods.

1.1.1 Intertidal Hand Collection

It is possible to collect *Ensis spp.* by hand or with the use of bait pump on the lower shore during low water spring tides. The *Ensis spp.* burrow is identified by its characteristic keyhole shaped burrow and by the "spurt" of water being ejected when the animal attempts to burrow when disturbed.

There are a number of methods employed to extract *Ensis spp.* from its burrow.

- A small thin blade quickly inserted into the burrow can jam the animal against the burrow side and then the can be dug out by hand
- A razorfish spear (a small spear with a metal barb) can be inserted into the burrow. When it passes into the animal it is twisted 90° after which it can be gently prized out
- The most common and effective hand collection is 'salting'. *Ensis spp.* exhibit an escape response enabling them to leave their burrow and actively move over the seabed when exposed to an irritant such as salt. A common method of 'salting' employs plastic washing up liquid bottles filled with a concentrated brine solution. This solution is poured into the burrows and after a few minutes the animals will appear at the surface and gently extracted.
  'Salting' can be employed to harvest large quantities from an intertidal *Ensis spp.* bed; large quantities of salt is scattered on the beach concentrating on the *Ensis spp.* burrows whereupon the animals are collected as they appear on the surface.
  There is limited information on the environmental effects of the use of large quantities salt on intertidal communities although a recent report on the use of salt to manage invasive seaweeds

by inducing osmotic shock reported significant effects on marine invertebrate communities with recovery times up to six months (Creese *et al*, 2004).

1.1.2 Diver gathering

This method employs similar methods to intertidal hand gathering with divers swimming over a bed looking for the burrow openings. Identification of burrow openings is easier underwater as the distinctive *Ensis spp*. siphons are visible at the sediment surface. To collect the *Ensis spp*. the diver thrusts their fingers or a suitable tool into the sand surrounding the burrow which prevents the animal burrowing and the animal extracted which a gentle twisting movement.

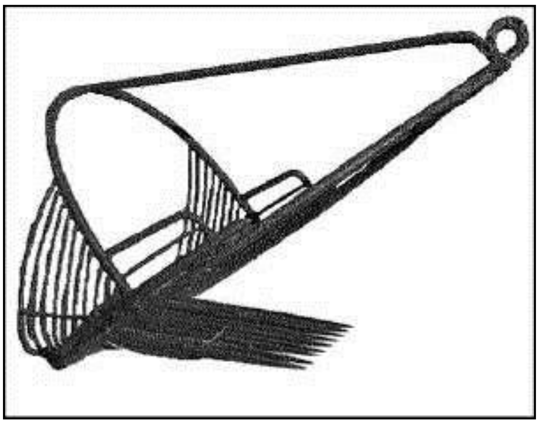
1.1.3 Divers employing salt

In a process similar to intertidal 'salting' divers use concentrated salt solution applied using a plastic washing-up liquid bottle or similar larger container. The salt solution is spread over a wide area and the animals collected when they emerge. Anecdotal reports from divers working in Scottish razorfish fisheries suggest that in sheltered sites the salt may remain in a layer on the seabed and encourage the formation of microbial mats.

1.1.4 Toothed dredges

Gaspar *et al* (1998) described the toothed dredges are commonly employed in the Portuguese shell fishery where *Ensis siliqua* are targeted along with other bivalve species (*Spisula solida*, *Chamelea gallina* and *Donax trunculus*) (Figure 1). The dredges are towed two per vessel in relatively shallow water < 10 m.

Figure 1. Typical Portuguese toothed dredge (From Gaspar et al, 1998, 2003)



Although optimised for other bivalve species (Gaspar, 2003), the key commercial limitations of this type of dredge are the high level of breakage and damage to *Ensis spp.* inflicted during fishing and the high level of grit and sand remaining in the razorfish after fishing which may preclude them from being sold to the live market without a viable method of de-gritting or depuration.

The negative effects of dredges on soft seabed habitats are well reported including: the formation of tracks and mounds in the sediment; the suspension and winnowing of fine fractions of sediment habitat; reduction in faunal abundance in dredge path lasting a number of months and indirect ecological effects such as exposing otherwise buried fauna to predation (see review in Sewell & Hiscock, 2005).

1.1.5 Hydraulic dredges

This technique is employed in the UK, Ireland, Italy Portugal, Spain, and in the USA in New England waters where is a commonly used method of harvesting bivalve shellfish from the sediment. Hydraulic dredges operate by directing a water-jet into the seabed which acts to fluidise the sediment.

There are a variety of hydraulic dredge designs but all are variations on a common theme. The dredge body is constructed of a steel frame covered with a steel mesh or parallel bars with 10-35 mm spacing. Water is supplied under pressure (2-3 bar) from a pump either on the vessel or on the dredge itself (hydraulically powered) and is directed through a manifold into the seabed sediment fluidizing it. The dredge is slowly dragged across the fluidized sand assisted by a blade on the front edge of the dredge. The dredge/blade can penetrate to a depth of 300 mm and retain any animals passing into the dredge. The mesh or bar spacing allows sediment and smaller fauna to pass through and the dredge proceed. Recent innovations have reduced the penetration of the dredge which can be adjusted to skim the sediment surface collecting *Ensis spp*. (pers. comm. Barry Thomas, SWWFC Ltd). These dredges are usually limited to water depths of less than 10 m due to the difficulty of providing sufficient water pressure at deeper depths.

Recent studies have indicated that an optimised dredge may be as much as 90% efficient in harvesting Razorfish (Hauton *et al*, 2006) and other adaptations may increase the sorting and condition of the target species such as the vibrating and sorting bottom grid described by Rambaldi *et al*, 2001. Gear development trials have been recently carried out in the Wash *E. directus* fishery by Cefas and Seafish (Palmer et al. 2006).

Levels of breakage and damage to the Razorfish incurred during fishing appear to be variable but can be reduced with optimisation of the gear (see Hauton et al, 2007; Palmer et al, 2006). The high level of grit and sand remaining in the razorfish landed from hydraulic dredge fisheries may preclude them from being sold to the live market without a viable method of de-gritting or depuration. Dredged animals suffer from increased stress and mortality and may not survive long enough to supply the large Far East live market. Dredged *Ensis spp*. would likely be limited landings to the UK and European live markets and the less economically attractive frozen or processed market.

The negative ecological effects of hydraulic dredges on sheltered seabed habitats have been highlighted by a number of researchers (

Table 1). The potential scale of these impacts is a key driver for the development of more benign *Ensis spp.* harvest methods for use in South Wales; notwithstanding the wider biodiversity and ecological impacts, South Wales has extensive European Marine Sites which require a greater level of protection and therefore constrain the potential fishing opportunities for SWWFC Ltd members.

Table 1. Negative ecological effects of hydraulic dredges.

Physical Effect	**Biological Effect**	**Reference**
Formation of trench or track Long-term fluidization of the sediment	Damage to non-target species	Tuck et al, 2001
Long-term sediment changes Increase in shell material	Changes in community structure Changes in diversity Stock population changes	Fahy & Carrol, 2007
Sediment plumes (short-term < 1hour)		Meyer et al, 1981
	Changes in community structure	Morello et al, 2006
Short-term (<40 days) physical effects	Short-term (<40 days) recovery	Hall et al., 2006

1.1.6 Electrical fishing

> The capture of marine organisms using methods incorporating electric currents is prohibited in European waters:
>
> *Council Regulation (EC) No 850/98 of 30 March 1998 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms*
>
> *Article 31 Unconventional fishing methods*
>
> *1. The catching of marine organisms using methods incorporating the use of explosives, poisonous or stupefying substances or electric current shall be prohibited.*

At the time of the project inception fishermen in the UK (mainly Scotland) had been illegally experimenting with the use of electrical stimulus to harvest *Ensis spp*. This method acts to stimulate the *Ensis spp*. escape response of leaving its burrow when exposed to an irritant, as in the use of salt. These early operations involved a series of electrical cables fly-dragged[1] over the seabed in a V-shaped configuration and energised using a DC generator running at low voltage and variable amperage. As the electrical field passes over the *Ensis spp*. they leave their burrows to be collected by divers or less commonly a dredge.

Subsequent enforcement activity by Scottish Fisheries Protection Agency and the Health and Safety Executive has effectively stopped this activity in most areas.

Anecdotal reports from fishermen involved in this fishery and video footage circulated at the time suggested little seabed disturbance or prolonged negative effects on non-target species including diving birds (cormorants) and seals which habitually followed the divers. Some fish species were reported to be affected showing signs of being stunned and other bivalve species exhibited burrowing or escape response behaviour. These reports inspired the direction of the current study into developing this approach and to determine the environmental effects of electrofishing for *Ensis spp*.

A project to develop a novel *Ensis spp*. dredge design employing electrical stimulus was recently carried out in Ireland. The dredge employed pulsed current at 20 Volts DC at ~100 Amps and used a skimming blade to pick up *Ensis spp*. This project is still in the reporting stage but early reports were promising in that landings were comparable to those achieved by hydraulic dredges and crucially, the condition of the *Ensis spp.* once landed were better with lower breakages and long survival (Pers. Comm. Andrew Verwijs). This project obtained a derogation in Ireland under SI 171 Sea Fisheries (Technical Conservation Measures) Regulations 2006 giving effect to Article 31(1) of Regulation (EC) No. 850/98.

[1] A process in which the fishing vessel is hauled back at a slow speed across the fishing area to its own anchor.

Table 2. Review of commercial and ecological constraints, requirements for potential *Ensis spp*. harvest methods (adapted from Woolmer, 2007)

Harvest method	Operating procedures	Operating requirements	Limiting factors	Estimated equipment costs	Catch quality	Catch rates	Environmental impacts	Management measures	Potential for sustainable fishery
Intertidal hand collection	Walking on foot on lower shore, and extraction by hand/tool	None specific but ATV may be necessary for access	Limited to lower shore, and constrained by tides	ATV £1-4,000 Personal Protective Clothing ~£100 Bait Pump ~£40	Variable depending on method. Although potentially high quality live product achievable	Low <100 per hour	Low No physical Possible bird disturbance	MLS Access Permissions	Likely to be sustainable at very low effort
Intertidal collection using salt	Broadcast spreading of salt	None specific but 4x4 or ATV may be necessary for access	Limited to lower shore, and constrained by tides. Likely to be a 'one time' harvest due to size of bed accessible. May be a legal issue with the use of a chemical substance in the sea.	4x4 or ATV £1-4,000 Personal Protective Clothing ~£100	High quality live product achievable	Medium Potentially 1000+ per tide	No direct evidence but indications of some effects – likely to be limited by exposure of site	MLS Access Permissions	Not sustainable due to the potential for the removal of whole portions of bed.
Hand collection by divers	Diving from shore or vessel	Commercial diving qualifications (HSE IV) Need 3 divers on-board vessel operating in a fishery capacity	Weather dependant and visibility certainly a factor. Limited diver bottom time in deeper water	Diving gear ~£2-3000 Training ~£1500	High quality live product	Low <100 per hour	Low No Physical	MLS Effort Limitation	Sustainable but viability questionable due to catch rate
Divers using salt	Diving from shore or vessel	Commercial diving qualifications (HSE IV) Need 3 divers on-board vessel operating in a fishery capacity	Weather dependant and visibility certainly a factor. Limited diver bottom time in deeper water. May be a legal issue with the use of a chemical substance in the sea.	Diving gear ~£2-3000 Training ~£1500	High quality live product	Medium Potentially 3000+ per tide	No direct evidence but indications of some short and medium term effects of salt on fauna	MLS Effort Limitation	Unable to assess sustainability without more information on the environmental effects.
Hydraulic dredge	Dredge towed or fly-dragged from vessel	10m or larger vessel	Limited to water depths of less than 10 m	High Capacity Pump ~£1000-2500 Dredge ~£1000-2000 Pipes etc. ~£500	Lower quality product which require de-gritting	High 5000+ per day	Significant seabed impacts due to disturbance in stable sediments. May be acceptable in mobile sediment habitats	MLS Effort Limitation	Potentially sustainable if stock sensitively managed and suitable habitats selected. Unsustainable without sensitive management

Harvest method	Operating procedures	Operating requirements	Limiting factors	Estimated equipment costs	Catch quality	Catch rates	Environmental impacts	Management measures	Potential for sustainable fishery
Divers using electro gear	Diving from vessel	Commercial diving qualifications (HSE IV) Minimum of 3 divers on-board vessel operating in a fishery capacity	Weather dependant and visibility maybe a factor. Limited diver bottom time in deeper water. Currently illegal use electricity for fishing. (Article 31 EU 850/98)	Diving gear ~£2-3000 Training ~£1500 Generator £1-2000 Associated Equipment £500	High quality live product	High 5000+ per day	Limited information but early indications are favourable	MLS Effort Limitation	Potentially sustainable if stock sensitively managed and if environmental impacts can be demonstrated to be acceptable. Unsustainable without sensitive management
Electro Dredge	Dredge towed or fly-dragged from vessel	10m or larger vessel	Currently illegal use electricity for fishing. (Article 31 EU 850/98)	Generator £1-2000 Associated Equipment £500	High quality live product	Potentially high 5000+ per day	Limited information but early indications are favourable	MLS Effort Limitation	Potentially sustainable if stock sensitively managed and if environmental impacts can be demonstrated to be acceptable. Unsustainable without sensitive management

1.2 Review of Electrofishing

Traditionally electric or electro fishing is the use of an electric current passed between electrodes to attract or stun fish, facilitating their capture. The current can be either alternating (AC) which involves constantly changing positive and negative poles, direct (DC) which flows from a permanent negative electrode to a permanent positive electrode or pulsed DC which flows intermittently from a permanent negative to a permanent positive electrode.

1.2.1 Electrofishing in Freshwater

In freshwater, electric fishing is often used as a sampling technique to carry out fish population and community surveys. In this case the aim is often to attract the fish towards the anode where it is immobilized and easily captured with a net. Backpack electric fishing uses a system whereby the user holds a pole attached to a ring-shaped anode in front of them while the cathode trails on a cable behind them and the power unit is carried as a backpack. This allows the user to see fish that are attracted to the anode and capture them with a net. As the fish are often returned to the water it is important that this process causes as little stress, injury and mortality as possible. For this reason AC is rarely used as it has been shown to cause higher fish injury and mortality than either DC or pulsed DC (Beaumont *et al.* 2002). While continuous DC shows strong attraction of fish and low injury rates, it has weaker immobilizing capabilities and can be difficult to maintain in water with high conductivity and so pulsed DC is the most commonly used current for freshwater electric fishing as it can both attract and immobilize fish, and requires less power (Beaumont *et al.* 2002). Voltages of 100-400V are used with higher voltages being used in waters with lower conductivity, and frequencies of 50Hz or 100Hz are standard with 50Hz generally being used in shallower water and 100Hz in deeper water. Electric fishing has proven to be a very efficient method of sampling fish in rivers. Growns *et al.* (1996) caught almost 30 times more fish per hour and more than twice as many species using electric fishing compared to gill netting, allowing community effects to be seen which were undetected in the gill net samples.

1.2.2 Electrofishing in Seawater

A body of work exists describing the development and effects of electrofishing gears from the 1960s to the present day (Marlen, B. van, et al., 1997). Much of this research focused on the use of electrified beam trawls for the flatfish and shrimp fisheries (see Table 3). These designs were developed primarily to replace the heavy tickler chains on conventional beam trawls with electrodes connected to a power source either on-board or mounted on the beam. The electrical field created by the electrodes causes the target species to leave the bottom and enter the trawl net. The conductivity of seawater is higher than freshwater so the electric field is more concentrated between the electrodes, resulting in more power being required for a given field strength.

