FIFG OUTSIDE OBJECTIVE 1 PROGRAMME: GRANT FOR INNOVATIVE MEASURES

Development of a suitable dredge for exploitation of razorfish (*Ensis directus*) in The Wash

FINAL REPORT

April 2006

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Cefas Contract No. C2323

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EXECUTIVE SUMMARY

The key aim of this project was to identify a suitable design of dredge for exploitation of razorfish (*Ensis directus*) in The Wash. The project involved an investigation of the designs of dredge in use currently in other fisheries and sea trials of the preferred design in The Wash. The gear trials provided important information on the effectiveness of harvesting razorfish in terms of catch and damage rates, but the primary purpose was to evaluate the potential impact of the use of the dredge on the sediment features of The Wash and north Norfolk candidate Special Area of Conservation (cSAC).

Visits were made to talk to fishermen and inspect dredge designs in The Wash, South Wales and Ireland and information collected on dredge designs from Scotland and Italy. As a result of these observations and discussions with fishermen, it was decided to base the design of the experimental dredge to be used in trials in The Wash on those seen at Skerries and Balbriggan in Ireland. The relatively simple design of dredge would allow two physical aspects of the dredge, the angle of the jets and the depth of the blade below the runners, to be made adjustable. This would allow these two aspects of design to be tested as variables alongside towing speed and water pressure.

The contract for construction of the dredge was awarded to Craven and Nicholas Engineering Limited in Boston as this company's quote was the most competitive of the three estimates obtained. An invitation to tender to carry out the field trials was placed in Fishing News and the charter vessel contract was awarded subsequently to FV Wash Princess owned by Heiploeg and Lynn Shrimpers Inc. Ltd., King's Lynn.

The geographical locations of the field trials were based upon information gathered on distribution and abundance of *E. directus* from annual stock surveys carried out by Cefas. Two areas in The Wash, on the north edge of Seal Sand and on the west side of Sunk Sand, were selected for the field trials. These areas have a dense stock of *E. directus* close to minimum landing size, and are in exposed positions so that the physical impact of dredging is likely to be short lived.

Prior to starting the sea trials, particle size analysis (PSA) and faunal analysis was undertaken for 15 substrate samples collected by Day grab from the experimental plots, and along with testing of the substrate by MacKintosh probe, these analyses contributed towards the 'Appropriate Assessment' produced for the field trials in consultation with English Nature and signed off by Defra as the competent authority. Development of the fishery is also dependent on obtaining a classification for the area for this species under the EU Shellfish Growing Waters Directive, and the opportunity to initiate this process was taken up during this project. Samples from each experimental plot were collected and initial results were very encouraging giving *E. coli* levels comfortably below the limit for Class A waters. Sample collection continues.

Initially, towed dredge trials were carried out using a submersible pump and the vessel's cockle pressure pump, which demonstrated that the dredge could function in this configuration and catch razorfish. However whilst various gear parameters such as pump pressure and excavation depth of the blade could be varied, it proved very difficult to control and measure the speed and direction of the vessel whilst towing. These results did demonstrate however that damage rates were a function of towing speed, and whilst low damage rates were achieved on some tows, damage rates of up to 35% at higher speeds were considered to be unacceptably high.

The most effective method of deployment was to use an anchor dredge. In this set-up, the anchor is dropped with the vessel head to tide and the vessel is allowed to drop back on the anchor. This permits relatively good control of speed and direction of the dredge, and allows calculation of actual speed from the time and distance travelled. This method of dredging was found to be controllable, safe and considered a potentially viable commercial operation by the fishermen. The results of the hauls using the anchor system showed that both catch rate of razorfish and damage rates are functions of vessel speed, with both higher catch and damage rates occurring at higher towing speeds. At slow speeds, damage rates were on average 15-20%.

Initial observations of the sediment particle size distribution and the density of the sediment deploying the Mackintosh probe indicated that the sediment was composed mostly of well sorted sand of between 0.1 and 0.5 mm nominal diameter. The sediment was described as very loose sand down to approximately 0.65 m in the locations surveyed. The project examined the way in which the dredge interacted with the seabed through instrumentation, with particular attention given to the excavation depth of the dredge. The key methodology involved the use of two trailing arms, one designed to measure the excavation depth of the dredge, and the other offset to the port side of the dredge intended to be on undisturbed seabed. The data showed that there was variation in all the angles (heel and inclination of the dredge and angles of the trailing arms to the horizontal) which would affect the estimated excavation depth. Mean, maximum and minimum results were taken therefore over selected time intervals, and the data allowed an estimate of the heel and inclination of the dredge and the mean excavation depth in an assumed horizontal seabed. The key dimension to be assessed was the mean difference in depth of the 'experimental' and 'control' trailing arms.

The results showed that the mean excavation depth is principally a function of pressure with a pressure of 3.6 to 3.75bar required to achieve the depth necessary to dig out the razorfish without damaging them. Excavation depth will also be determined by towing speed (slower towing speeds result in deeper excavation) and nature of the substrate. The results were consistent with the modelling studies which formed part of the Appropriate Assessment.

On the Seal Sand, mean maximum depth of excavation was found to be 240 mm whereas on Sunk Sand there was a shallower depth of excavation of 73-163 mm which may be attributable to denser sediment. These estimated excavation depths are well under the figure of 650 mm of loose substrate identified by the Mackintosh probe. It is concluded that any commercial dredge is unlikely to be deployed in such a way that would impact on the interest features of The Wash and north Norfolk cSAC. There is no commercial gain to excavate deeper than about 200 mm and therefore only the coarse, mobile sediments would be disturbed by such dredging activity. It appears unnecessary to adopt fixed criteria for dredge design and operation for vessels that wish to participate in any experimental commercial fishery. Guidelines based on the results of this project can be offered to potential participants, but these will inevitably be modified by individual vessels to maximise catch rates and minimise damage rates of *E. directus*.

ACKNOWLEDGEMENTS

We would like to thank all the fishermen who gave advice on dredge design, particularly Noel Sharkey and Kevin Phillips in Ireland, and Bill Price of Rockabill Shellfish who gave general advice on the razorfish business.

At Heiploeg and Lynn Shrimpers, Steve and John Williamson and their team rendered much assistance. Skipper Gary Taylor and crew Doug Fisher and Gene Fisher of the FV Wash Princess deserve thanks for their patience and hard work. The workshop engineers, Pat Baldry, Andy Clark and Andrew Staunton constructed trailing arms of the instrumentation after much patient trial and error.

Peter Allan and his team at SEtech carried out the geotechnical engineering studies. We would also like to thank Tim Ingram of Katon-Ingram Ltd, Newport, Isle of Wight who supplied the instrumentation.

1. INTRODUCTION

1.1 Background

The fishery for razorfish in The Wash was still in an experimental phase in 1998 when, following advice from English Nature, Defra introduced an Order prohibiting dredge fishing for razor shells, trough shells and carpet shells in The Wash and north Norfolk coast area, specifically the area designated as a candidate Special Area of Conservation (cSAC) under the European Habitats Directive.

The Razor Shells, Trough Shells and Carpet Shells (Specified Sea Area) (Prohibition of Fishing) Order 1998 (Statutory Instrument No. 1276) came into force on 23 May 1998 following concerns from English Nature that a prospective new unrestricted fishery in the cSAC for razor shells in particular could lead to damage of the very habitat which the area has been designated to protect.

When the Order was introduced, the then Fisheries Minister Elliot Morley, stated that:

"Any new fishery in the area for razor shells or other molluscs needs to be managed sustainably. The Order provides the breathing space necessary to work out with local interests an effective management regime. I hope that local fishermen will co-operate with English Nature, the Eastern Sea Fisheries Committee and the Ministry in drawing-up management arrangements. As part of this process, we will be looking to work with a local fisherman or fishermen to carry out a controlled fishery for the purpose of scientific investigation. The results will then feed into the establishment of sustainable management rules so that the precautionary prohibition can be lifted as soon as possible."

There are four species of razorfish exploited commercially in British waters: *Ensis arcuatus*, *E. siliqua, E. ensis* and *E. directus.* The first three are native, whilst *Ensis directus*, the American jack-knife clam, is an alien from North America which has become established in European waters over the last 20 years (von Cosel *et al*., 1982). In The Wash, there are some native *Ensis spp.*, but by far the largest biomass is *Ensis directus*, and it is this species for which any commercial harvesting would be directed if the Order was to be lifted.