During the period 1966-1988, the Netherlands (RIVO) were at the forefront of this research attempting to improve the efficiency of the shrimp and flatfish (sole) fisheries. The focus of this research was to improve the efficiency of the gear and reduce discards (primarily benthic invertebrates) while reducing the drag of the gear, subsequently lowering fuel consumption. Behaviour experiments were used to identify optimum pulse widths for shrimp (0.2ms) and flatfish (0.7ms). Although some promising catch results were obtained (Boonstra & de Groot 1974), where electrodes were connected through cables to an on-board generator, there was a significant loss of voltage between the electrodes, and when a pulse generator and internal power unit was mounted directly onto the beam, the amplitude was low and malfunction rates were high. In 1976, after a series of configurations and experiments, catch ratios of around 1:1 between conventional and electric gear were obtained but malfunction rates remained high and as a result research on shrimp trawling ceased and priority was given to flatfish.

In the early 80's trials were conducted to investigate the effects of frequency, voltage and length and arrangements of electrode. Increased catches were obtained as frequency and voltage were increased but electrode length and arrangement had little effect. After experimenting with different voltages and frequencies, in 1984 a design using 700V at 20Hz appeared to be successful, recording 45% higher catches of sole during the day and 65% higher catches of sole at night, however, size selectivity was not improved. From 1986 there were attempts to commercialise this gear, with reliability and robustness improved by mounting two capacitor containers on the shoes of the beam trawl and using a three phase power unit. Test of the prototype showed increased sole catches but no improvement in size selectivity. However, in 1988 the Dutch Ministry of Agriculture and Fisheries put a ban on electric fishing through fear of increasing effort of the already under pressure beam trawling fleet.

At the same time, Belgium was also researching the use of electric beam trawls. In this case a transformer was used to convert the 24V produced by the boats dynamo into 220V for the pulse generator. Although this system obtained higher catches for both shrimp and sole, the use of 220V on board, along with the cable required to connect the electrodes to the on-board pulse generator were considered a serious safety issue. A later design in 1976 using a voltage of 60-100V with a frequency of 5-10 pulses per second and a pulse length of 1ms showed that electrodes could replace the heavy tickler chains without any loss of catch. A distance of 0.75m between electrodes was found to be optimal as greater distances resulted in a weaker electric field and smaller distances often resulted in electrodes colliding and causing short circuits. Research into electrified otter trawls was also carried out in Belgium and showed promising high catches of sole and reductions in undersized individuals when alternating positive and negative pulses were used instead of direct current. However, when the ban in electro-fishing was introduced in the Netherlands, research in Belgium also ceased with the issue of connecting electrodes to pulse generators through cables still remaining unresolved.

From 1976 to 1986 the White Fish Authority (WFA) and Sea Fish Industry Authority (Seafish) conducted a series of trials researching electrified beam trawls and otter trawls in the UK. The optimum beam trawl configuration to come out of these trials used pulsed DC of 150V at a frequency of 4Hz with a 1ms pulse length. The main results of the beam trawl trials was a reduction in fuel cost per catch due to lighter gear and slower towing speeds but a drop in fuel cost in the early 80's rendered these savings insufficient and research into this system was stopped. Research on electrified otter trawls was also stopped due to the difficulty in maintaining the gear in a constant geometry and greater handling difficulties.

Work in Germany initially concentrated on the freshwater eel fisheries, for which the use of electrified bottom trawls increased catches by a factor of 10-20. However the small size of fishing boats and the traditional views of fishermen prevented this becoming a commercial method. This knowledge was then focused on the inshore sole fishery in 1975 with the aim of reducing fuel costs and decreasing the destructive impact of gear. The optimum configuration was found to be a pulsed DC voltage of 110V, a current of 1.31A at each pair of electrodes and a pulse length of 0.51ms at a frequency of 25Hz. This configuration obtained an increase of 114% in catches of sole (by weight) and a reduction in bycatch of benthic organisms of 50%. However, in 1987 the German authorities decided not to allow the use of electrical fishing on a commercial basis and so research was discontinued despite promising results.

Research has taken place in Lithuania on the use of electricity on mid-water and bottom trawls, but not beam trawls which are uncommon in this region. Research into the behaviour of different species of fish when exposed to different types of electrical current, a system was designed in which on board pulse generators were connected through cables to the anode on the lower panel of the net and the cathode on the upper panel. DC pulses of 7s every 60s at 100Hz resulted in the capture of all encountered fish into the codend. The gear was not developed commercially due to lack of industry support and poor robustness.

Electric beam trawls are reported to be used commercially to catch shrimp in China from 1992-2001 (Yu *et al*. 2007). From 1992 a cabled system was in operation which linked an on-board generator and DC transformer to a pulse generator and copper electrodes. In 1996 a cable-less system was introduced which used a beam mounted battery pack as a power source, making deploying and hauling the gear much easier but meant that voltage decreased as trawl length increased and batteries had to be changed and recharged after every trawl. The typical parameters used for the Shrimp Electrical Pulse Stimulus Apparatus (SEPSA) system were a pulse amplitude of 40-60V, a frequency of 4-5Hz and a pulse width of 0.3-0.5ms (Yu *et al*. 2007). The use of this system increased shrimp catches by around 40% and catches of large shrimp by 100% and at the peak of its usage, more than 3000 vessels in the East China Sea were using SEPSA. This led to difficulties in managing the use of SEPSA and illegal modifications to increase voltages, and eventual over-fishing. As a result the use of SEPSA was banned in the East China Sea in 2001.

While several countries have developed similar gears using different voltages and frequencies (Table 3) and to different degrees of success, they all ran into the same problems, namely the resistance of authorities, lack of interest from fishermen, high investment costs, poor reliability of equipment and safety issues. With the recent focus on improving selectivity, reducing environmental impact and lowering fuel costs, research into the use of electricity as a stimulus in fisheries has begun to resurface.

Recently, research on the electric shrimp trawl has begun again in Belgium (Polet *et al*. 2005a & b) focusing on improving selectivity and reducing seabed impact. This has resulted in the development of the HOVERCRAN system which replaces the heavy bobbin rope with lightweight electrodes and raises the ground rope to allow escape of non-target species. Early trials have given promising results, reducing bottom contact by 75% and lowering by-catch by 35% while obtaining catches comparable to traditional gear (Mees & Seys 2009). The electricity settings of HOVERCRAN have not been published but Polet *et al*. (2005b) determined that a pulsed DC of 65V with pulse duration of 0.6ms at 5Hz was sufficient to cause a startle response in brown shrimp (*Crangon crangon* Linnaeus) causing them to jump above the ground rope and into the net without eliciting a reaction in non-target species.

Shrimp are not the only crustaceans which have been subjected to research involving electric fishing methods. Crawfish have been shown to react to electrical stimulation, exhibiting movement towards the anode by walking and tail-flipping and immobilization at higher voltages (Chen *et al*. 1993). Cain Jr & Avault Jr. (1983) made an attempt to establish the potential of an electrified trawl to catch crawfish commercially and found that catches were consistently higher than conventional trapping methods but, as with many early beam trawl attempts, there were mechanical and safety issues which were not resolved. Norway lobster *(Nephrops norvegicus* Linnaeus*)* and rock lobster *(Panulirus cygnus* George*)* have also been shown to react to electric currents which can be used to assist in their capture (Stewart 1975, Phillips & Scolaro 1980). Phillips & Scolaro (1980) used pulsed DC to create a field of 25 V m^{-1} to induce movement of rock lobsters from their burrows and then an AC field of 10 V m^{-1} sustained for 5 minutes to stun the lobsters, immobilizing them for several minutes, allowing divers to collect them. This method was found to be much quicker than the traditional baited pot method and allowed capture of post-moult, non-feeding individuals. The presence of female *N. norvegicus* in trawls reported by

Stewart (1975) suggests that the gear may induce the habitually cryptic females to emerge from their burrow and become vulnerable to trawls; the cryptic behaviour of females is a key factor in maintaining a sustainable fishery and therefore this effect of the gear is viewed as undesirable from the perspective of long-term sustainability.

A study by Pol & Carr (2002) examined the potential of using electricity to stimulate sea scallops *(Placopecten magellanicus* Gmelin*)* and bay scallops *(Argopecten irradians* Lamarck*)* from the seabed. The primary aim of this project was to develop a dredge with less bottom impact while maintaining catch rates. An 8 m New-Bedford dredge was fitted with 3 steel electrodes (1 cathode, 2 anodes) in addition to the usual tickler and rock chains. Using a DC of 88V, 30Hz frequency and 0.2ms wavelength, stimulation of around 40% of scallops was observed but lower voltages and lower frequencies resulted in fewer scallops exhibiting the 'clapping' response. Catch rates were not significantly different between electrified and standard dredges but overall results were deemed inconclusive due to the small sample sizes.

1.2.3 Effects on fish and shellfish

Three stages of the response of fish to an electrical current have been identified: i) galvanotaxis or forced swimming towards the anode, ii) galvanonarcosis or muscle relaxation in an immobile sleep-like state, and iii) tetany or muscle rigidity and seizures (Schreer *et al.* 2004). Galvanotaxis is often the response desired for electric fishing applications as fish can easily be collected at the anode. Vibert (1963) attributed each of these responses to the interruption of the central nervous system at various points throughout the body resulting in varying abilities of the brain to control the muscles. Recently Sharber and Black (1999) have likened these responses to epilepsy as seen in other vertebrates when exposed to electricity, with twitching and galvanotaxis compared to automatisms, galvanonarcosis compared to petit mal seizures and tetany to grand mal seizures.

Experiments on the physical effects of electricity on fish have been carried out for some time. Hauck (1949) first to investigated the internal effects of electric shock on rainbow trout (*Salmo gairdnerii*) and found incidences of fractured vertebrae, curved spines, ruptured arteries and veins, haemorrhaging and tissue death. Subsequent studies have confirmed and attempted to quantify these effects. The most common internal injury caused by electrofishing is haemorrhaging. Schreer *et al.* (2004) found that in groups of rainbow trout subjected to different voltages, frequencies and shock duration, haemorrhaging occurred in 29-100% of fish, showing that even the lowest voltages and frequencies caused a substantial occurrence of internal haemorrhaging. Spinal injuries can also be common during electrofishing activities. While it was initially thought that the severe muscular contractions experienced during tetany were responsible for the compression fractures often seen in fish exposed to electric fields, Sharber *et al.* (1994) have shown that rather than the higher voltages which cause tetany, spinal injuries are associated with higher frequencies and can occur at any point after the onset of galvanotaxis.

Aside from these recorded physical effects electrofishing is reported to cause physiological changes in fish. When exposed to an electrical current, oxygen consumption of rainbow trout increases rapidly to 150% of resting levels with AC, 130% with DC and 110% with pulsed DC and can take from 30-120 minutes to recover to pre-shock levels (Emery 1984). This is possibly as a result of lactic acid build up due to the rapid muscular contractions induced by the electricity. While most fish will recover from this build-up of lactic acid within 4-12 hours some fish will never recover resulting in delayed mortality (Emery 1984). Electric shock also has some effect on cardiac functions. Schreer *et al.* (2004) noted that rainbow trout suffered cardiac arrest when they encountered an electric field, which lasted for the duration of the shock. Immediately after shock there was a period of arrhythmia which lasted a few seconds to several minutes. While heart rate increased to only 108-132% of resting values and took 40-114 minutes to return to normal, cardiac output increased to 165-189% of resting values and took 100-186 minutes to return to normal. With regards to cardiac functions shock duration appears to be the major factor, while higher voltages and frequencies result in longer recovery times (Schreer *et al.* 2004).

It is important to note that level of response varies between species and individuals. The studies reviewed here were all carried out on Salmonids, which are species recognised to be particularly sensitive to electricity (Snyder 2003). However similar responses have been seen in other species of fish (Adams *et al.* 1972, Dolan & Miranda 2004, Henry *et al.* 2004). Different species of fish are believed to have different electrical resistance, affecting the level of power needed to elicit a response (Emery 1984). Fish size is also an important factor in level of response. Many studies have reported that larger fish are more affected or are affected at lower voltages and frequencies than smaller fish (Adams *et al.* 1972, Emery 1984, Dolan & Miranda 2003) however it is not clear whether the size descriptor should be larger surface area (Emery 1984) or greater volume (Dolan & Miranda 2003). It is generally accepted that larger fish develop a greater head-to-tail voltage gradient resulting in greater reactions at lower power outputs. While this may lead to biases in population sampling it may help to improve size selectivity in fisheries.

As well as the physical damage caused by electric fishing, organisms that have been stunned by an electric current may become more exposed to predation during recovery. Organisms who are unable to control their muscles or who are suffering from physiological stress after encountering an electrical field will be unable to execute their usual escape response effectively.

There is little literature on the use of electricity to harvest molluscs, however studies have been done on the effects of electro-fishing on freshwater mussels (Hastie & Boom 2001, Holliman *et al.* 2007). These studies were carried out to assess any risk to freshwater mussels of electro-fishing used to sample fish communities in the same area. It was found that both 60Hz AC and 60Hz pulsed DC had no effect on mussel behaviour or survival at any life stage.

An extensive search of the literature revealed a paucity of studies on the effects of electric currents on marine invertebrate species. The majority of studies focus on commercially important species such as crustaceans including crawfish, *Nephrops*, rock lobsters which have been reported to react to electrical stimulation including stunning but no assessment of long-term effects are reported (Stewart 1975, Phillips & Scolaro 1980; Cain & Avault,1983; Chen *et al,* 1993). Elliot and Bagenal (1972) found that some species of freshwater stream invertebrates were dislodged by the use of electric fishing apparatus indicating similar effects.

Table 3. Examples of electrofishing gear types and configurations studied.

Gear Type	Target Species	AC/DC	Voltage	Amps	Pulse	Stimulation Type	Country	Reference
Beam Trawl	Flat fish	PDC	50-60		1 second, 20Hz	Tickler	UK	Stewart, 1978
Beam Trawl	Shrimp	PDC	40-60	1000	0.3-0.5ms, 5Hz	Tickler	China	Yu *et al.*, 2007
Beam Trawl	Shrimp	PDC	60		0.2ms, 5Hz	Tickler	Netherlands	Boonstra & De Groot, 1974
Beam Trawl	Flat fish	PDC	700		0.7ms, 20Hz	Tickler	Netherlands	Kraaijenoord, 1985
Beam Trawl	Shrimp & Flat fish	PDC	60-100		1ms, 5-10Hz	Tickler	Belgium	Van Marlen, 1997
Otter Trawl	Norway Lobster & Fish	AC				Tickler	Belgium	Van Marlen, 1997
Beam Trawl	Flat fish	DC	150V/m		1ms, 4Hz	Tickler	UK	Neve, 1978, 1980
Beam Trawl	Flat fish	PDC	110	1.31	0.51ms, 25 Hz	Tickler	Germany	van Marlen,, 1997
Pelagic Trawl	Pelagic fish	DC			7s every 60s, 100Hz	Stunner	Lithuania	van Marlen, 1997
Beam Trawl	Shrimp	DC	65		0.6ms, 5Hz	Tickler	Belgium	Polet *et al.*, 2005
New Bedford Scallop Dredge	Scallops	DC	88	112	0.2ms, 30Hz	Ticker	USA	Pol & Carr, 2002
Paddles/Pole	Rock Lobster	PDC AC	25V/m 10V/m		 5min	Shocker Stunner	Australia	Phillips & Scolaro, 1980

2.0 Methods

2.1 Description of electrofishing gear

Although a number of designs were tested during the project a simple set of gear was used for the benthic impact studies. This set of gear is constructed by attaching 3 mild steel flat bar electrodes (30 mm x 8 mm x 3000 mm) to a 1.5 m wooden beam (Figure 2). The electrodes were coated on the upper surfaces with bitumous paint which was thought to provide some electrical insulation and limit the extent of the electrical field in the water column (the utility of this was not tested). The electrodes were fitted with two wooden stringers in order to keep them parallel on the seabed at a distance of 600 mm. The central electrode is the positive cathode and the outer electrodes are the negative anodes.

In order to ensure the safety of dive contractors, maximum electrical field strength was limited to the equivalent of 50 vm^{-1} by applying a voltage of 30 v DC over the electrode separation distance of 0.6 m. At this voltage guidelines consider it is safe for divers to come into direct contact with the electrodes[2]. For the purposes of the experimental work field strength of 40 vm^{-1} was generated by applying 24 v DC over the 0.6 m between electrodes. A current of 140 A was used throughout the experimental work. Electrical power was supplied from a standard diesel welding generator.

Figure 2. Simple electrofishing gear used in the experimental work (photo SWWFC Ltd.)

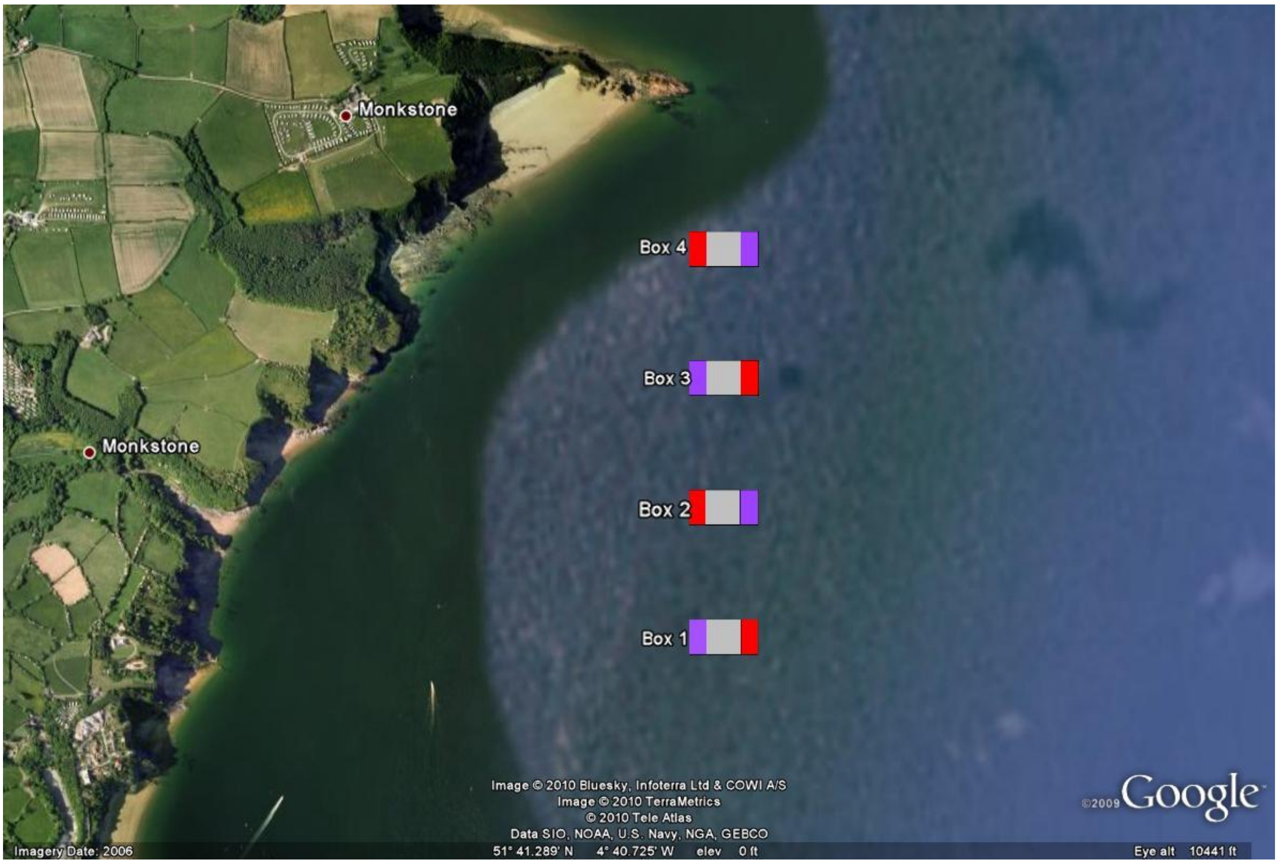
2.2 Field experiments

The field experiment aimed to determine negative effects on non-target invertebrate macrofauna. The experimental design followed a modified BACI (before-after-control-impact) strategy based upon a series of four 200 m x 100 m experimental areas containing 50 m x 100 m fished (treatment) or control sectors separated by 100 m x 100 m buffer zone between control and treated areas (Figure 3). The first treatment area of box 1 was assigned randomly to the east or west side of the box and then the other boxes were assigned alternately along the long axis of the grid.

The experimental plots were situated in the west of Carmarthen Bay south Wales where an area of sandy seabed, typical *Ensis spp*. habitat, was identified from previous surveys in a location sheltered from the prevailing westerly wind and swell.

[2] AODC 35, Association of Offshore Diving Contractors "*Code of Practise for the Safe Use of Electricity under Water*").

Figure 3. Location of experimental boxes. Red sub-sectors indicate fished (treatment) areas, magenta sub-sectors indicate control areas and grey areas indicate buffer zones.



2.2.1 Electrofishing gear deployment

The electrofising gear was deployed in the 'treatment' areas by fly dragging a process in which the fishing vessel is hauled using a winch back at a slow speed across the site to its own anchor, itself towing the electrofishing gear. This method enables accurate control over the speed of the gear on the seabed and is slower than is required for a vessel under power to maintain steerage.

By accounting for wind and tidal vectors the vessel was anchored in positions that enabled deployment of the gear and subsequent effort inside of the 'treatment' areas.

2.2.2 Macrofaunal sampling

In order to determine whether the electrofising gear had negative effects on non-target macrofauna a series of macrofaunal samples were collected; the study aimed to collect 4 replicate 0.1 m^2 macrofauna grab samples from each sample sub-sector before fishing, and then variously at 1, 6, 9, 12, 15, 24, 25 and 28 days at post-fishing. The original aim of sampling at 1, 7,14 and 28 days post-treatment was confounded by weather and logistical constraints. Due to logistical issues samples collected in April and August were taken using a 0.1 m^2 long-armed Van-Veen grab and those during September with a 0.1 m^2 Day grab; sample volumes were monitored to ensure parity of sample sizes of > 4 litres. All samples were passed through a 0.5 mm mesh and stored in 8% formaldehyde (equivalent to 20% formalin) in seawater with a Rose Bengal stain to assist laboratory sorting. Macrofaunal sampling and processing closely followed National Museum of Wales Biodiversity and Systematic Biology Department's sampling protocols (see Mackie et al, 1995).

All samples were identified and enumerated by EMU Ltd's Benthic Taxonomy Laboratory.

A series of sediment samples were collected at stations in each treatment sector of each experimental box and Particle Size Analysis (PSA) undertaken by EMU Ltd.

2.2.3 Epibenthic diver surveys

Non-target invertebrate epifauna and fin-fish were recorded during a series of dive transects. 200 m transects were surveyed within each sample sub-sector before fishing, and then on a single occasion post-treatment. The staggered post-treatment periods at time of dive survey reflects the logistical constraints of carrying out the experimental fishing operations (Table 4).

Quantitative species data were recorded from a series of 24 randomly placed quadrats (0.25 m^2) per treatment and control area. For the purpose analysis these were classified into quadrate group based on Box (1-4), East or West sector (E/W), on treatment fished/control (F/C) and before or after experimental fishing (B/A) (Table 4). This sampling was supported with a series of field notes and video footage of the transect.

Table 4. Dive survey transects with post-treatment periodicity.

Box	E/W	Treatment	'Before' Quadrate Group Code	'After' Quadrate Group Code	Post-Treatment Period
1	E	Fished	1EFB	1EFB	5
	W	Control	1WCB	1WCB	
2	E	Control	2ECB	2ECB	6
	W	Fished	2WFB	2WFB	
3	E	Fished	3EFB	3EFB	9
	W	Control	3WCB	3WCA	
4	E	Control	4ECB	4ECA	27
	W	Fished	4WFB	4WFA	

2.2.4 Observations of behaviour and visual effects on fauna

In addition to the formal survey work a comprehensive set of observational notes on effects of electricity on epifauna and fish species were taken throughout the project from divers and surface observers using underwater video equipment fitted to the electrofishing gear. These observations record the behaviour of fauna in close proximity to the electrofishing gear during operation and pay particular attention to speed of recovery (normal behaviour) after the passage of the gear.

2.3 Statistical analyses

Two forms of statistical analysis were carried out, multivariate analysis which focused on the community response to experimental fishing. A series of univariate analyses focused on the abundance of individual species and their response to experimental fishing sampled over time.

2.3.1 Multivariate analyses – grab sample macrofauna and dive survey epifauna data

The analysis of the macrofauna data produced from the field experiments closely follow the non-parametric multivariate strategy for analysing multi-species patterns described by Field et al. (1982) and also Clarke and Warwick (2001). These methods are commonplace in marine environmental assessment and monitoring programs and have been recommended as the first step of data exploration in a monitoring study (Gray et al., 1988, Warwick and Clarke, 1991). In this study an iterative approach was adopted in order to explain patterns in the macrofaunal data related to physical environmental factors and experimental treatments before formal hypothesis testing took place. This approach enables informed interpretation of results.

The macrofaunal dataset was rationalised in order to remove those taxa sampled only qualitatively, such as colonial hydroids. In order that an interpretable outcome from analyses was possible species accounting for < 0.1% were removed from the dataset as these were considered to be rare and their occurrence at a particular station was largely due to chance rather than any experimental effect (following Clarke & Warwick, 2001). All analyses were carried out on a Bray-Curtis similarity matrix was produced from the species/abundance table using a Log (X-1) transformation.

Classification and ordination was carrying out applying cluster analysis and non-metric multidimensional scaling (MDS). The SIMPER function was employed to identify those species responsible for the dissimilarity between station groups and between Control and Fished sites. The BIOENV function was used to determine the subset of environmental variables best explaining the distribution of sample stations within the classification and ordination process The multivariate categorical ANOSIM (analysis of similarities) technique (Clarke and Green, 1988; Clarke, 1993) provides a multivariate analogue for the univariate ANOVA test and was utilised to determine the significance of differences between *a priori* defined groups e.g. Control and Fished sites.

All multivariate analyses were performed by the PRIMER (Plymouth Routines in Multivariate Ecological Research) software version 5.1.2 (Clarke & Gorley, 2001) on a personal computer.

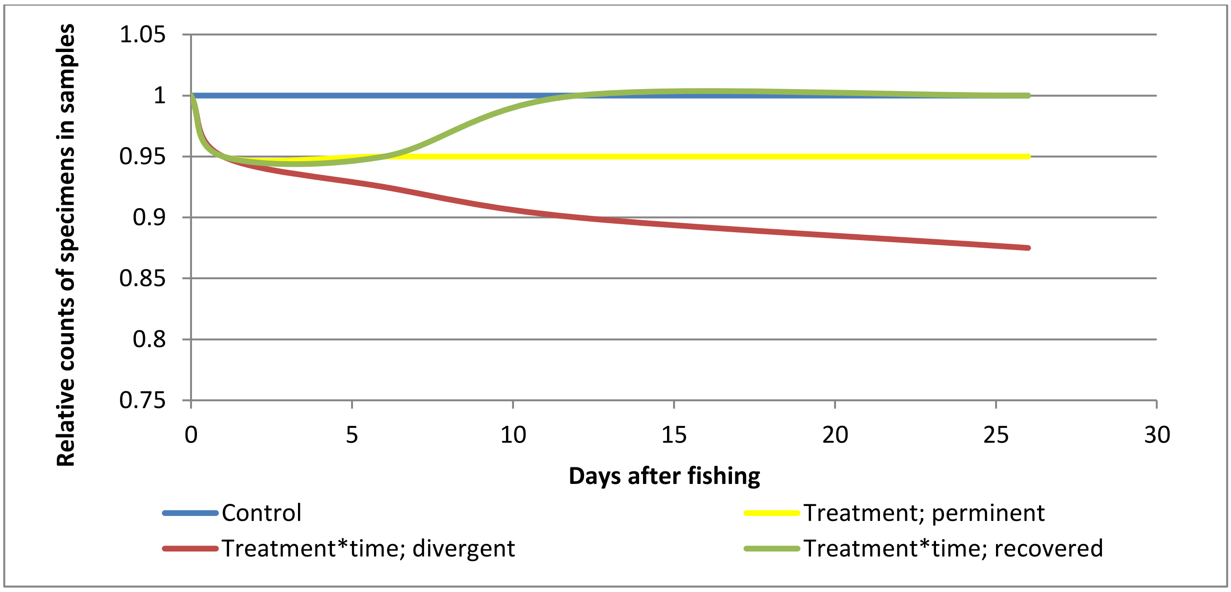
2.3.2 Univariate analyses

The available data is counts of individuals of each species in the grab samples. Four replicate samples were taken from each plot on each sampling occasion. The counts by species for each of these replicates were added together and analysed for changes with treatment and over time. There are several possible scenarios some of which are described in Figure 4;

1. The yellow line represents a permanent reduction in the counts of organisms in the grab samples; this would be described as an effect of 'treatment'.
2. The green line represents an initial reduction in the counts of organisms in the grab samples followed by recovery within the period of observations; this would be described by the term 'treatment*time'.
3. The red line represents a decreasing count over time after treatment; this would be represented by the term 'treatment*time'.

There are other possible scenarios there may be an increase in the; the counts of organisms may increase in the treated (electro fished) plots. However in they are all represented by effects of "treatment" and/or "treatment * time". The modelling process assesses the effect of treatment independently of treatment * time. The cause of variation in the counts may be variation in the relative abundance and/or behaviour of the organisms sampled.

Figure 4. Representation of some of the types of response effected in terms of numbers of specimens in samples pre and post fishing; "treatment" and "treatment* days after fishing"



2.3.2.1 Analysis of repeated measures

Sampling took place at 120 days (see section 3.3.1) prior to experimental treatment and then at 1, 6, 9, 12, 15, 24, 25 and 28 days post fishing. However, to achieve a balanced design was necessary to combine the results for samples at days 9, 12 and 15 and designated these as day 12 samples and the results from days 24, 25 and 28 were combined to be designated as day 26 results; there still remained some missing values. The statistical technique used examines the effects of treatment against the background variation observed. This Before After Control Impact BACI experiment is described as 'repeated measures' experiment, where observations are made on the same sites over a period of time. Therefore the results from each plot taken on subsequent days are expected to be correlated and therefore violate the assumptions on which classical analysis of variance (ANOVA) is based in that each observation should be from an independent sample. Normally, this is allowed for in the analysis using the specialist 'repeated measures ANOVA', which enables the effect of the correlations between repeated measurements to be allowed for in the ANOVA analysis. However, in this case this was not possible because of the distribution of missing values.

Therefore it was necessary to analyse these data using the Residual Maximum Likelihood (REML) analysis (Payne 2000) run on Genstat® version 13.1. In the location and time after fishing are incorporated as random variables and the experimental terms; treatment (electro fished or control) and treatment *time are described as fixed effects. There are various methods that can be used to remove the effects of the correlation between samples from the same plot. The method used is decided by iteration; in this case the best model was found to be ante dependent with uniform correlation within location. Missing values are interpolated from others in the results.

2.3.2.2 Transformation of the data

The numbers of specimens in the grab samples from each of the individual plots on each sampling occasion were added together (N) and 1 added to each result (this is to avoid the situation where attempts are made to calculate the loge of 0), the data were then loge transformed (Loge (N+1). This transformation implies that the same proportion of individuals react to the treatment (electro fishing) across all densities. Thus the effects examined were relative effects; that is a 10% increase or decrease was treated in the same way; change of 10% of 200 specimens would be 20 specimens, whilst it would also be 10 of 100 or 1 of 10. It mean that individuals carry more weight at low densities, but it also means that there is an assumption of homogenous behaviour across all densities, and hence homogeneous variance, which enables the assumptions behind the REML model to be considered valid. The validity of this assumption was checked by suitable residual plots.