As a precursor to any future controlled fishery, the Centre for Environment, Fisheries and Aquaculture Science (Cefas) has undertaken a series of resource surveys since 1998, which demonstrate highly variable settlement rates and often high over-wintering mortality rates suggesting that, although in some years individual year classes of *Ensis directus* would survive in sufficient numbers to be harvested in a sustainable manner, there may be some years when there would not be sufficient stock biomass of *E. directus* to allow a commercial harvest (D. W. Palmer, unpublished Cefas report). The

2002 year class has persisted over recent winters, and by the end of 2005 some of the population had reached or were about to reach the minimum landing size (MLS) of 100 mm length, although there was still a significant proportion of the population that was still under the MLS. This year class should be ready for exploitation in 2006 and beyond, and the latest stock estimates indicate that there may be 2000 tonnes or more available for exploitation, which would represent a major fishing opportunity for The Wash fishing fleet, which in recent years has suffered considerably from low stock levels of mussels and cockles. Total stock biomass of *E. directus* in The Wash is estimated to be in excess of 10000 tonnes.

Previous studies in the UK have identified the potential for impact on the seabed features and infaunal community from dredging for razorfish (e.g. Hall *et al*., 1990; Tuck *et al*., 2000; Hauton et al., 2003), but the level of impact will depend upon the nature of the substrate, the species of razorfish targeted and the design of the dredge. In contrast to the native species, which populate fine sand sediments in full salinity, *E. directus* are found over a range of sediments from mud through silt to quite coarse sand and can tolerate more estuarine conditions. Since the physical impact of dredging will be persistent on muddy substrates in sheltered areas, English Nature would be likely to express concern about any commercial harvesting on them. It is important therefore, that dredging should target stocks in exposed areas with highly mobile sediments. In the course of annual grab surveys, Cefas have identified two such areas with low benthic diversity and dense aggregations of *E. directus*. It seems likely that these *E. directus* beds could be exploited without impacting significantly on the key features of the cSAC. On the basis of these stock surveys and accompanying information, English Nature may now be willing to agree to a controlled or experimental fishery providing an "Appropriate Assessment" is carried out beforehand, and that they are satisfied that initial studies show that dredging can be carried out without causing significant damage to the interest features of the cSAC.

Damage to the local interest features will be dependent on the design of the fishing gear used to extract razorfish, and so before any controlled fishery can commence within the cSAC, it is essential that criteria are drawn up concerning the type of dredge that can be used to fish for *E. directus*.

1.2 Purpose of project

The key aims of this project were to:

- review the design and operation of dredges used currently in other European fisheries for razorfish, and identify a suitable design for use in The Wash and
- conduct field trials using an appropriate dredge in The Wash on a chartered commercial fishing vessel, primarily to identify the potential impact of the dredge on the interest features of The Wash, but also to evaluate the efficiency of the dredge in relation to catch and damage rates of *E. directus.*

Field trials of dredges within The Wash will require a derogation from the Order from Defra's Sea Fisheries Conservation Division.

Development of the fishery will also be dependent on obtaining a water classification for the area for this species under the EU Shellfish Growing Waters Directive, and the opportunity to progress this issue will be taken up as a relatively small component of this project.

1.3 Expected outcome

The expected outcome of the project would be the designation of appropriate gear for use in a controlled fishery for *E. directus* in The Wash, if the prohibition on dredging was lifted.

This development is an opportunity to introduce a relatively invasive fishing technology within a cSAC whilst applying measures to minimise its impact on the environment. As well as developing this fishery it will enable consensus to be built on how fisheries within SACs should develop in the future.

1.4 Project structure and management

The proposal is split into two parts covering firstly the collection of information on current gear and its impacts and the implications of the likely processing requirements and, secondly, sea trials of suitable dredges in The Wash along with appropriate sample collection and analysis. The project was managed by CEFAS with collaborative input from gear technology experts from Seafish[1], who also sub-contracted a consultant in sediment mechanics (SEtech). There was significant industry participation both in the gear review and field trial stages of the project.

1.5 Overview of report

Section 2 of the report provides a brief summary of visits made to talk to fishermen and inspect dredge designs in The Wash, South Wales and Ireland, collection of information on dredge designs from Scotland and Italy, and the justification for the choice of the experimental dredge design for field trials in The Wash.

Section 3 describes field trials of the experimental dredge in The Wash. Initial trials showed that whilst conventional towing of the dredge was successful in harvesting razorfish, variations in speed and direction made it almost impossible to achieve satisfactory results with the instrumentation utilised to assess key parameters relating to depth of the dredge during its operation. As a result, we developed an alternative procedure using an anchor onto

[1] Sea Fish Industry Authority

which the dredge was allowed to drop back, and this procedure allowed successful utilisation of the instrumentation, and hence permitted an evaluation of the key question of the potential effect of the dredging operation on the interest features of The Wash cSAC. We had envisaged some evolution of the fishing practices during the course of the field trials, but not such a major change in the method of deploying the experimental dredge, and consequently we undertook significantly more days at sea on the charter vessel than was anticipated in the original project proposal.

Section 4 discusses the results of the field trials in relation to the adoption of criteria for dredge design and operation for vessels that may wish to participate in any future experimental commercial fishery.

2. REVIEW OF DESIGN AND OPERATION OF EXISTING DREDGES FOR ENSIS

2.1 Introduction

In addition to the development of a fishery for razorfish in The Wash prior to the prohibition of dredging in 1998, fisheries for razorfish have developed in Wales, Ireland and Scotland and there have been significant advances in gear design for harvesting of other similar bivalve species in Italy and other European countries. As a starting point for this project, a review of all designs of Ensis dredge was undertaken, and this section summarises some of the key findings in relation to identifying a suitable dredge for the gear trials in The Wash.

2.2 The Wash fishery and gear

The initial fishery for *Ensis* in The Wash was developed by John Lake Shellfish Limited in the late 1990s. At that time the “tongue” water-jet dredge was in use in Scotland and Ireland. This dredge has a steel blade with forward pointing water jets on its cutting edge which digs into the seabed, and it was on this design that John Lake Shellfish based their dredge for The Wash fishery. However instead of a collection cage they installed a continuous lift system, which delivered the animals through a pipe into a net bag suspended over the side of the vessel so that the shellfish were delivered into water, thus minimising damage. At that time it was not realised that, with the odd exception, all the razorfish taken in The Wash area were *Ensis directus,* rather than the native *E. siliqua* and *E. arcuatus* that were familiar to the market. Nevertheless John Lake Shellfish marketed the animals successfully, selling them live to Spain.

2.3 The UK and Ireland fishery and gear

As noted above, the gear used in The Wash fishery was based on the Scottish and Irish design of dredge, and although dredging was prohibited from 1998 in The Wash cSAC, the fisheries for native *Ensis* species continued in Scotland and Ireland. In the latter case development occurred quickly and problems of over-supply and poor product quality surfaced during 1999. Dredges continued to develop and were now influenced by those employed in Italy, which use a manifold of downward pointing water jets that fluidise the sediment ahead of the dredge blade. This system has been taken on by the industry in Ireland, and in South Wales and it was to these areas that Cefas / Seafish turned their attention during this study.

2.4 Summary of visits to South Wales and Ireland

As an initial step in identifying a dredge suitable for use in gear trials in The Wash aimed at evaluating its potential impact on the interest features of the cSAC, visits were made to investigate the design of Ensis dredges used in the South Wales and Ireland fisheries and to discuss their operation with local fishermen. In South Wales, two vessels have employed water-jet dredges to fish for *Ensis siliqua.* Cefas staff were able to visit one skipper at Swansea in May 2005. His dredge had been successfully employed at 1.5m wide, but in order to comply with a local South Wales Sea Fisheries Committee byelaw, the skipper had been forced to reduce the effective fishing width to 75cm. In this particular design of dredge, water to the jets is delivered from a submersible hydraulic pump mounted on the manifold. On this vessel the jets are angled vertically down onto the seabed.

In Ireland, a dredge fishery for the native razorfish (*Ensis siliqua)* developed during the 1990s. Of particular importance is the area from Dublin north to Dundalk Bay on the east coast, and it was to this area that a visit of Seafish and Cefas staff was made in May 2005. During this visit, three fishermen and one major shellfish buyer were interviewed.

A fisherman from Clougherhead, whose vessel was based at Drogheda due to works at her homeport, was the first to be visited. The dredge on this vessel is 1.5m wide and based on a much-modified Italian dredge. As was to prove the case for all the dredges examined in Ireland, the water jets are angled back so that the water is directed to a point in front of the blade formed by the lower front edge of the cage. Uniquely in this case, water is also forced through holes in the blade. This is a hangover from the original Italian design and while the skipper felt that it was an aid to digging on some grounds did not consider it essential. Another modification not seen elsewhere are runners under the cage, designed to tip the dredge forward and counter the tendency for the front of the dredge to lift in operation. The dredge is deployed over the stern of the vessel from a specially constructed gantry, and towed on the vessel's main propulsion, although the skipper had successfully tried the anchor method used in Italy. The towing speed is less than 1kt. The skipper has a system of stacking boxes with flow-through seawater supply to de-grit the catch.