3.0 Results

3.1 Observations on fauna

3.1.1 Invertebrate and fish species

A series of observations were recorded during the ~50 hours in which the electrofishing gear was in operation. No observable long lasting behavioural effects were observed; the majority of individuals returned to normal behaviour in under 5 minutes. In general, both invertebrates and fish species become disorientated and stupefied in close proximity to the electrodes. This state tends to be short lived and individuals were observed to return to normal swimming or burrowing behaviour a short (< 5 minutes) after the passage of the gear. Table 5 presents the observation on individual species including recovery times.

Table 5. Diver and CCTV observations of effects and behaviour of electrofishing gear on invertebrate and fish species. Recovery is defined as return to normal swimming or burrowing behaviour

Species	Type of Effect	Description	Recovery Time
Crustacea			
Corystes cassivelaunus (masked crab)	Escape response & disorientation	Individuals observed to leave burrow during passage of gear whereupon they appear disorientated and stupefied. Recovery was seen to take place 1-2 minutes after passage of the gear whereupon individuals were seen to rebury.	1 – 2 minutes
Maja squinado (common spider crab)	Disorientation	Individuals to appear disorientated and stupefied with the passage of gear. Recovery was seen to take place 2 - 5 minutes after passage of the gear whereupon individuals were seen to become active.	2 – 5 minutes
Liocarcinus depurator (harbour crab)	Disorientation/ occasional escape response	Individuals to appear disorientated and stupefied passage of gear. Some have been observed to 'shoot' chelipeds when exposed to electric field for prolonged period (stationary gear) Recovery was seen to take place 2 - 5 minutes after passage of the gear whereupon individuals were seen to become active.	2 – 5 minutes
Pagurus bernhardus (hermit crab)	Disorientation	Individuals to appear disorientated when in close proximity of the electrodes. Recovery was seen to take place 1 - 2 minutes after passage of the gear whereupon individuals were seen to become active.	1 – 2 minutes
Mollusca			
Buccinum undatum (common whelk)	Disorientation	Individuals become unable to orientate themselves and topple over when in close proximity to electrodes. The foot remains extended searching for seabed. Recovery was seen to take place 1-2 minutes after passage of the gear whereupon individuals were able to right themselves and behave normally.	1 – 2 minutes
Ensis siliqua (razorfish)	Escape response	Individuals are commonly seen to push themselves out of the sand using their muscular foot. Some continue attempt escape by swimming away from the gear but others remain on the sediment surface. On occasion and especially at a distance from the gear individuals will only half emerge. Recovery was observed to take place 3 – 10 minutes after the passage of the gear when the individual reburies.	3 - 10 minutes

Species	Type of Effect	Description	Recovery Time
Pharus legume (eggshell, bean or blood razor)	Escape response	Individuals are commonly seen to push themselves out of the sand using their muscular foot. A large proportion only half emerge. Recovery was observed to take place faster than *E. siliqua* after the passage of the gear when the individual reburies.	< 3 minutes
Acanthocardia acauleate (spiny cockle)	Escape response	Individuals are commonly seen to push themselves out of the sand using their muscular foot. The foot is utilised to propel the individual over the seabed away from the gear Recovery was observed to take place 1 – 2 minutes after the passage of the gear when the individual reburies.	1 – 2 minutes
Lutraria lutaria (otter clam)	Escape response (?)	Individuals rapidly withdraw their siphons as the gear approaches them. It is unknown whether this behaviour is in response to the electric field or to the physical stimulus of the gear. Unable to determine recovery (feeding behaviour or re-extension of the siphon) but individuals exposed to the gear survived unsupported by sediment in a tank for 10 days.	Unrecorded
Echinodermata			
Echinocardium cordatum (sea potato)	None	Not observed on surface. 3 individuals excavated 5 minutes after the passage of the gear immediately began to rebury.	–
Ophiura ophiura (brittlestar)	Disorientation	Individuals to appear disorientated and stupefied with the close passage of gear. Individuals observed to begin moving after 1 – 2 minutes	1 – 2 minutes
Asterias rubens (common starfish)	Disorientation	Individuals to appear disorientated and stupefied with the close passage of gear. Individuals observed to begin moving after 1 – 5 minutes	2 – 5 minutes
Fish			
Rajiforme (rays)	No reaction/ escape reaction	One individual was observed by divers within 1 m of gear and did not exhibit any obvious behaviour. Rays were observed to encounter the gear on underwater video footage, on both occasions they exhibited an escape response and swam rapidly away	–
Solea solea (dover sole)	Escape response /disorientation	Individuals generally avoid the gear and swim away. Individuals appear disorientated and stupefied, and curl up with the close (<25 cm) passage of gear. One individual was observed to come into contact with an electrode whereupon it exhibited a vigorous escape response and swam rapidly away. Individuals observed to recover and swim away after 1 – 2 minutes	1 – 2 minutes
Limanda limanda (dab)	Escape response /disorientation	Individuals generally avoid the gear and swim away. Individuals appear disorientated and stupefied with the close (<25 cm) passage of gear. Individuals observed to recover and swim away after 1 – 2 minutes	1 – 2 minutes

Species	Type of Effect	Description	Recovery Time
Pleuronectes platessa (plaice)	Escape response /disorientation	Individuals generally avoid the gear and swim away. Individuals appear disorientated and stupefied with the close (<25 cm) passage of gear. Individuals observed to recover and swim away after 1 – 2 minutes	1 – 2 minutes
Ammodytes tobianus (lesser sand eel)	Disorientation	Individuals appear disorientated and stupefied with the close (<25 cm) passage of gear. One individual was observed to come into contact with an electrode whereupon it exhibited a vigorous escape response and swam rapidly away. Individuals observed to recover and swim away after 1 – 2 minutes	1 – 2 minutes
Gaidropsarus mediterraneus (shore rockling)	Disorientation	Individuals appear disorientated and stupefied with the close (<25 cm) passage of gear. Individuals observed to recover and swim away after 1 – 2 minutes	1 – 2 minutes
Pomatoschistus minutes (sand goby)	Disorientation	Individuals appear disorientated and stupefied with the close (<25 cm) passage of gear. Individuals observed to recover and swim away after 1 – 2 minutes	2 – 5 minutes
Labrus bergylta (ballan wrasse)	Disorientation	Individuals appear disorientated and stupefied with the close (<25 cm) passage of gear. Individuals observed to recover and swim away after 1 – 2 minutes	1 – 2 minutes

3.1.2 Bird species

A number of bird species were observed while the electrofishing gear was in operation during the experimental work. No obvious effect on bird behaviour was observed. Of particular relevance was the presence of a single little auk (*Alle alle*) that was observed diving 20 m behind the vessel in the vicinity of the electrofishing gear for a period of 3 minutes before it moved away with no obvious effect.

3.1.3 Marine mammal species

No cetacean species were observed during the experimental work.

A single grey seal (*Halichoerus grypus*) was observed diving behind the vessel on a single occasion during the operation of the electrofishing gear. The seal did not stay in the vicinity and moved on without exhibiting unusual behaviour.

3.2 BACI experiment epifauna dive survey

3.2.1 Cluster and ordination of dive survey transects before and after treatment

Quadrates were classified by treatment and before/after fishing (see Table 4). A cluster analysis of quadrates and treatments (Control and Fished) sampled on all dates established that all samples are grouped above 57.46 % similarity (Figure 5). A distinct cluster of Control and Treatment transects recorded during the post fishing period clustered at the 73.37 % similarity. The 3 quadrate groups clustering out below 66.8 % similarity were all from Box 4 both pre- and post-treatment period and included a control. An MDS plot of the same data revealed that quadrate groups tend to group by experimental Box irrespective of treatment (Control/Fished) or whether sampled before or after experimental treatment period (Figure 6). A before/after within-Box effect is apparent in the MDS plot; transects surveyed in April tend to be placed in the upper left of each Box group whereas the September transects are placed to the lower right of the group irrespective of treatment.

These analyses do not reflect a treatment dependant effect rather a more general change across all experimental Boxes during the April-September experimental treatment period.

Figure 5. Cluster analysis of dive survey epifauna transects

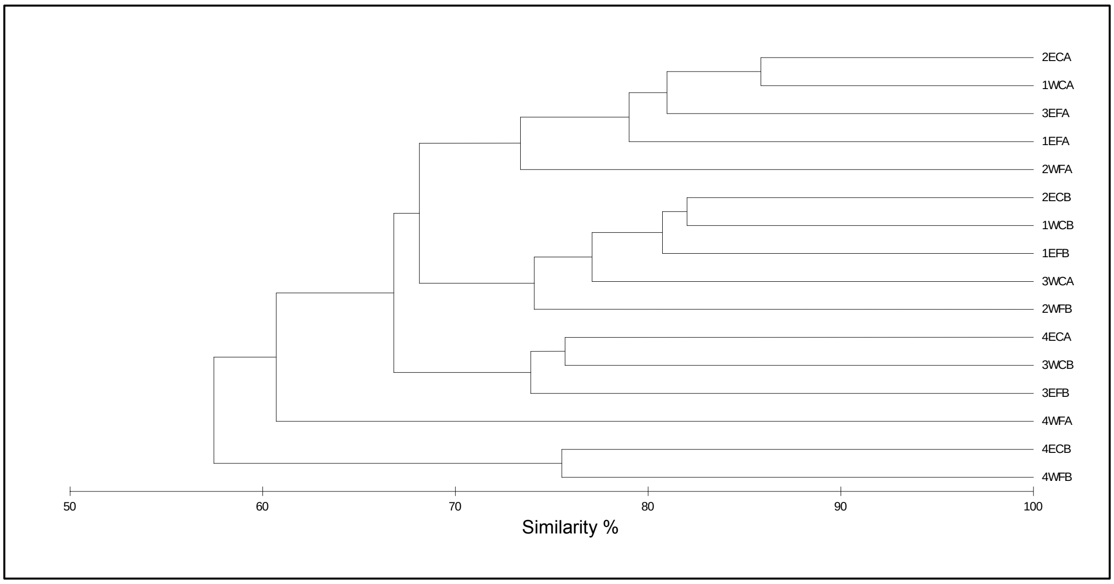
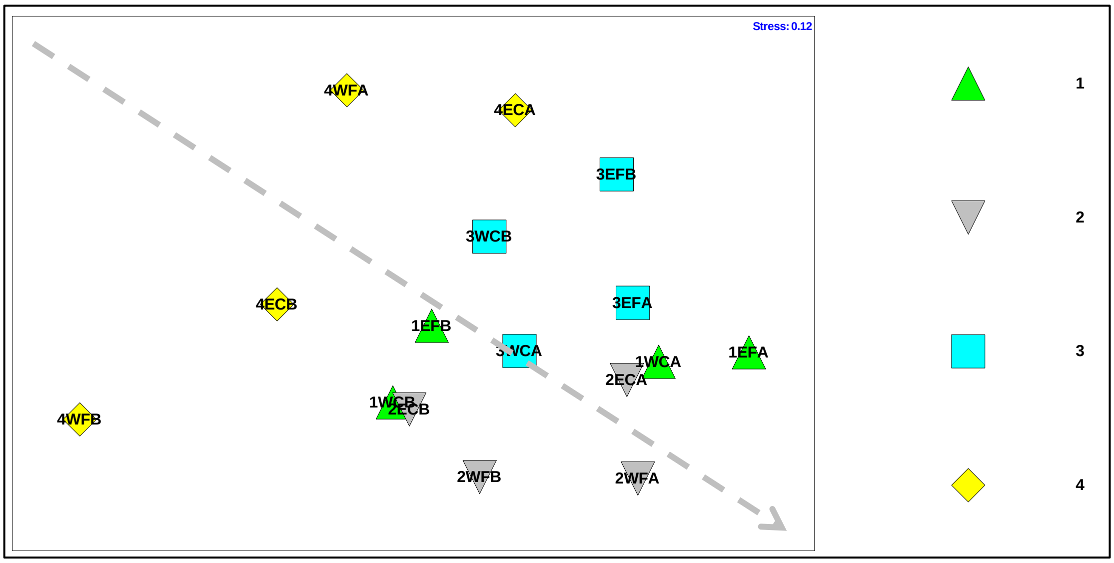


Figure 6. MDS of dive survey epifauna transects. Symbols indicate experimental Box, labels indicate quadrate groups (refer to Table 4). The hatched line indicates the proposed before/after effect.



3.2.2 ANOSIM of *a priori* groups (all quadrates before and after experimental fishing period)

A one-way ANOSIM test provided a formal test of the null hypothesis that there is no difference between quadrate groups surveyed before and after the April-September experimental fishing period (irrespective of treatment).

- The null hypothesis that there no differences between all samples taken before and after experimental fishing is rejected: R-Statistic = 0.329 (Significance 0.2 %)

This result confirms a broad change in epifaunal communities across all Boxes occurred between April-September inter-sampling period.

3.2.3 SIMPER of dive survey transects (before and after experimental fishing period)

A SIMPER analysis was performed to determine those species responsible for the significant dissimilarity between quadrates groups surveyed in April and September surveys. In general the dissimilarity between surveys is due to relatively small differences in relative abundance of species common in all boxes (Table 6).

Table 6. Results of Simper analysis of transects surveyed before and after April-September experimental period (species contributing 50% dissimilarity).

Average Dissimilarity = 36.33	**April**	**September**				
Species	**Av.Abundance**	**Av.Abundance**	**Av.Diss**	**Diss/SD**	**Contrib.%**	**Cum.%**
Hinia reticulate	1.13	3.13	2.84	1.76	7.81	7.81
Bivalve siphons	40.00	49.38	2.76	1.24	7.60	15.40
Terebellidae	2.50	4.13	2.60	1.26	7.15	22.55
Sertularia cupressina	1.50	3.63	2.54	1.36	7.00	29.56
Paguridae	1.50	4.38	2.44	1.54	6.73	36.28
Echinocardium cordatum	8.13	13.00	2.35	1.69	6.46	42.74
Sagartia troglodytes	26.63	24.25	1.95	1.18	5.38	48.12
Obelia spp.	0.13	1.25	1.83	1.15	5.05	53.17

3.2.4 ANOSIM of *a priori* treatment groups (Control and Fished)

A one-way ANOSIM test provided a formal test of the null hypothesis that there is no difference between macrofaunal community in Control and Fished experimental areas surveyed post fishing in September.

- The null hypothesis that there no differences between experimental treatments is accepted: R-Statistic = -0.135 (Significance 85.7 %)

This result confirms a there is no difference between epifaunal communities in fished and control sectors of the experimental boxes post fishing.

3.3 BACI experiment grab sample macrofauna multivariate analyses

3.3.1 Cluster and ordination of all sampling dates before and after treatment

A cluster analysis of all stations and treatments (Control and Fished) sampled on all dates established that all samples are grouped above 57.22 % similarity. An MDS plot of the same data revealed 2 clear group based on sampling time -/+ treatment (fishing); stations sampled 120 days before treatment grouped apart from the post-treatment grouping (Figure 7a). The clustering and grouping of the Pre- and Post-treatment stations indicate that the macrofauna community, irrespective of treatment, had been subject to change between pre-treatment sampling and the post-treatment sampling. Rough weather during the 2008 summer necessitated the 120 day delay between sampling periods and is likely to be a key factor implicated in community change between groups.