Figure 2.1 Ensis dredge operated on Drogheda vessel

A second visit was made to another skipper who works an under 10m vessel from Skerries. The dredge on this vessel is 3 ft (0.91m) wide and deployed over the side of the vessel. As with all the dredges observed during this visit, water to the jet manifold is supplied from a deck-mounted pump. However, the skipper expressed an interest in trying a submersible pump.

Figure 2.2 Ensis dredge operated on Skerries vessel

A third vessel was visited at Balbriggan where two Ensis dredges were standing on the quayside and were easy to examine and measure. Both dredges were similar in all respects to the Skerries dredge (Figure 2.2) and, as with all the Irish dredges observed, these dredges have the water jets angled back to a point just in front of the blade.

Figure 2.3 Ensis dredge operated on Balbriggan vessel

Dredges were also observed on two vessels at Howth. These were larger vessels and, although we were unable to contact the skippers/owners to examine the dredges closely, they appeared to be similar in width to the dredge seen at Drogheda.

In addition to the various vessels we also visited a processor who has been a major buyer of razorfish since the fishery first developed in the area. The processor emphasised that de-gritting is essential; and that the animals should be banded together or packed tightly into containers and maintained upright in seawater for at least twelve hours. The processor sells live to the Spanish market but there are problems with the water quality classification, which has led to a loss of markets in the Far East. He has not tried to enter the frozen or canning markets. In general the Spanish market has proved difficult for the industry in Ireland beacuse strong competition from Scotland and Chile can hold down prices. In consequence, Irish vessels have to fish to order because there is no general market for the product.

The information gained during these visits was of great value in deciding how to proceed and it was felt unnecessary to undertake further visits.

2.5 Identification of design of dredge suitable for field trials in The Wash area

As a result of observations and discussions with fishermen in Ireland, it was decided to base the design of the dredge to be used in trials in The Wash on those seen at Skerries and Balbriggan. It was felt that the relatively simple design would allow two physical aspects of the dredge, the angle of the jets and the depth of the blade below the runners, to be made adjustable. This would allow these to be tested as variables alongside towing speed and water pressure. It should be stressed here that the key aim of the field trials is to evaluate the potential impact of the dredge on the interest features of the cSAC, and that the effectiveness and efficiency of the dredge in terms of catch and damage rates of the razorfish is of secondary importance. The field trials are aimed at setting criteria for dredge design and operation which will ensure that the interest features of the cSAC are not impacted, and that the most effective design of dredge would be likely to emerge following the controlled, experimental fishery.

3. FIELD TRIALS OF SPECIALLY-CONSTRUCTED DREDGE IN THE WASH

3.1 Introduction

As noted in the Introduction, English Nature required the completion of an "Appropriate Assessment" for the experimental dredge trials prior to commencing those trials. Responses by Cefas to a series of questions posed by English Nature in relation to potential impacts of dredging for razorfish in The Wash are provided in Appendix A, and this document in conjunction with the report by SETech in Appendix D form the full Appropriate Assessment for the dredge trial. This Appropriate Assessment was signed off by Defra as the competent authority and English Nature accepted that the dredge trials could go ahead.

Following the review of dredge designs used commercially in other parts of the UK, we drew up specifications for the construction of the dredge, put the construction out to tender, and also tendered for a commercial fishing vessel to carry out the field trials under charter. This section of the report covers those tendering processes, the collection of samples for analysis, the evolution of gear deployment and the results from the various field trials.

3.2 Dredge specification and construction

The dredge was constructed from the plan shown in Appendix B and was based on observations of Irish dredges as described in Section 2. Figure 3.1 shows the dredge in operation. (Full engineering drawings are available from Bill Lart at Sea Fish Industry Authority, St Andrew's Dock, Hull HU3 4QE. Tel. 01482 327837.) The dredge was designed so that the position of the cage relative to the side runners could be adjusted by moving the bolt position on the side of the cage up and down through six holes. The angle of the jets could also be adjusted using the bolts shown in the drawing. The angle was changed when the cage was changed so that the jet was aiming for a consistent distance in front of the blade (the bottom leading edge of the cage). This distance was 170 mm on the initial set of trials, but we then increased this distance to 210 mm on the second set of trials because we perceived that the jet appeared too close to the cage in the first set of trials.

When used with the cockle pump an additional 140 kg of weight was attached to the dredge in the form of railway fishplates on the runners between the jets and the cage and also forward of the cage. This replaced the weight of the hydraulically driven pump and was intended to counter the up thrust from the water jet.

Three tenders were received from local companies in The Wash area for construction of the dredge. The contract was awarded to Craven and Nicholas Engineering Limited in Boston, Lincolnshire. (Full details of the successful and unsuccessful tenders can be found in Appendix C. For reasons of commercial confidence Appendix C is not reproduced in copies of the report which are available on general release).

Figure 3.1. a   The experimental dredge constructed for use in the field trials in The Wash

Figure 3.1. b Emptying the catch of razorfish following deployment of the experimental dredge

3.3 Charter of commercial fishing vessel to carry out field trials

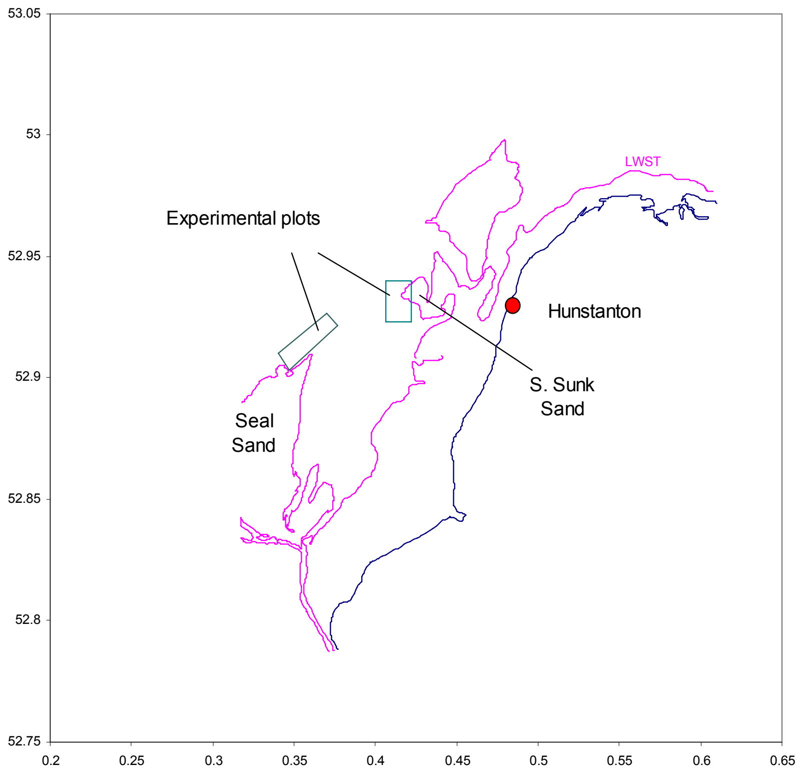
An advertisement was placed in Fishing News requesting tenders from commercial fishing vessels to carry out the trials of our experimental dredge in The Wash. Four tenders were received and the contract was awarded to *Wash Princess*, LN161, owned by Heiploeg and Lynn, Alexandra Dock, King's Lynn, Norfolk. (Full details of the successful and unsuccessful tenders can be found in Appendix C. <u>For reasons of commercial confidence Appendix C is not reproduced in copies of the report which are available on general release</u>).

The geographical locations of the field trials were based upon information gathered on distribution and abundance of *E. directus* from the annual stock surveys. The annual survey of 2003 recorded a widespread and well-grown settlement of the 2002 year-class of *E. directus*. This was confirmed in 2004 and 2005 when the surveys recorded that this 2002 year-class had survived well. There were few survivors from earlier year-classes and the 2003 settlement was negligible. The 2002 year class would therefore form the mainstay of any experimental fishing in the short to medium term.

Two areas, on the north edge of Seal Sand and on the west side of Sunk Sand (Figure 3.2), were selected for field trials based on the following criteria:

- There was a dense stock of *E. directus* on the ground.
- The animals had grown to a good size and might be expected to reach a marketable size by the time of any commercial exploitation.
- The plots were in an exposed position so that the physical impact of dredging is likely to be short lived relative to those in sheltered positions on the edges of the channels.
-

Figure 3.2 Geographical location of two experimental plots



Each plot covers an area of approximately 2 km^2 and given average growth and mortality might be expected to hold stock of more 2000 tonnes in the autumn of 2006.

Dispensation to fish for *Ensis directus* within the area specified in the schedule of The Razor Shells, Trough Shells and Carpet Shells (Specified Sea Area) (Prohibition of Fishing) Order 1998 (Statutory Instrument No. 1276) was issued by Defra under the provisions of Section 9 (2) of the Sea Fish (Conservation) Act 1967.

3.4 Collection of samples for analysis

3.4.1 Day grab samples for particle size analysis (PSA)

A total of 15 Day grab samples was collected from each plot, sieved and all benthos identified. The positions of these samples and the results of them are shown in Figure A1 and Table A1 respectively, in the Appropriate Assessment report (Appendix A).

From each experimental plot, five Day grab samples were used subsequently for particle size analysis. The analysis carried out at the Cefas laboratory in Burnham-on-Crouch typified the sediment in the top 20cm as silty, fine to medium sand. The full results from these samples are reported in the SETech report in Appendix D.

The SETech report also gives results of testing the substrate with a MacKintosh probe, which suggested that the sediments can be characterised as very loose to a depth of 0.65m.

3.4.2 Collection of samples for analysis as part of water classification

Under the EU Shellfish Growing Waters Directive, obtaining a water classification for any potential future razorfish fishery requires the collection and analysis of samples of razorfish over a specific minimum time, usually 6 months, although it is possible to obtain a classification based on a minimum of 10 samples from each site over three months. Depuration of dredge caught razorfish has not proved possible as yet despite extensive trials (BIM, C-Mar and Seafish unpublished data), and thus an A classification would be required for the high value fresh live market. There is a company in Boston, Lincolnshire (DANI Seafoods) interested in processing (canning) the product for which a classification of C or above would be required. Although this project is aimed primarily at evaluating a suitable dredge for razorfish in The Wash, the opportunity will be taken during the project to initiate the process of sample collection and analysis for water classification. Although each species is different, based on other species in The Wash the likely classification would be A.

During the field trials of the experimental dredge in late December 2005, a sample from each experimental plot was sent to the Environmental Health

Laboratory at Kings Lynn to begin the process of classifying the beds. These initial results were very encouraging giving 40 and 70 *E. coli* / 100g flesh at Sunk Sand and Seal Sand respectively. These are comfortably below the 230 *E. coli* / 100g limit for class A waters. Trials were then carried out with an anchor dredge from the Eastern Sea Fisheries Joint Committee (ESFJC) vessel, RV Three Counties, to see whether this simple sampling tool might be used to obtain further samples. The results, although hampered by lack of time, were encouraging, and it is hoped that ESFJC can provide the necessary samples over the coming months, alongside their normal activities, to obtain a water classification prior to any projected re-opening of the fishery.

3.5 Initial field trials of the experimental dredge

The specially-constructed experimental dredge was delivered by Craven and Nicholas engineering to Heiploeg and Lynn Shellfish in King's Lynn on 10 October 2005, along with the submersible pump and hydraulic power pack. Over the next five days the dredge was rigged on the charter vessel FV *Wash Princess* and the vessel was modified to deploy the dredge.

The specifications of the charter vessel FV *Wash Princess* are shown below:

Engine power (Cummings Diesel)	269kW permanently de-rated to 203kW
Overall length	13.10m
Registered Length	11.70m
Breadth	4.80m
Depth	1.60m
Gross Tonnage	17.35
Net Tonnage	17.35
Displacement Tonnage	40
Year of build	1992

On 17 October 2005 the charter vessel sailed from King's Lynn and the first successful deployment was carried out on the Seal Sand plot. In the following days, a series of experimental hauls were carried out within both the Sunk and Seal Sand plots in locations identified from the annual stock survey as being areas of very high density of *E. directus*. Initial trials used a hydraulically driven pump. This was driven by a power pack on the deck of the vessel with flexible hydraulic power pipes leading down to the submersible pump (Hydrainer 150-D25 with high head impeller) mounted on the front of the dredge (Figure 3.3). The dredge was towed on a chain at approximately 3:1 warp depth ratio, with the engine on tick over, the vessel moving as slowly as possible balanced between wind and tide. The dredge was towed in this configuration for approximately 5 minutes per haul. Nineteen valid hauls were made using this specification. These initial trials showed that the dredge could function in this configuration and catch razorfish.

However, the dimensions of the submersible pump and the additional risk of having a valuable pump on the seabed meant that this was not a satisfactory configuration. Examination of the specification of the vessel's cockle pressure pump suggested that it should produce adequate performance. Thus modifications were made to the dredge and vessel to accommodate a 150 mm diameter rubber pressure pipe leading from a standpipe on the deck of the vessel. This was tested at sea over a series of nine hauls with the dredge towed as described above.

The cockle pump used for this second set of hauls was a Etanorm 125-315 marketed by KSB, 2 Cotton Way Loughborough Leicestershire LE11 5TF.

The estimated outputs from the pump are shown in Figure 3.4 and the pump curve is shown in Figure 3.5.

Figure 3.3 Hydrainer 150-D25 pump with high head impeller bolted to experimental dredge

Figure 3.4 Estimated outputs from the Etanorm 125-315 pump

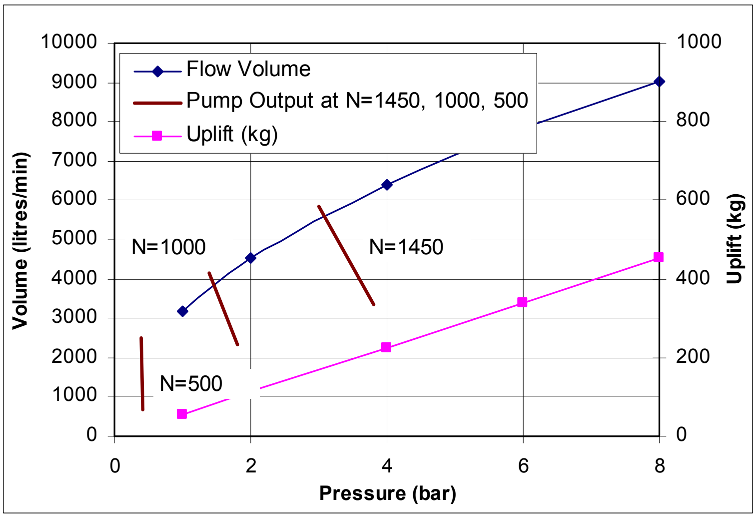
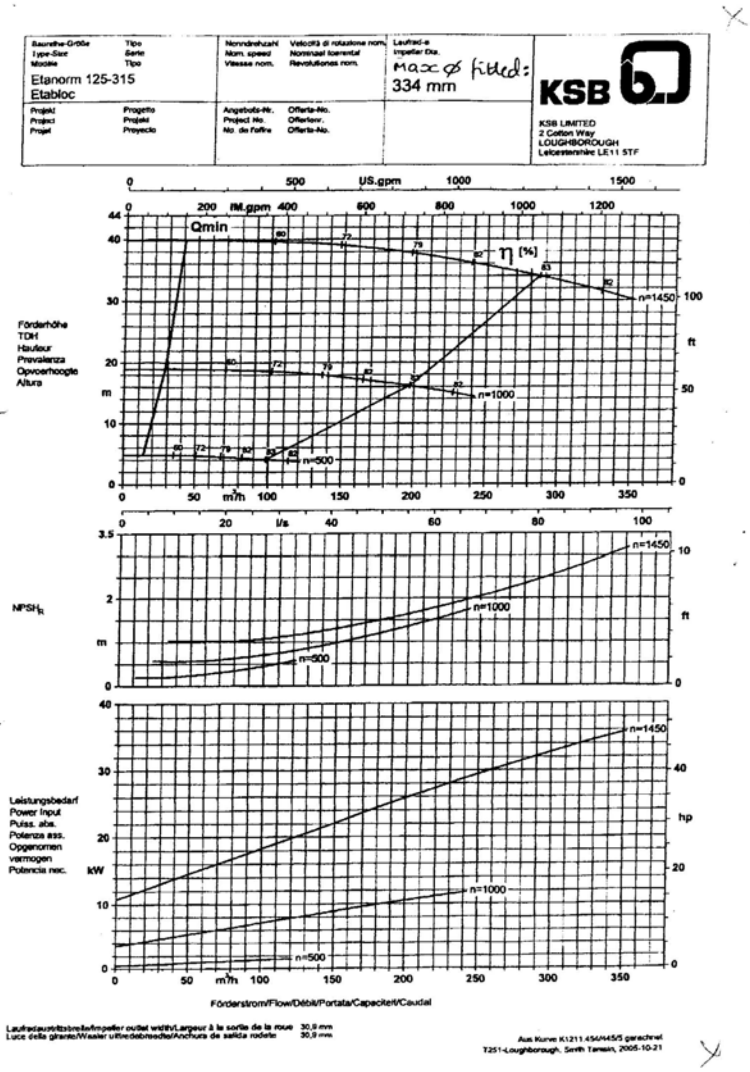


Figure 3.5 Pump curve for the Etanorm 125-315 pump



3.4.1 <u>Results of initial towed dredge trials</u>

Yields

The overall yield for the 200 minutes of valid hauls in towed dredge trials was 159 kg of razorfish making a yield of approximately 0.8 kg per minute of fishing time. However there were approximately another 200 minutes of fishing time that yielded no catch of razorfish at all because the gear was not functioning. Thus the overall yield was approximately 0.4 kg min^{-1} overall. Yields could be quite variable as shown in Figure 3.6, and the yields (kg min^{-1}) for the hydraulic and cockle pumps were similar (Table 3.1). Whilst it would be preferable to present catch rates in terms of kg per distance towed, difficulties maintaining direction of the dredge precluded such a calculation.