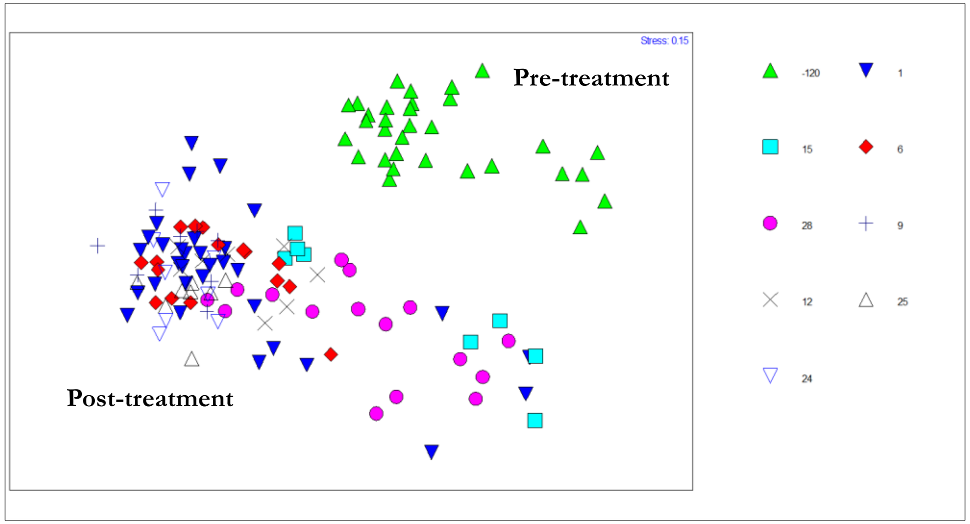
An MDS plotted with experimental Boxes demonstrated a structure based upon Experimental Box; Boxes 1 and 2 form homogeneous subgroups within both of the Pre- and Post-treatment groups (Figure 7a). Box 4 forms a subgroup separate from the homogeneous Box 1+2 group with Box 3 forming a subgroup between these in Post-treatment group (Figure 7b). An MDS plotted with East-West Sectors highlighted suggested a structure based upon the East-West Sector of each experimental Box; the sectors of Boxes 1 and 2 form homogeneous subgroups within the Pre- and Post-treatment clusters whereas sectors of Boxes 3 and 4 show a distinct within Box separation (Figure 7c).

The pattern of distribution of sub-groups based on Box and East-West sectors are very similar in both the Pre- and Post-treatment groups. This suggests that irrespective of the delay between pre-treatment sampling and that taking place post-treatment the environmental factors structuring the communities are relatively constant and stable.

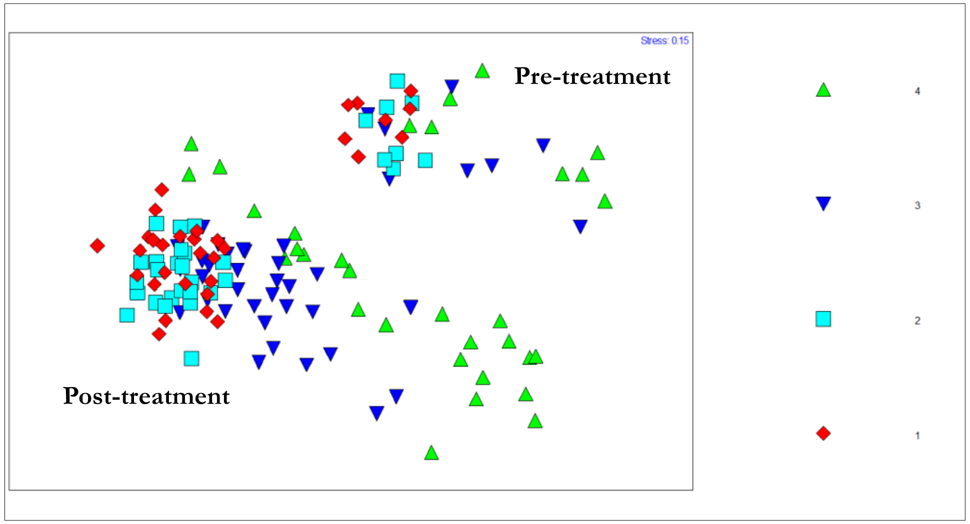
An MDS replotted with experimental treatment type (Control/Fished) highlighted demonstrated structure based upon experimental treatment but which reflected the North-South sub-groups described above (Figure 7d). The Control and Fished sub-group distribution pattern is similar in both the Pre- and Post-treatment groups suggesting that inter and intra-Box differences may be more powerful drivers of community structure than the effect of experimental treatment.

Figure 7 a-d. MDS Plot produced from macrofauna data from all stations across all dates.

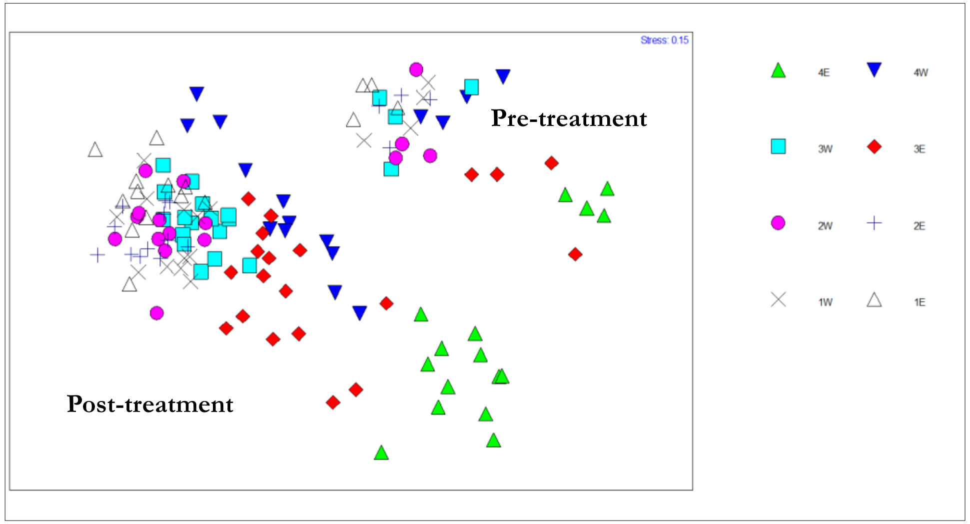
a. Key indicates days +/- treatment.



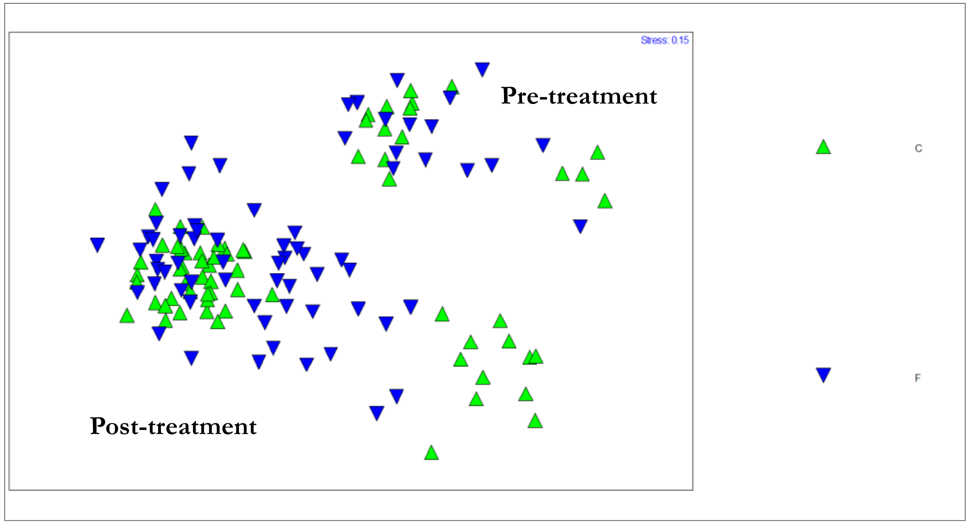
b. Key indicates experimental boxes.



c. Key indicates Experimental Box East or West sector



d. Key indicates control/experimental treatment



3.3.2 ANOSIM of *a priori* groups Experimental Treatments

Experimental Treatments: A one-way ANOSIM test provided a formal test of the null hypothesis that there is no difference between experimental treatments (Control and Fished) on all sampling occasions before and after experimental fishing, immediately after experimental fishing and on all post fishing sampling occasions.

- **Combined Before and After samples**: The null hypothesis that there no differences between experimental treatments is accepted: R-Statistic = 0.01 (Significance 11.8 %)
- **Post-fishing samples (day 1 post fishing)**: The null hypothesis that there no differences between experimental treatments 1 day after fishing is accepted: R-Statistic = 0.028 (Significance 17.8 %)

The 1 day post-fishing sample ANOSIM test demonstrates that there is no short-term difference between the macrofaunal communities fished and control experimental boxes

- **Post-fishing samples (all days post fishing)**: The null hypothesis that there no differences between experimental treatments is accepted: R-Statistic = 0.052

Note: Very low R-statistics such as this are considered to be non-significant

The post-fishing sample ANOSIM test demonstrates that there is no difference between the macrofaunal communities fished and control experimental boxes.

Experimental Boxes: A two-way ANOSIM test provided a formal test of the null hypothesis that there is no difference between experimental Boxes 1-4.

- The null hypothesis that there no differences between Boxes 1-4 is rejected: R-Statistic = 0.232 (Significance 0.1.%)

The ANOSIM test confirms that there is a statistical significant difference between the macrofaunal communities in Boxes 1-4.

The R-Statistics calculated in for pairwise test provide a useful comparative measure of the degree of dissimilarity between samples from experimental Boxes. Experimental Boxes 3 and 4 are significantly dissimilar to the other Boxes and when ranked according to R-statistic reflect their geographical distribution.

Table 7. Results of the ANOSIM pairwise tests (Experimental Boxes)

Pairwise Tests		
Groups	**R-Statistic**	**Significance Level %**
4, 1	0.51	0.1
4, 2	0.47	0.1
4, 3	0.26	0.1
3, 1	0.12	0.2
3, 2	0.09	0.4
2, 1	0.04	5.9

East-West Sectors (Pre-treatment samples): A one-way ANOSIM test provided a formal test of the null hypothesis that there is no difference between Pre-treatment samples from experimental East-West Sectors.

- The null hypothesis that there no differences between East-West sectors is rejected: R-Statistic = 0.157 (Significance 0.1%)

East-West Sectors (Post-treatment samples): A one-way ANOSIM test provided a formal test of the null hypothesis that there is no difference between Post-treatment samples from experimental East-West Sectors.

- The null hypothesis that there no differences between East-West sectors is rejected: R-Statistic = 0.134 (Significance 0.1%)

Although the ANOSIM test confirms that there is a difference between the macrofaunal community in the East and West sectors of the experimental Boxes, the R-Statistic is very low and therefore indicates a weak significance.

3.3.3 SIMPER analysis of experimental boxes (Pre- and Post-treatment)

A SIMPER analysis was performed to determine those species responsible for the significant dissimilarity between Boxes 1-4. In general the dissimilarity between Boxes is due to differences in relative abundance of species common in all boxes. In all cases the polycheates *Magelona filiformis* and *Owenia fusiformis*, the bivalves *Angulus tenuis* and *Abra alba*, and the amphipod *Bathyporeia tunipes* were the species contributing the most to the dissimilarity between Boxes (Table 3). The bivalve *Angulus tenuis* was ranked as the most important contributing species due to differences in its relative abundance in all comparisons. The small bivalve *Abra alba* was also an important species contributing to dissimilarity between Boxes and demonstrates an inverse relationship with *A. tenuis* (See Figures 6-8 below).

Table 8. Results of Simper analysis of significantly different (ANOSIM) experimental Boxes (top 5 contributing species).

Average dissimilarity = 41.92						
	Box 4	**Box 1**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Angulus tenuis	48.88	11.34	2.66	1.72	6.34	6.34
Abra alba	1.41	11.19	1.85	1.97	4.42	10.76
Bathyporeia tenuipes	8.47	27.84	1.76	1.42	4.21	14.97
Owenia fusiformis	6.41	8.53	1.65	1.32	3.93	18.89
Magelona filiformis	22.78	40.00	1.61	1.39	3.84	22.74
Spiophanes bombyx	4.38	16.41	1.55	1.56	3.69	26.43
Average dissimilarity = 39.38						
	Box 4	**Box 2**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Angulus tenuis	48.88	15.84	2.42	1.69	5.79	5.79
Abra alba	1.41	14.28	1.98	1.83	4.74	10.53
Bathyporeia tenuipes	8.47	33.41	1.92	1.48	4.61	15.14
Owenia fusiformis	6.41	10.78	1.81	1.43	4.33	19.47
Magelona filiformis	19.69	5.47	1.58	1.52	3.78	23.25
Average dissimilarity = 34.40						
	Box 4	**Box 3**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Angulus tenuis	48.88	17.53	1.92	1.53	5.12	5.12
Bathyporeia tenuipes	8.47	28.35	1.78	1.44	4.77	9.89
Abra alba	1.41	8.88	1.49	1.46	4.00	13.88
Owenia fusiformis	6.41	6.20	1.48	1.29	3.95	17.84
Magelona filiformis	22.78	23.28	1.43	1.50	3.82	21.66
Magelona johnstoni	3.75	4.98	1.31	1.47	3.49	25.16

Table 7 continued. Results of Simper analysis of significantly different (ANOSIM) experimental Boxes (top 5 contributing species).

Average dissimilarity = 32.40						
	Box 3	**Box 1**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Angulus tenuis	17.53	11.34	1.76	1.39	5.33	5.33
Owenia fusiformis	6.2	8.53	1.4	1.34	4.24	9.57
Spiophanes bombyx	9.93	16.41	1.14	1.22	3.46	13.04
Pseudocuma longicornis	10.65	5.44	1.12	1.28	3.39	16.42
Abra alba	8.88	11.19	1.1	1.28	3.35	19.78
Magelona filiformis	23.28	40	0.98	1.16	2.98	22.76
Magelona johnstoni	4.98	6.53	0.98	1.39	2.98	25.74
Average dissimilarity = 32.40						
	Box 3	**Box 2**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Angulus tenuis	17.53	15.84	1.66	1.34	5.09	5.09
Owenia fusiformis	6.2	10.78	1.47	1.37	4.5	9.59
Abra alba	8.88	14.28	1.26	1.31	3.87	13.46
Pseudocuma longicornis	10.65	5.47	1.16	1.39	3.55	17
Magelona johnstoni	4.98	5.88	0.99	1.36	3.04	20.05
Spiophanes bombyx	9.93	11.69	0.97	1.2	2.98	23.03
Iphinoe trispinosa	5.1	2.19	0.96	1.42	2.96	25.98

3.3.4 BIOENV analysis of environmental influences (post-treatment samples only)

It was necessary to restrict the BIOENV analysis to samples collected post-treatment as the 120 day delay between the pre- and post-treatment sampling combined with the effects of heavy weather during that period resulted in distinct groupings in the MDS (Figure 7a). The BIOENV procedure identifies the subset of environmental variables that maximizes the rank correlation (ϱ) between the macrofaunal and environmental (dis)similarity matrices underlying the MDS ordinations. It can therefore only explain the distribution of macrofaunal assemblages from one sampling period and as the sediment data was collected during the post-treatment sampling period BIOENV was applied to samples from this period.

A BIOENV analysis of the available physical environmental factors revealed that a combination of median Phi grain size, % gravel and distance of experimental box from MLWS best matched the distribution of stations in the MDS with a harmonic rank correlation (ϱ_w) of 0.795, judged 'very good' by Clarke & Ainsworth (1993). Distance from MLWS to experimental box was the single physical environmental factor best matching the distribution of stations in the MDS with a harmonic rank correlation (ϱ_w) of 0.673. An MDS plot of all post-fishing stations with "distance from MLWS" thematically plotted demonstrates a progression from Box 4 to Boxes 1 & 2 (Figure 8), this pattern suggests a physical gradient reflected in benthic community across the experimental boxes. This equates to a geographic North-South gradient at the experimental site in Carmarthen Bay (refer to Figure 3 above)

Median Phi grain size also returned a relatively high a harmonic rank correlation (ϱ_w) of 0.579. An MDS plot of all post-fishing stations with median Phi grain size thematically plotted reflects the North-South gradient from the western most sector of Box 4 to Boxes 1 & 2 reflecting the North-South gradient described above (Figure 9). The eastern (seaward) sector of Box 4 was shown to characterised by slightly smaller phi grain sizes (coarser sediments) and this is reflected in the macrofauna samples grouping apart from the other stations from Box 4.

The proportion of gravel in the sediment sample (% gravel) returned a lower harmonic rank correlation (ϱ_w) of 0.295. An MDS plot of all post-fishing stations with % gravel thematically plotted highlights that this particular factor is heterogeneously distributed between and within experimental boxes (Figure 10). This pattern of patchy gravel distribution does not appear to follow a gradient but does suggest an East-West difference in samples from Boxes 3 and 4.

Figure 8. MDS Plot produced from all stations post treatment with distance from MLWS superimposed. Experimental box number indicated.

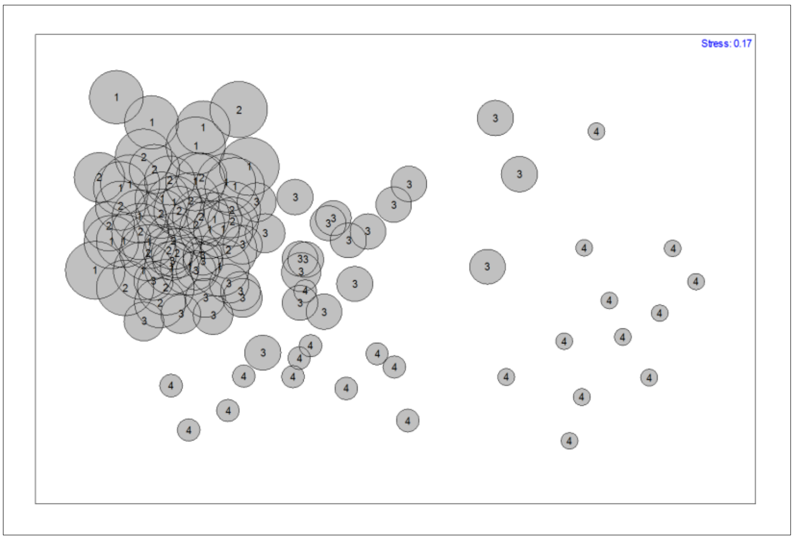


Figure 9. MDS Plot produced from all stations post treatment with median Phi grain size superimposed. Experimental box number indicated.

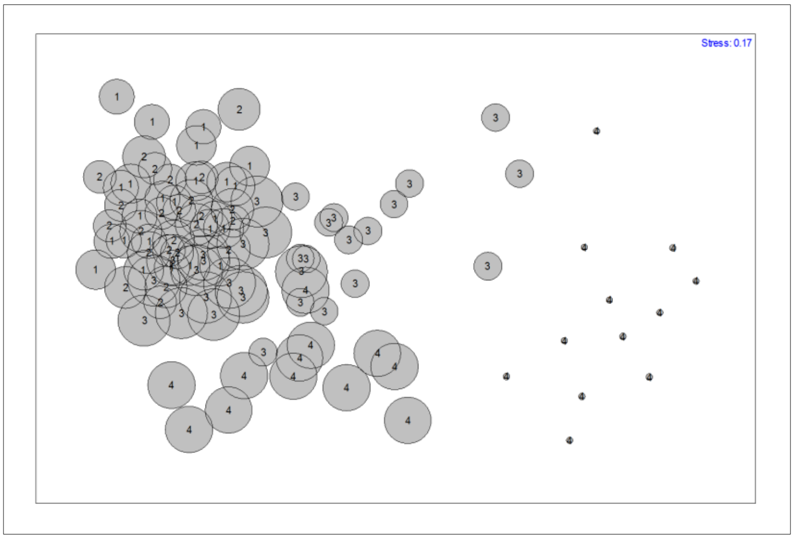
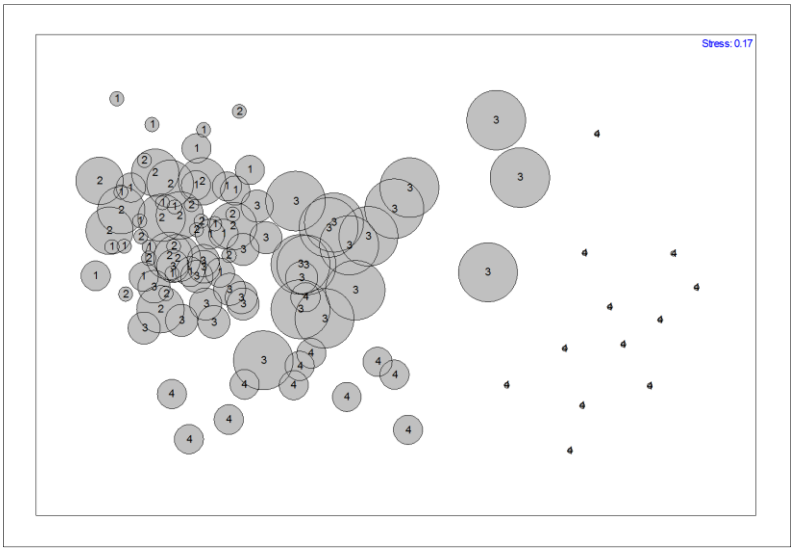


Figure 10. MDS Plot produced from all stations post treatment with % Gravel superimposed. Experimental box number indicated.



3.3 Univariate analysis (REML)

The SIMPER analysis showed that the bivalves *Angulus tenuis* and *Abra alba,* the polycheates *Magelona filiformis* and *Owenia fusiformis* and the amphipod crustacean *Bathyporieia tunipes* were the species contributing most highly to the dissimilarity between boxes (Table 6). These species were chosen for univariate analysis for the effects of treatment with electrofishing. Also there were large settlements of bivalves *Donax vittatus* and *Mytilus edulis* during the course of the experiment, which were not included in the multivariate analysis, so it is of interest to examine the effects of treatment on these settlements.

3.3.1 Before treatment

The before treatment (April 2008) mean Log_e (N+1) transformed counts of the adult species are shown in Table 9. Because there were only four replicates it is not possible to carry out a formal statistical test. However, the overlap of the standard deviations indicate that there is not likely to be a significant difference between mean results for the designated fished and control plots.

Table 9 Before treatment results; mean Log_e (N+1) by treatment $\pm$ standard deviation (s.d) by species

	Treatment designated			
	Control	**± s.d.**	**Fished**	**± s.d**
Angulus tenuis	5.368	0.148	5.572	0.444
Abra alba	2.138	1.010	1.981	1.368
Magelona filiformis	4.375	0.7765	4.710	0.4445
Owenia fusiformis	0.347	0.6931	0.000	0.0000
Bathyporia teniupes	3.159	1.0620	3.366	0.3449

The counts of these species varied between the before samples taken in April 2008 and the post treatment samples taken in August-September to the extent it was not possible to fit the REML analysis to the combined data. However, these results show that there is no reason to expect a significant difference in the counts in the plots designated for the two treatments prior to the experiment. Therefore we can expect any observed of effects 'treatment' and 'treatment*time' (Section 2.3.2) to be due to the electro fishing treatment.

3.3.2 Adult bivalves

The spatial distributions of the most numerous adult bivalve species *Angulus tenuis* and *Abra alba* are shown in

Figure 11. This shows that these species tend to have an inverse distribution, where *A. tenuis* is abundant *A. alba* is not and *vice versa.* Therefore analyses of the results these species could be considered representative of small bivalves across the habitats present.

Figure 12 and

Figure 13 and show the mean Log_e (N+1) counts of *A. tenuis,* and *A. alba*; respectively post treatment. Table 10 summarises the results of REML analysis for these species.

These results show no significant effects for time and treatment for *A. tenuis,* but the effect on treatment*time approaches significance (P>0.09 the normal threshold level being P>0.05). This could be accounted for by the divergence between the mean results for the control and fished during day 6 (Figure 12). However, examination of the box by box results (

Figure 14) shows that for all boxes except box 3, all the results suggest a constant ratio between the fished and control boxes. In box 3 during day 6 there is an apparent increase in the quantity of *A.*

tenuis , probably due to random variation, and this, together with the use of the results from box 3 to interpolate results for missing values in boxes 1 and 4 accounts for the apparent divergence between the results for fished and control on day 6.

The *A. alba* results show no significant effects for time, treatment or treatment*time; the only variation appears to occur in box 4 (

Figure 15) where this species is least numerous.

3.3.3 Juvenile Bivalves

The trajectories of the mean Log_e (N+1) counts of juvenile *Donax vittatus* and *Mytilus edulis* post fishing are shown in Figure 16 and Figure 17 respectively and the results of the REML analysis summarised in Table 10. For *D. vittatus* there is a highly significant increase in numbers of juveniles over time probably due to an on-going settlement post treatment, but no significant effects of treatment or treatment*time. It was not possible to establish significance for juvenile *M. edulis* but there is no evidence of any reduction in this species in the fished plots post treatment

Table 10 Results of REML analysis; significance of effects of time, treatment and treatment*time on Log_e (Numbers of bivalves +1)

Effect	**Significance (probability that the null hypothesis is correct)**			
	Angulus tenius	*Abra alba*	Juvenile *Donax vittatus*	Juvenile *Mytilus edulis*
Time	0.283 Not sig	0.193 Not sig	p<0.001 highly significant	Model failed to converge
Treatment	0.778 Not sig	0.884 Not sig	0.776 Not sig	
Treatment*time	0.09sig at p<0.1	0.548 Not sig	0.959 Not sig	

3.3.4 Polycheates

The post treatment results are shown in

Figure 18 for *Magelona filiformis* and Figure 19 for *Owenia fusiformis* and a summary of the REML analysis of the post treatment results is shown in Table 11. These results show that variation in the mean counts of these organisms is significant over time; they both decrease significantly over time during the period post fishing, this is probably related to seasonal factors, but there is no significant difference between treatments, or treatment * time.

Table 11 Results of REML analysis; significance of effects of time, treatment and treatment*time on Log_e (Numbers of polycheates +1); post fishing results only.

Effect	**Significance (probability that the null hypothesis is correct)**	
	Magelona filiformis	*Owenia fusiformis*
Time	p=0.049 significant at p<0.05	p<0.001; highly significant
Treatment	p=0.452 Not sig	p=0.869 Not sig
Treatment*time	p=0.785 Not sig	p=0.438 Not sig

3.3.5 Crustacean

The post treatment results for the most numerous crustacean *Bathyporeia tenuipes* are shown in Table 12 and Figure 20. These results show that variation in the mean counts of these organisms is significant over time; the numbers decrease significantly over time during the period post fishing, this is probably related to seasonal factors, but there is no significant difference between treatments, or treatment * time.

Table 12 Results of REML analysis; significance of effects of time, treatment and treatment*time on Log_e (Numbers of *Bathyporeia tenuipes* +1)

Effect	**Significance (probability that the null hypothesis is correct)**
Time	p=0.038 significant at p<0.05
Treatment	p=0.759 Not sig
Treatment*time	p=0.413 Not sig

Figure 11. Thematic map demonstrating the relationship between the bivalves *Angulus tenuis* and *Abra alba*. All stations pre- and post-treatment

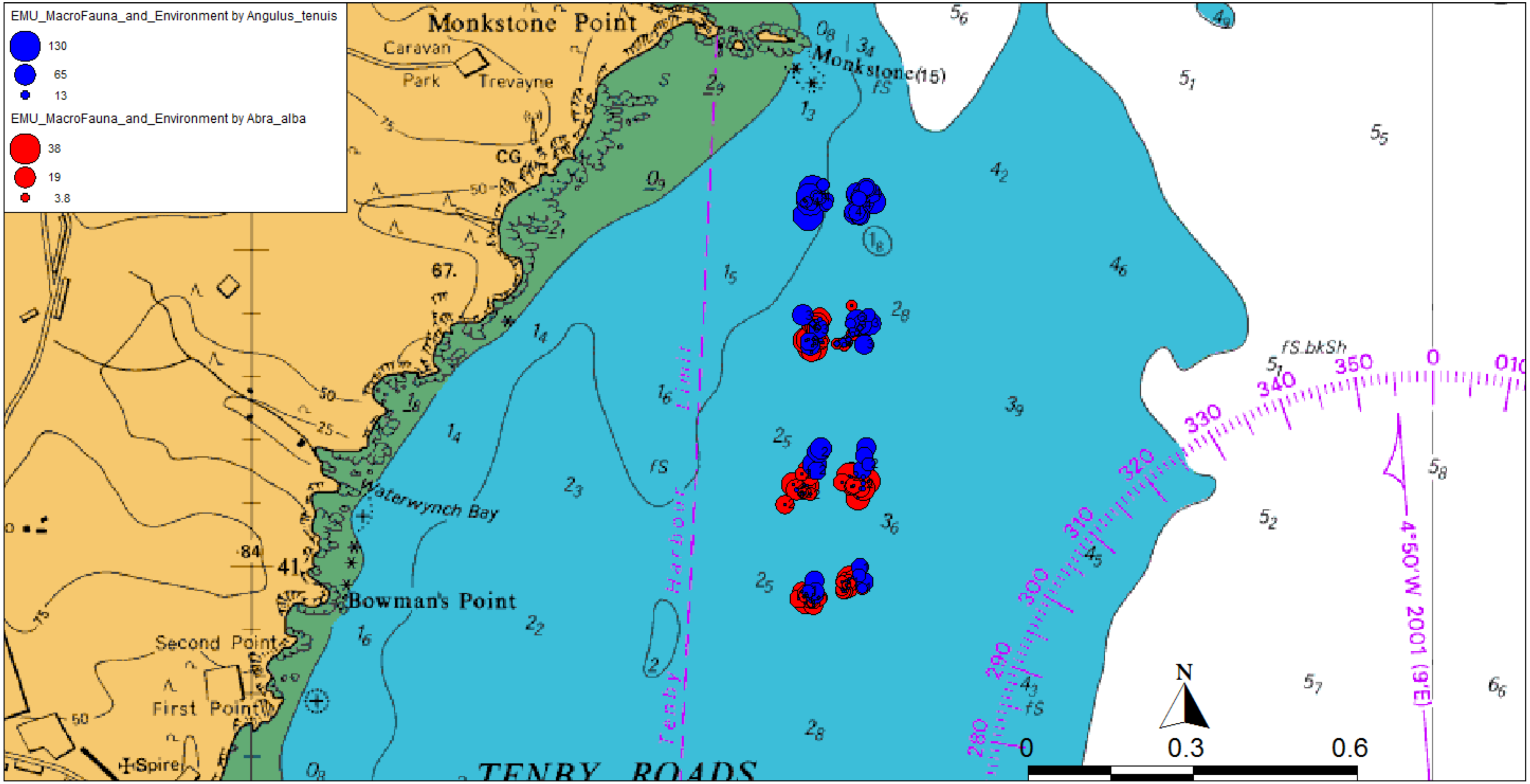


Figure 12 Mean results Log_e (N+1) *Angulus tenuis* ±standard error vis time post treatment. Post treatment results only