Figure 3.6 Frequency of hauls for various yields (kg min^{-1})

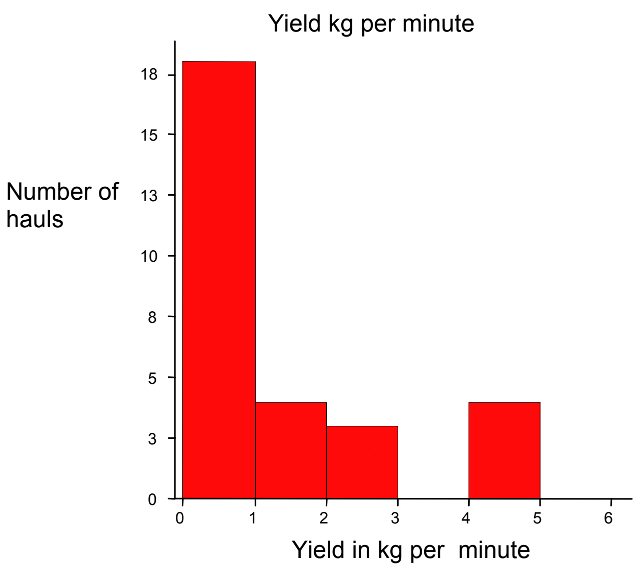


Table 3.1 Yields of the two types of pumps used for towed dredging

Pump	**Number of valid hauls**	**Yield per minute (kg)**	**Range min-max (kg/minute)**
Hydraulic	19	0.7	0.12-5.0
Cockle	10	1.0	0.3-4.6
Overall	29	0.8	0.12-5.0

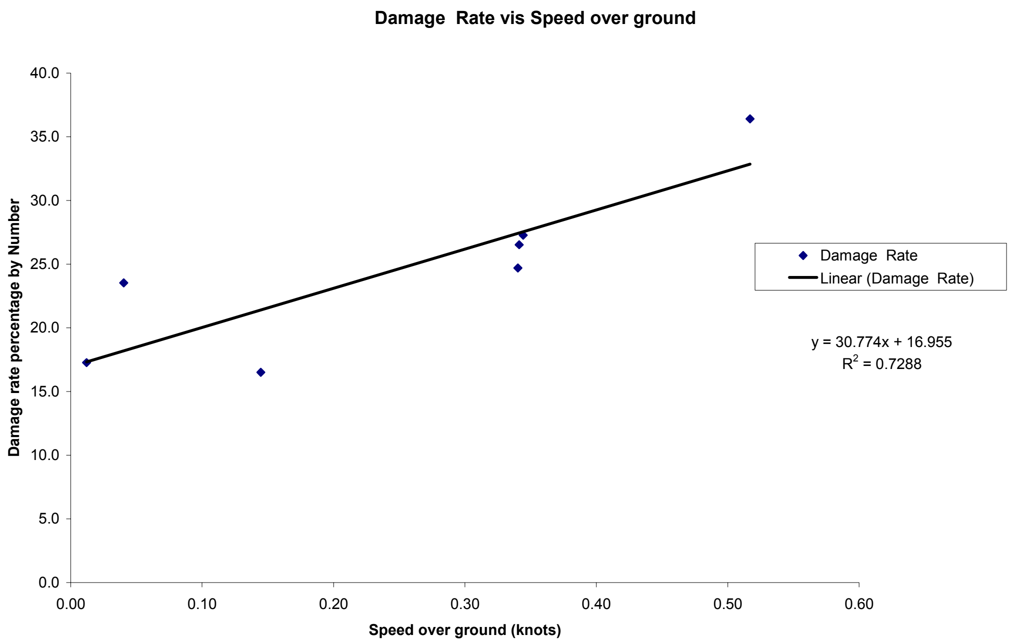
Damage Rates

In addition to observing catch rates of the dredge, it was important to estimate damage rates of the catch of razorfish. Damage rates were defined as:

$$\text{Percentage damage by numbers} = \frac{\text{No of damaged animals}}{\text{Total No in catch}} * 100$$

and the initial aim was to estimate damage rates under various scenarios. Various gear parameters were varied therefore including pump pressure (4 and 5bar; hydraulic pump only) and the orientation or angle of the cage (i.e. digging depth of the blade) in a manner which would enable comparison of catch and damage rates. However, there were no clear trends and it proved very difficult to control and measure the speed of the vessel whilst towing. For 9 of the 10 hauls using the cockle pump (the remaining haul was undertaken at low pressure and was not directly comparable), the speed of the vessel was estimated and compared with the damage rate as shown below (Figure 3.7). A significant positive relationship between speed and damage rate was observed, with the faster the speed of the vessel the greater the damage observed.

Figure 3.7 Effect of speed of dredge over the ground on damage rate of razorfish



Discussion

The results of the towed dredge trials indicate that the vessel's cockle pump would generate suitable sufficient pressure and volumes of water to catch razorfish in commercially significant quantities. However it was clear that speed over the ground was the most important factor affecting damage rates. The damage rates of up to 35% of the catch at the higher speeds were considered to be unacceptably high.

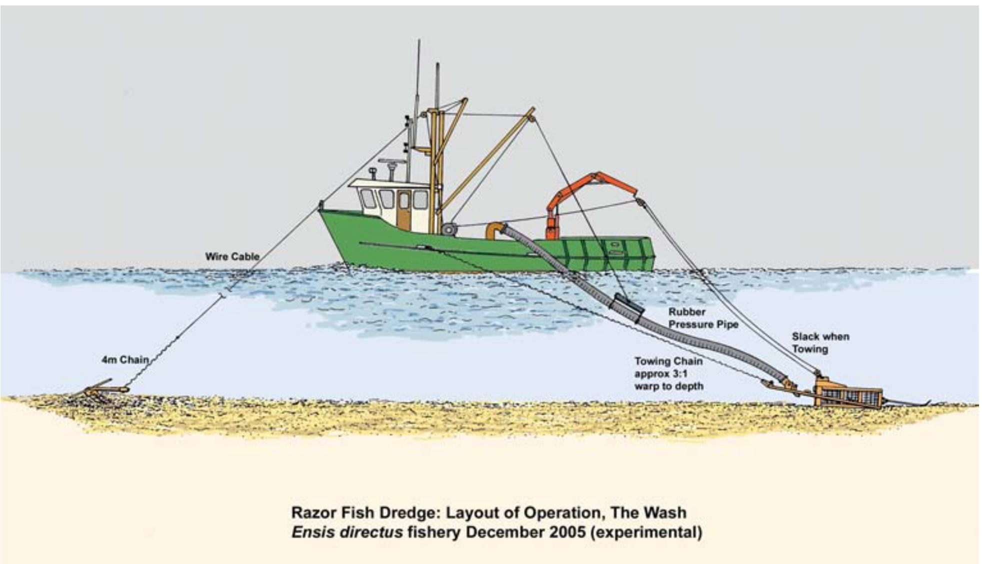
The key problem with towing the experimental dredge under propeller propulsion was that it was extremely difficult to control speed in order to consistently reduce the damage rate or carry out useful instrumented trials. A consequence of the inability to control speed was that it proved very difficult to tow in a straight line, and hence to calculate distance towed. There was a need to make the operation as safe and repeatable as possible, and therefore it was agreed to alter the operation to anchor dredging which is practised by the Italian hydraulic dredge fishery. This technique was also practised by oyster dredgers historically. Accordingly the vessel was modified to suit anchor dredging for the next set of trials which it was hoped would permit dredging in a straight line at a controllable speed.

3.6 Anchor dredge trials of the experimental razorfish dredge

The configuration for anchor dredging is shown in Figure 3.8. The anchor (135 kg Danforth pattern) was dropped with the vessel head to tide and the vessel allowed to drop back on the anchor. One hundred metres (45 fathoms) of wire were run out in addition to 4m of chain shackled to the anchor. The wire used was the vessel's trawl wire which was lead over the wheelhouse roof via a block shackled into the rigging and out through a bow roller constructed with four rollers set as a square on the stem head of the vessel.