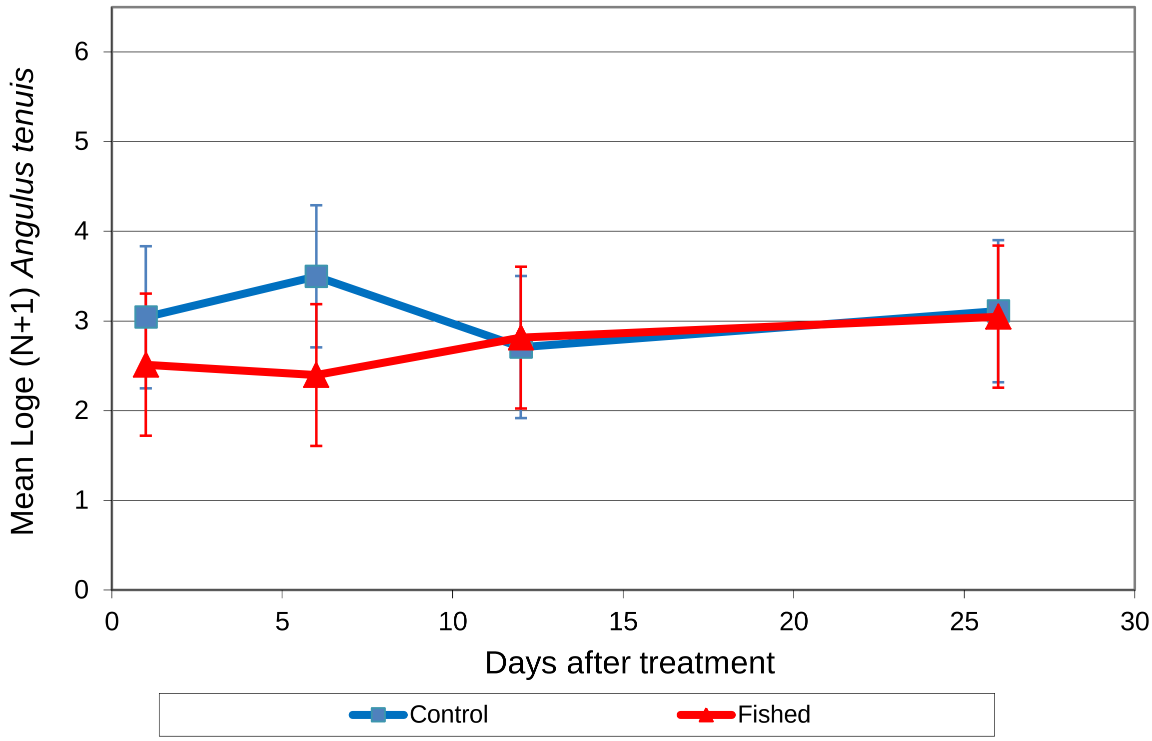


Figure 13 Mean results Log_e (N+1) *Abra alba* ± standard error vis time post treatment. Post treatment results only

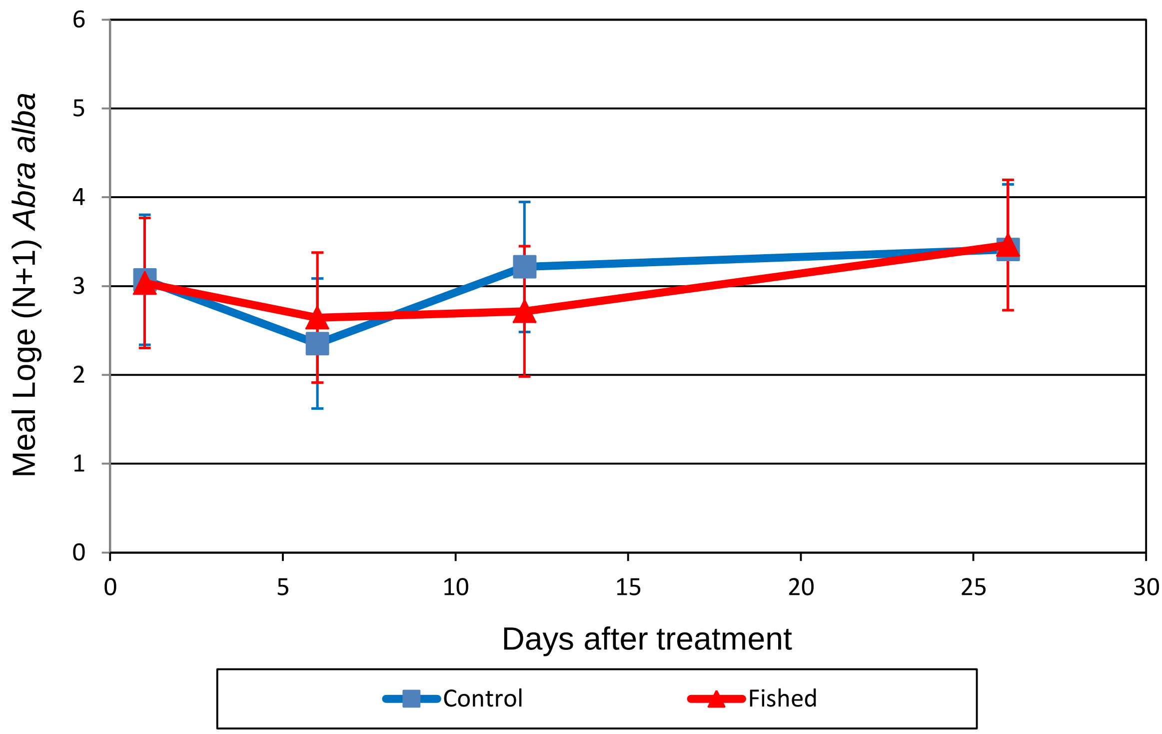


Figure 14 *Angulus tenius* vis time after treatment in individual boxes. Open symbols represent interpolated values with error bars representing standard deviation of the estimate

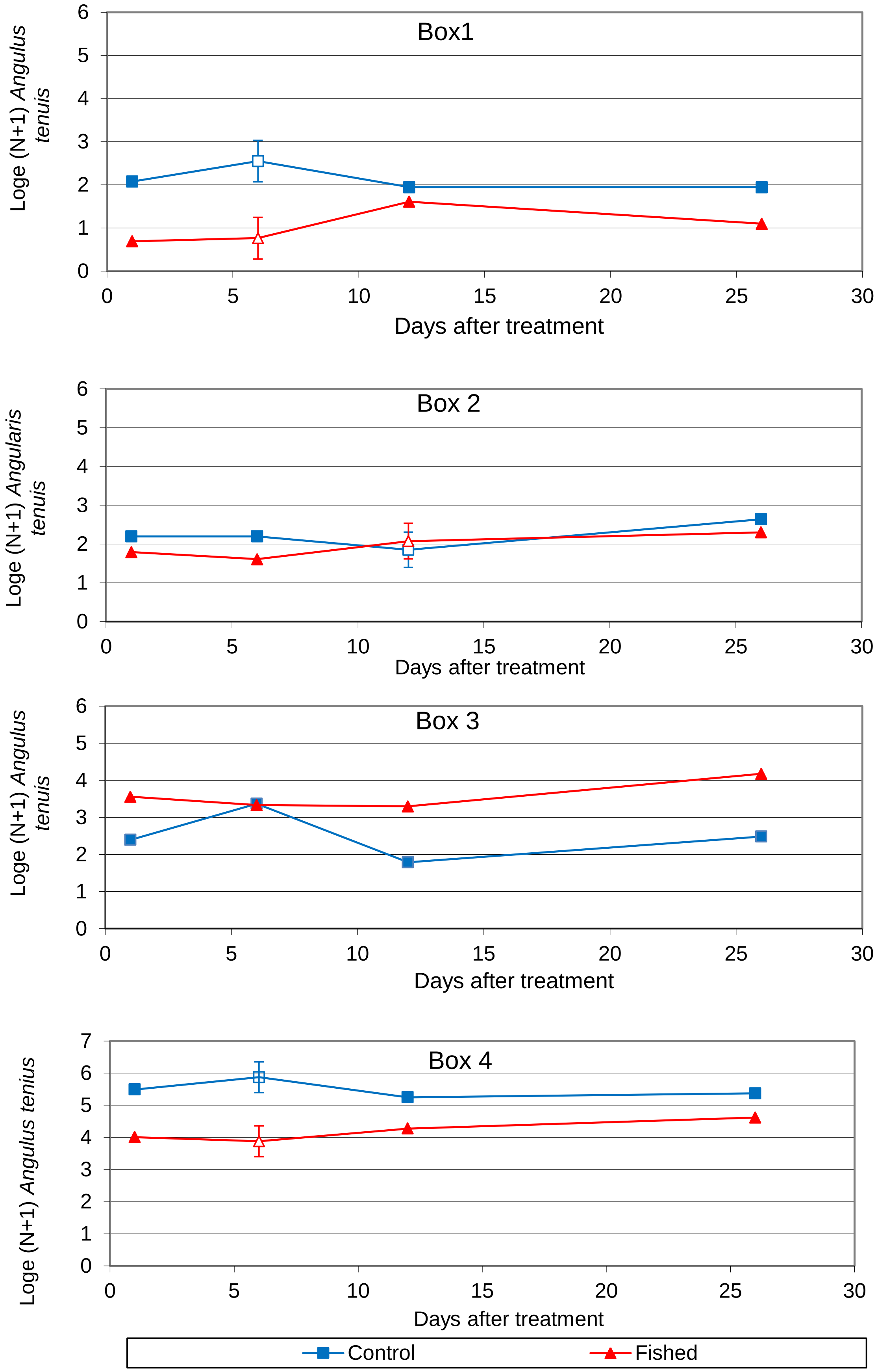


Figure 15 *Abra alba* vis time after treatment in individual boxes. Open symbols represent interpolated values with error bars representing standard deviation of the estimate

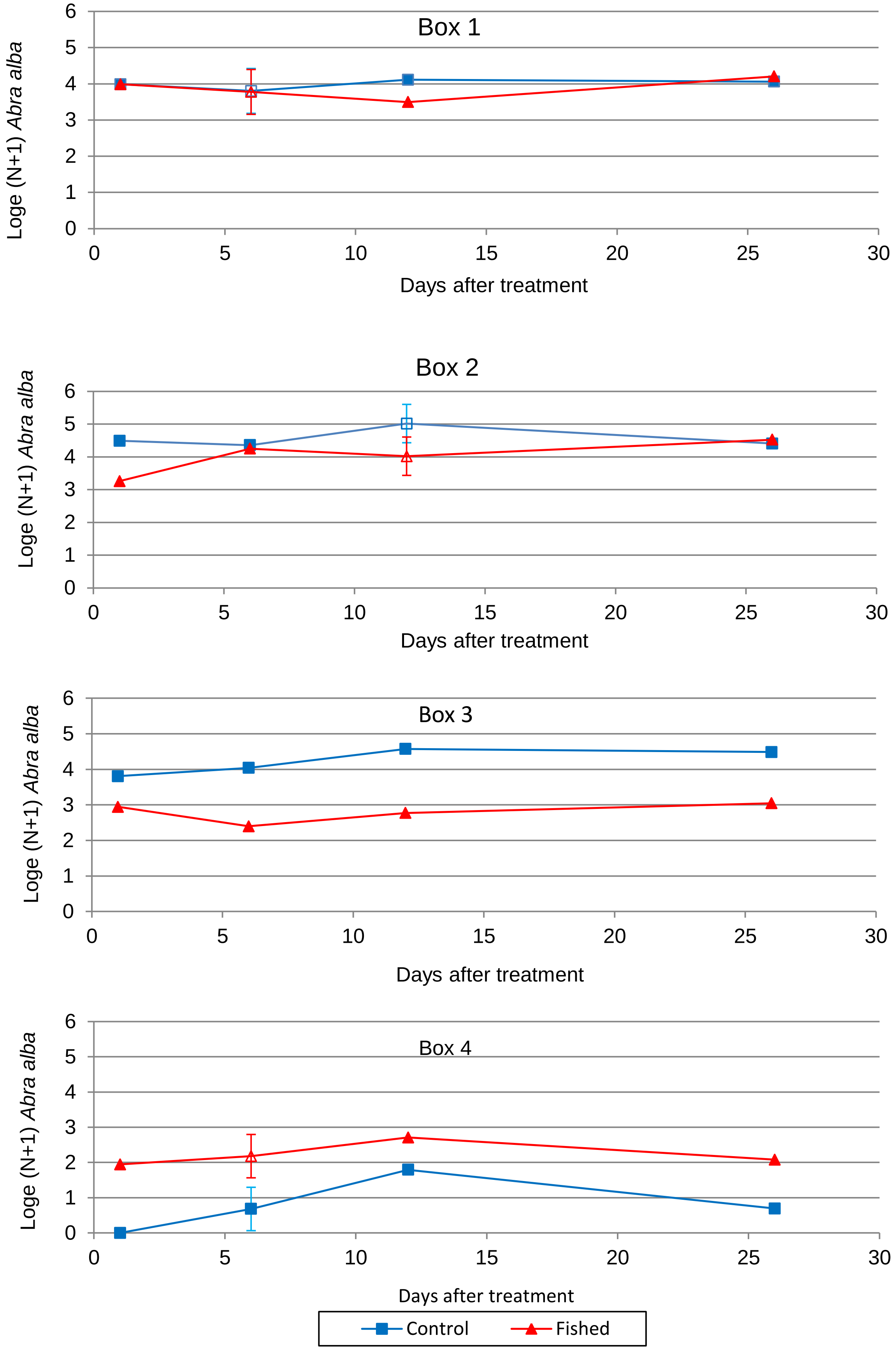


Figure 16 Juvenile *Donax vittatus* vis time post treatment; post treatment results only

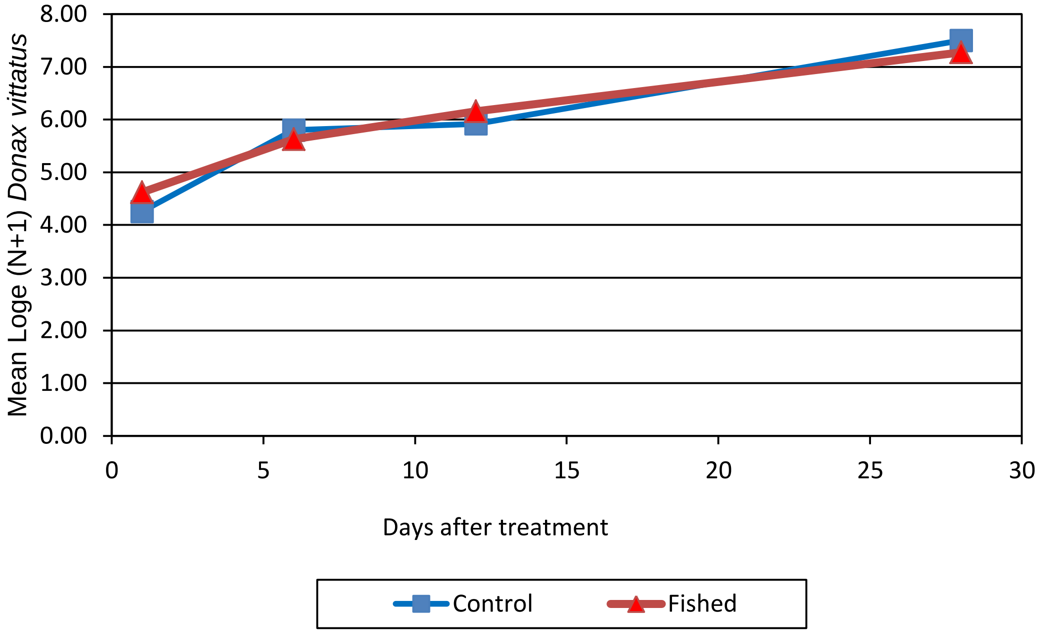


Figure 17 Juvenile *Mytilus edulis* vis vis time post treatment; post treatment results only