The dredge was then lowered to the seabed using the other trawl wire lead through a block on the arm of the vessel's 'HIAB' crane on the aft deck. This wire was then slackened. The tow was commenced by winching in the wire attached to the anchor, with the dredge being towed by the towing chain which was lead through the vessel's scuppers. The pressure pipe was lifted using a warp through the block on the derrick on the port side. The pump was started and set at the rpm for the pressure required. In addition to the instrumentation on the dredge (see below) there was also a pressure gauge set into the standpipe on the vessel's deck.

Figure 3.8 Configuration for anchor dredge operation



Sixty six metres (36 fathoms of wire) were hauled at the rate required. The distance covered was determined by the odometer reading on the GPS. This usually corresponded to 50-55m of distance over the ground dependent on the degree of slack in the system. The actual speed was computed from the time and distance travelled. The dredge was then hauled back alongside and placed on the aft deck using the HIAB crane. The catch was swept out of the back of the dredge using a broom via the rear door.

This method of dredging was found to be controllable, safe and was considered a potentially viable commercial operation by the fishermen. Further improvements to the set up would include better on-board handling of the dredge to improve safety and better handling of the catch to reduce the damage sustained during handling.

3.6.1 Results of the anchor dredge trials

A total of 27 successful hauls were made using the anchor dredge system. As hoped, the system allowed the dredge to be operated in a straight line at a relatively constant speed. The use of the anchor dredge also permitted variations in speed, depth of the blade and pressure to determine the effect of these parameters on catch rate of razorfish and the associated damage rates. The full results of all 27 valid hauls are given in Table 3.2. Catch rates varied from 14 to 169 razorfish per metre towed.

Table 3.2 Catch and damage rates from valid hauls using the anchor system

Date	Speed	Depth of blade	Pressure	Odometer(m)	Catch(No.)	Weight (kg)	% damaged	No/metre towed
13/12/05	S	4	3.2	48	2425	28.6	19.9	49
13/12/05	S	4	3.2	60	2223	26.2	20.2	44
13/12/05	F	4	3.2	52	2688	31.7	11.6	54
13/12/05	F	4	3.3	56	3043	35.9	19.6	61
13/12/05	S	3	3.4	55	2952	34.8	15.9	59
13/12/05	S	3	3.2	49	2496	29.5	20.3	50
13/12/05	F	3	3.4	54	6688	78.9	10.5	134
13/12/05	F	3	3.3	53	6916	81.6	17.0	138
14/12/05	F	2	3.4	47	3816	45.0	15.1	76
14/12/05	F	2	3.4	49	4032	47.6	19.4	81
14/12/05	S	2	3.4	58	1150	13.6	20.9	23
14/12/05	S	2	3.4	54	2184	25.8	14.1	44
14/12/05	VF	2	3.4	56	8440	99.6	48.1	169
14/12/05	VF	2	3.4	53	5453	64.3	35.5	109
14/12/05	F	1	3.4	60	1956	23.1	39.0	39
14/12/05	F	1	3.4	59	2484	29.3	29.7	50
14/12/05	S	1	3.4	51	684	8.1	33.3	14
15/12/05	F	3	3.4	43	4104	48.4	18.1	82
15/12/06	F	3	3.4	56	3588	42.3	23.2	72
18/12/05	F	3	2	55	2925	34.5	34.4	59
18/12/05	F	3	2	49	2112	24.9	34.1	42
18/12/05	F	3	3	34	1055	12.4	14.7	21
18/12/05	F	3	3	45	5488	64.8	20.4	110
20/12/05	F	3	3	55	2952	34.8	22.8	59
20/12/05	F	3	3.2	56	4356	51.4	16.5	87
20/12/05	F	3	3.2	52	3045	35.9	17.2	61
20/12/05	F	3	3.2	51	3825	45.1	16.9	77

Key to Table 3.2

Speed: Slow (S) c. 800rpm, Fast (F) c.1000rpm, Fastest (VF) c.1200rpm.

Depth: for each haul the depth of the dredge is varied by adjusting the distance between the blade and the runners by changing the bolt hole used on the dredge. Hole 1 is the most shallow and Hole 4 is the deepest (see table below). The distance between the blade and the runners is therefore the maximum possible depth of the dredge, although in practice, up-thrust caused by the water jets and the nature of the substrate may ensure that this maximum depth is not achieved.

Hole	Distance between blade and runners (mm)
1	165
2	216
3	266
4	317

There was a trend to higher catch rates with higher speeds but little trend with depth of the blade other than an apparent fall in catch rate at the shallowest setting. Damage rates tended to be higher at slow speeds and at shallow depths (Table 3.3).

Whilst catches were a secondary consideration in these trials, after the physical effects of dredging, it is encouraging that catch rates appeared relatively high. Average catch rates were 45 kg per 50m towed for the 12 tows carried out at fast speed at hole three, which equates to 10.8 kg per minute, which is significantly higher than catch rates achieved with the towed dredge system. Damage rates remain high and therefore reduce the yield from these catches but it is likely that such damage rates can be significantly reduced in a commercial fishery. The small size (and therefore fragility) of the animals at the time of the trials, together with a less than satisfactory method of emptying the dredge, will certainly have caused a significant proportion of the damage.

Table 3.3 Summary of catch and damage rates of razorfish at different speeds and depth of blade.

Mean catch rate (No./m towed

	Hole 4	Hole 3	Hole 2	Hole 1
Slow	43.04	52.38	29.77	13.41
Fast	53.06	78.03	81.75	37.31
Faster			127.46	

Damage rate

	Hole 4	Hole 3	Hole 2	Hole 1
Slow	20.08	17.81	16.97	33.33
Fast	15.14	19.83	17.02	34.33
Faster			43.02	

3.6.2 Effect of the dredge on the physical environment

In relation to the interest features of the candidate SAC, perhaps the key aspect of the dredge's environmental effect is its mechanical action on the seabed. This part of the project examined, through the use of instrumentation, the way in which the dredge interacted with the seabed. Of particular importance was investigation of the excavation depth of the dredge. This section describes the method and results of the instrumented trials and an analysis of their implications is discussed in Appendix D.

Instrumentation

The instrumentation consisted of a set of instruments designed specifically for this field trial. There were 6 sensors which fed data to a relay unit on top of the dredge and thence via cable to the surface to be logged on a PC at the rate of 4 observations per second.

The 6 sensors consisted of :

1) Inclinometers situated in the relay unit on the top of the dredge cage, calibrated to measure angle of heel and inclination. The angle of heel was negative to starboard and the angle of inclination was positive to tilt the forward end of the dredge upwards.

2) A shear pin load cell mounted in the pin of the towing shackle in order to measure towing loads.

3) A pressure sensor mounted on the water jet manifold.

4) Two trailing arms (connected to rotary potentiometers), one designed to measure the excavation depth of the dredge and the other offset (outboard 400 mm from the dredge) to the port side of the dredge intended to be on undisturbed seabed. These were mounted on the rear door of the dredge (see Appendix B and Figures 3.11-3.16). The trailing arms were set up and calibrated before each haul with shock cord springs set up to the same tension (9 kg).

Although instruments have been used on dredges before (Lart, 2003) there was some development work required to make the system compatible with this dredge.

Method

After tests to determine the location, length and suitable material for the trailing arms two valid hauls were achieved. The locations were on Sunk Sand and Seal Sand (see Figure 3.2. The pressure was increased over the course of the haul on the Seal Sand allowing approximately 1 minute at each of three different pressure levels up to the maximum of 3.5-3.7bar. The pressure was held at the maximum pressure for the entire haul on the Sunk Sand haul.

Results

The data from the instrumentation is shown in Figure 3.9 for Seal Sand (rising pressure) and Figure 3.10 for Sunk Sand (constant pressure). There is variation in all the angles (heel and inclination of the dredge and angles of the trailing arms to the horizontal) from which the various digging depths are estimated.

In order to describe these results mean, maximum and minimum results (Tables 3.4 and 3.5) were taken over selected intervals of time, shown on Figures 3.9 and 3.10. The mean angles of heel, inclination and the two trailing arms were drawn on the original AutoCAD® drawing of the dredge in Figures 3.11-14 for Seal Sand and Figures 3.15 and 3.16 for Sunk Sand. From these drawings it was possible to estimate the heel and inclination of the dredge and mean excavation depth in an assumed horizontal seabed.

In interpreting these drawings it must be recognised that they represent a mean result taken over a given interval of time. No account is taken of the unevenness in the seabed; and the most important dimension to be assessed is the mean difference in depth of the trailing arms.