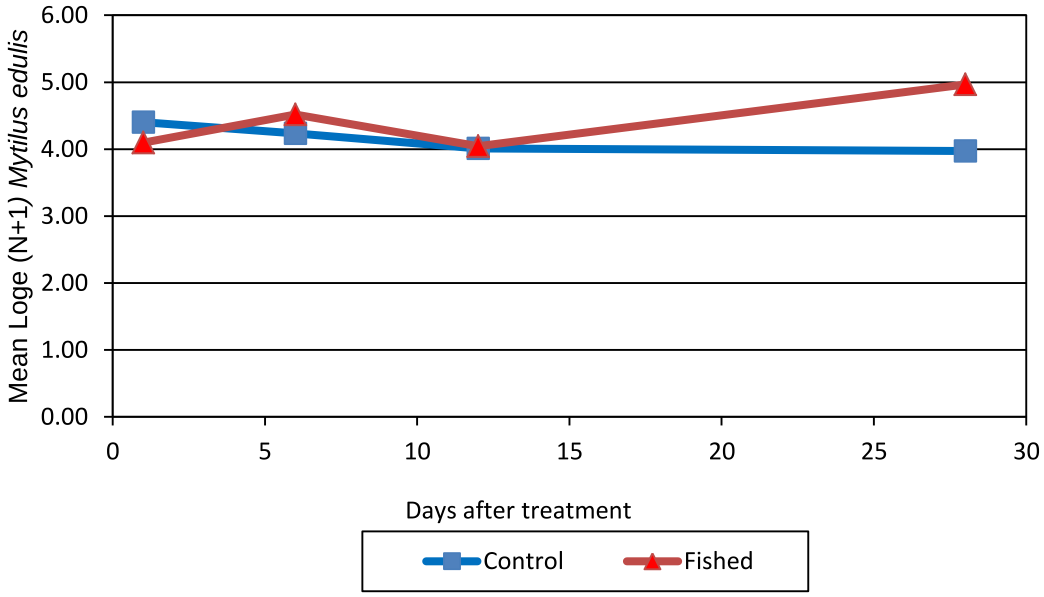


Figure 18 Mean results Loge (N+1) *Magelonia filiformis* ±standard error vis time post treatment. Post treatment results only

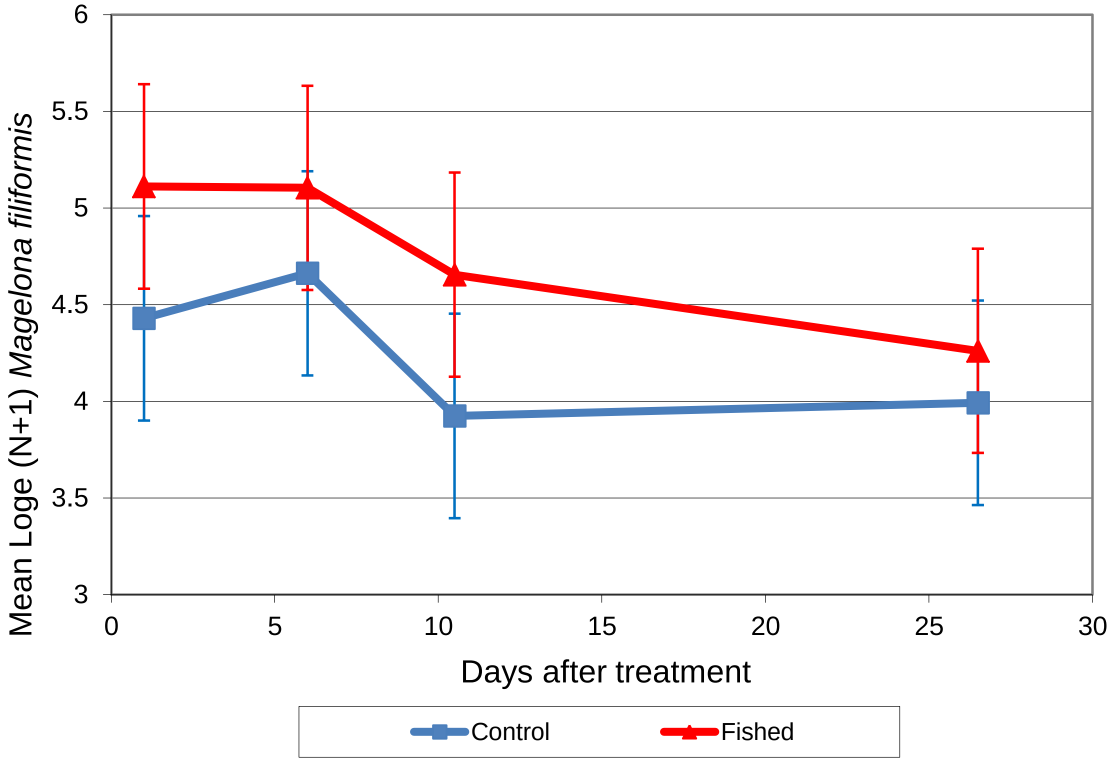


Figure 19 Mean results Loge (N+1) *Owenia fusiformis* ±standard error vis time time post treatment. Post treatment results only

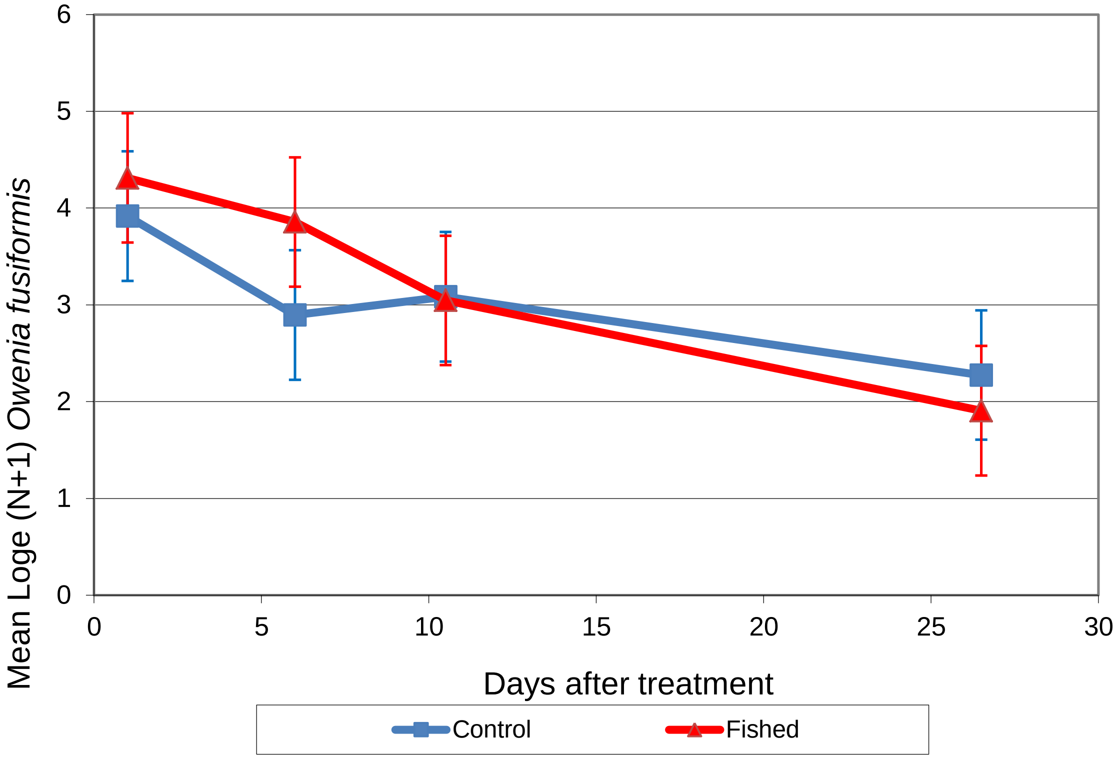
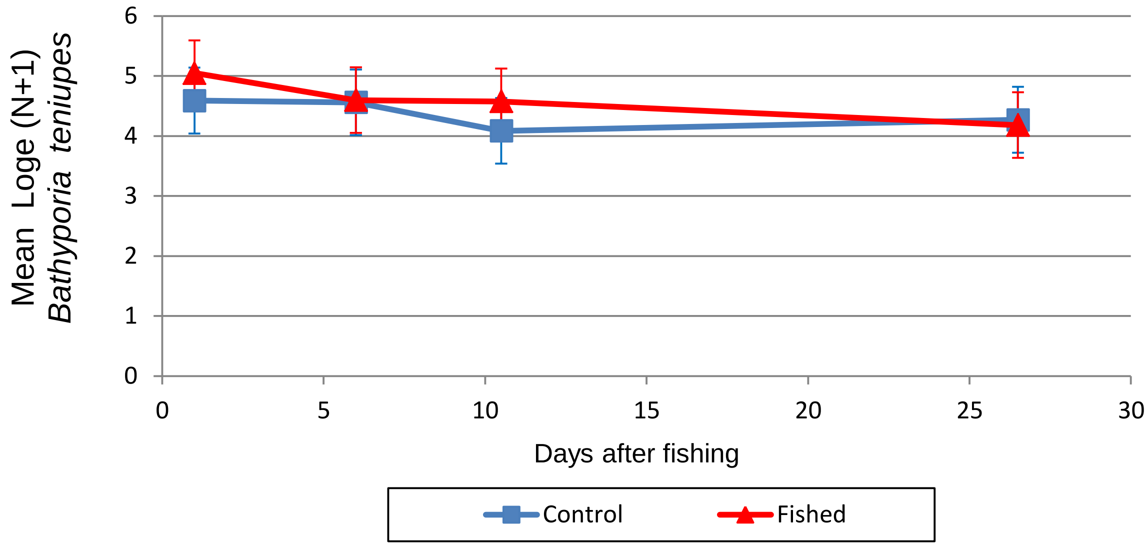


Figure 20 Mean results Log_e (N+1) *Bathyporia teniupes* ±Standard Error vis time post treatment results only



4.0 Discussion

The aim of this project was to develop a more environmentally benign harvest method for *Ensis spp.* in order to provide an alternative to the currently available but more environmentally disturbing hydraulic and toothed dredge methods. There is little doubt that the application of electrical fields to *Ensis spp.* is a viable method of harvest given the experience of fishermen operating in other areas of the UK and Ireland, and the observations of the current study. The paucity of studies on the effects of electric currents on marine invertebrate species gave rise to in a series of valid concerns about the potential for detrimental effects on non-target fauna from electrical fields which require addressing if regulators are to allow the development of its use for commercial fishing. This section will discuss the results of the current study and highlight negative effects on marine fauna and remaining information shortfalls that remain.

4.1 Effect of weather and periodicity on BACI experiment

The period of heavy weather over the summer of 2009 caused a 120 day delay between the initial April 'Before' survey and the beginning of experimental fishing with the electrofishing gear and subsequent sampling. Multivariate analysis demonstrated that the before samples were different from those taken after the experimental treatment (Figure 7a). It is probable that a combination of natural recruitment and the weather related disturbance during the inter-sampling period is responsible for the community changes; the MDS plot demonstrates a similar distribution of experimental boxes across the plot separated into pre- and post- treatment periods (Figure 7b). Due to these changes it is difficult to relate the results from the 'Before' survey directly to the post treatment survey. This does not preclude comparisons between fished and control treatments provided that there is evidence that the treatments were evenly distributed along the environmental gradients and communities.

There are several lines of evidence for this;

- The ANOSIM (section 3.3.2) analysis showed that there were significant east-west gradients in macrofaunal composition both pre and post treatment, and significant differences between boxes. To balance the experiment, the treatments, control and fished were equally distributed between the east and west sectors and there were two plots (one experimental and one control) in each box.

- In all cases the polycheates *M. filiformis* and *O. fusiformis*, the bivalves *A. tenuis* and *A. alba*, and the amphipod *B. tunipes* were the species contributing the most to the dissimilarity (SIMPER analysis Section 3.3.3) between experimental boxes. In the univariate analysis (Section 3.3) Table 9 shows that the counts of these species in the designated control and fished plots were similar in the pre-treatment 'before' survey.

These results broadly indicate that although there were seasonal changes in relative abundance of component species and spatial differences between boxes, there is evidence that the experiment was balanced in relation to the main environmental gradients, species and communities. Thus it is valid to make comparisons between control and fished plots using post treatment results both for multivariate and univariate analysis.

4.2 Effects of electrical field on large epifauna

The short-term effects of the encounter with the electric field are well described for the large epifauna listed in Table 5. The observable effects such as stupefaction and disorientation suggest an effect of the electrical field on the nervous system of these animals. These effects where observed to be temporary and short-term; of the 4 species of crustaceans, 6 species of molluscs, 3 species of echinoderms and 3 fish species observed only *E. siliqua* was recorded to take more than 5 minutes to resume normal behaviour. This species took a maximum of 10 minutes before a return to normal behaviour, i.e. extension of foot and reburial, took place. Whilst the subsequent fate of *E. siliqua* was not observed, reports from the commercial electrofishing trial carried out in Ireland where *Ensis spp.* commonly survive dry packed and refrigerated after electric fishing for up to 12 days (Andrew Verwijs, Pers. Comm.)

It may be pertinent to highlight that there were no reports of any physical damage to the epifauna encountering the gear as this is known to be a risk factor for increasing the risk of predation on molluscan shellfish (Lart et al, 2003).

The review of reported effects of electricity on fish and invertebrates in Section 1.2.3. highlighted the potential of detrimental effects particularly of electrical shocks on fish species. Observations recorded during this study do not suggest that the 30 v DC system operating at 130 A produced such extreme reactions. The most common behaviour of fish was avoidance of the gear and those that encountered it were reported to be temporarily stupefied (Table 5).

Determination of the long-term effects of the electrical field on fish species was outside of the scope of the present study and remains of interested particularly for those species commonly encountering the gear such as the flatfish *S. solea*, *L. limanda*, and *P. platessa*. Nevertheless, the escape response of fish to disturbance provides an effective natural protection from any unreported negative effects of the gear and should be considered as of low risk.

The long-term effects of the electrofishing gear on epifaunal community were investigated in this study by quantitative dive surveys. The analysis of dive data (Section 3.2) confirms a there was no difference between epifaunal post treatment communities in fished and control sectors of the experimental boxes. The analysis reported that a community wide change consistent over all experimental treatments and boxes had occurred between the April-September period resulting from small changes in relative abundance of component species. The component species of the community remained the same during the sampling period.

4.3. Effects of electrical field on benthic macrofauna from grab samples

The literature review highlighted that the short-term effects of the electric field are not well described for benthic macrofauna. These species cannot be observed by the divers and changes in the macrofauna can only be inferred by the results of the grab surveys.

4.3.1 Short-term effects

Analysis (ANOSIM) of macrofaunal samples 1 day post-fishing confirmed that there was no significant effect between fished and control treatments. This result confirms that short-term effects of the electrical field on the macrofaunal species are not fatal and are resolved in 24 hours. It is inferred from the results reported for fish species of varying sizes which report difference in effect due to body length and volume by Dolan & Miranda (2003) that the small invertebrate species in the macrofaunal community would be less affected by the electrical field.

4.3.2 Long-term effects

Analysis of the post-fishing macrofaunal samples using multivariate analysis ANOSIM found no significant changes in the community or relative species abundance over the 28 days post fishing. The post-fishing REML analysis of individual species, which included commonly occurring representatives from the polychaetes, crustacean and molluscs, found that there were no long-term effects to abundance. In addition to effects on existing fauna there was also no apparent change in the pattern of settlement of *Donax vittatus* and *Mytelus edulis* implying that the electric field treatment did not change the properties of the sediments in a which would inhibit settlement. The settlement continued at the same exponential rate on both experiment and control plots.

Multivariate analysis of the macrofaunal community data revealed that natural physical environmental gradients acting North-South across the site had a role in determining community structure (Figure 8-10). This gradient is considered to reflect hydrodynamic energy across the site and is reflected in the distribution of sediment grain size structure running North-South. That the analysis was able to detect this in the macrofaunal data highlights the sensitivity of the technique and adds confidence to the experimental results.

4.4 Conclusions

The results of this study demonstrate that the effects of electrofishing gear employing relatively low DC voltage and amperage can be effectively used in the harvest of *Ensis spp*. without serious negative effects on the epifaunal and macrofaunal benthic community. Given the commonly reported negative effects of alternative approaches such as hydraulic and toothed dredges the results of this study suggest that further development work is warranted in order to develop less disturbing fishing gears, both for *Ensis spp.* and for other species.

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