For the Seal Sand site the speed over the ground was 0.6 knots and the pressure was increased in stages over the course of the tow. At the low pressure (mean 1.63bar) the mean depth of excavation was estimated at 86 mm (Figure 3.11), estimated from the difference between the seabed levels of the outer and inner trailing arms (see the top diagram in Figure 3.11). At this pressure the mean angle of the dredge cage is tilted slightly forward on the seabed. However there is considerable range in the angles of inclination, heel and the trailing arm angles.

As the pressure increased to a mean of 2.47bar (Figure 3.12) this coincided with the mean angle of the forward end of the dredge lifting by approximately 3 degrees. The dredge heeled to starboard and the trailing arm angles become less variable with the estimated mean excavation depth increasing to 192 mm.

A further increase in pressure to a mean pressure of 3.7-3.74bar coincided with the dredge initially heeling to starboard and then becoming upright. Hence two figures (Figures 3.13 and 3.14) were drawn for this stage; it is notable that the back of the dredge had settled downwards into the seabed at this pressure. Mean excavation depth was estimated at around 240 mm at this pressure.

For the Sunk Sand site the dredge speed was reduced to 0.3-0.4 knots. The pressure was increased to approximately the pump's working maximum which, on this haul, corresponded to a mean of 3.57bar. This combination of speed and pressure has been found to produce the lowest percentage damage rates in the catch of *Ensis* for the previous hauls on Sunk Sand. On this haul the first part of the haul is relatively easy to interpret (Figure 3.15), the angle adopted by the dredge is similar to that found for the Seal Sand haul with an estimated mean excavation depth of 163 mm. The latter part of the hauls is less easy to interpret as there was an apparent reduction to 73 mm in the excavation depth (Figure 3.16). It is possible that some variation of the sediment occurred resulting in a shallower excavation depth, or alternatively the excavated trench widens at this point and the outside trailing arm tracked into it.

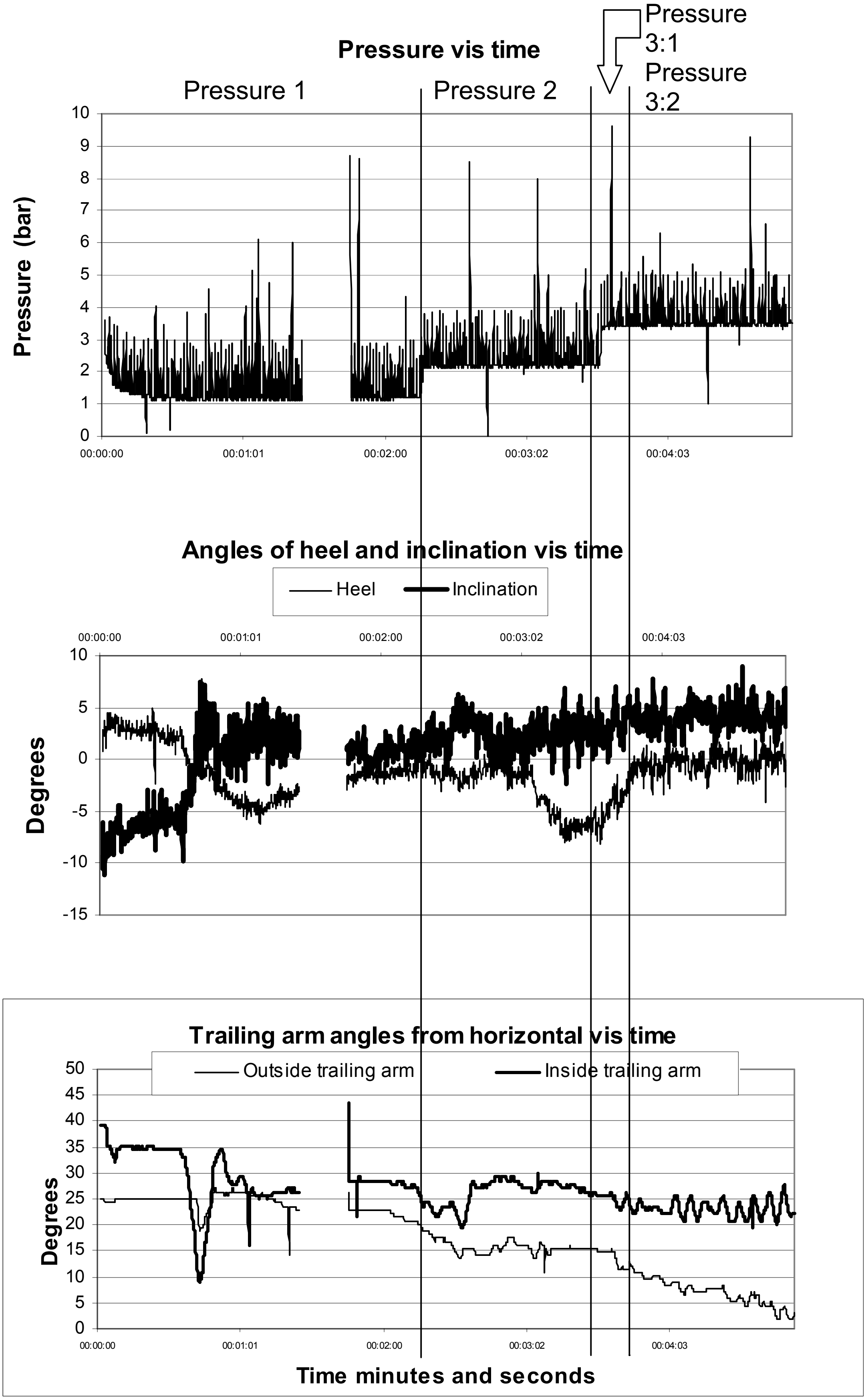


Figure 3.9 Instrumentation Data from haul on Seal Sand site. Vertical lines correspond to stages in Table 3.4 and Figures 3.11-3.14

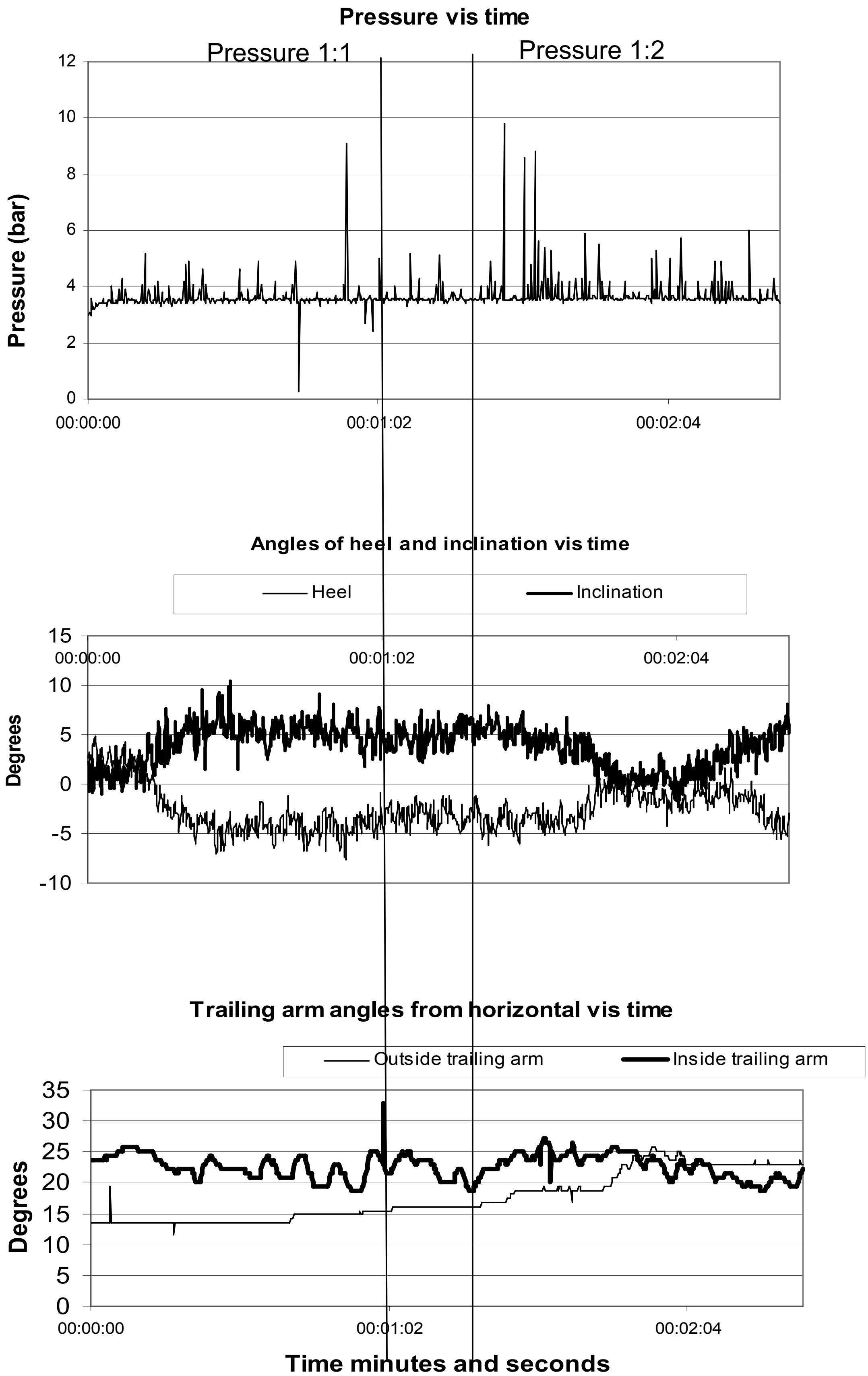
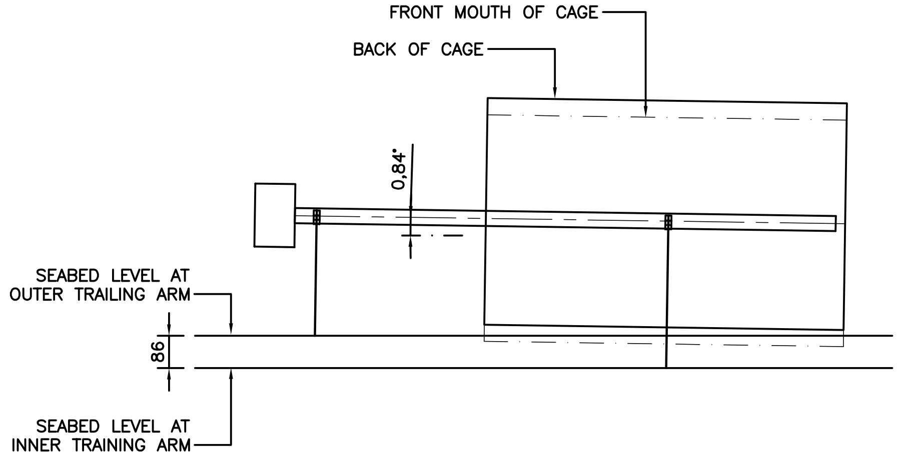
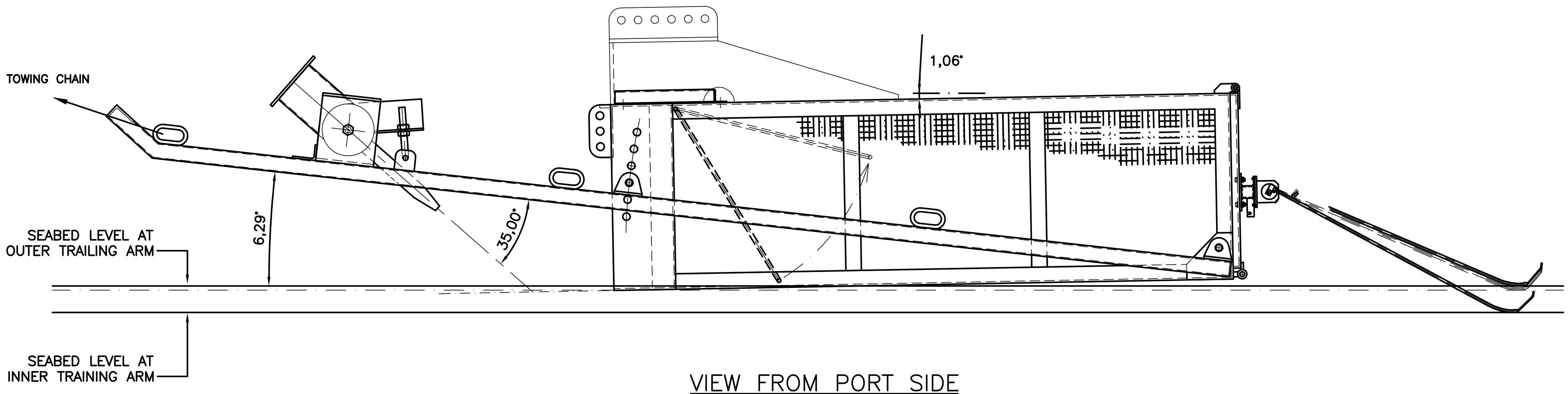


Figure 3.10 Instrumentation Data from haul on Sunk Sand site. Vertical lines correspond to stages in Table 3.5 and Figures 3.15 and 3.16



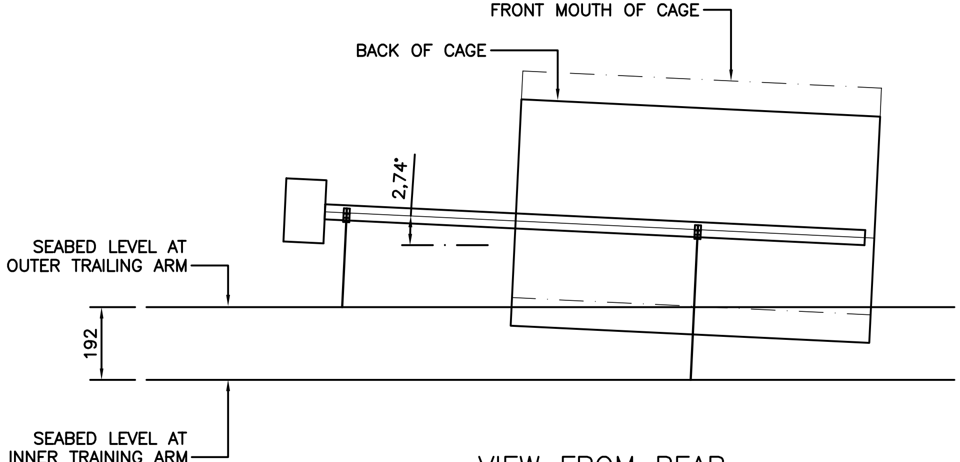
VIEW FROM REAR



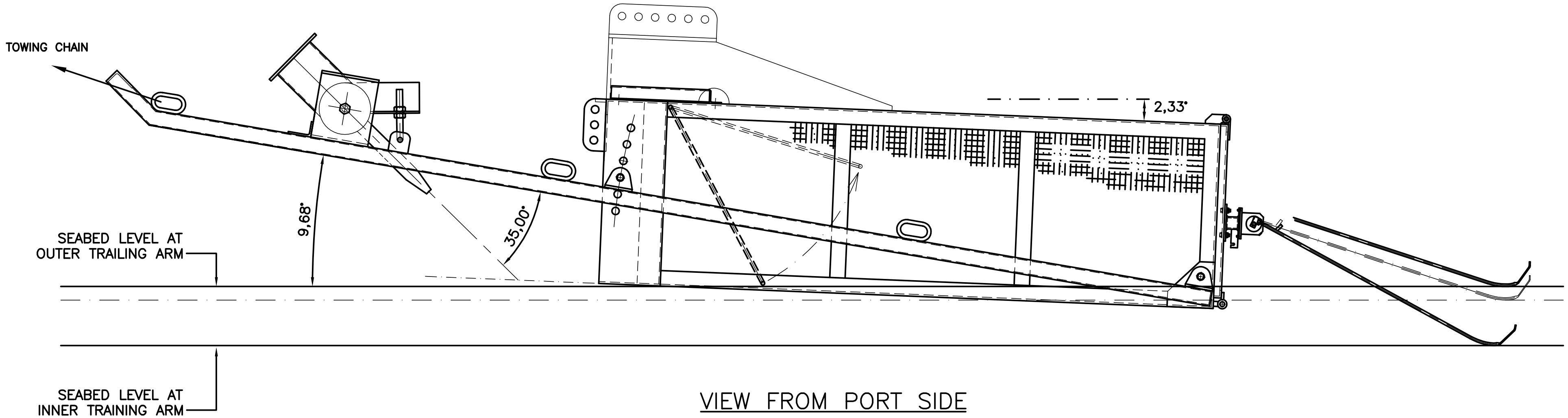
VIEW FROM PORT SIDE

FIGURE 3.11 SEAL SAND:
MEAN PRESSURE 1.63 BAR, SPEED 0.6 KNOTS

SEAFISH	PROJECT RAZOR FISH DREDGE	DWG No.	4950501/03
		SCALE	1:20 @ A4
SEAFISH HOUSE, ST. ANDREW'S DOCK, HULL, HU3 4QE TEL: 01482 327837	TITLE DATA REPRESENTATION 1.63BAR/0.6KNOTS	DRAWN BY	D. DEWICK
		DATE	24–01–06



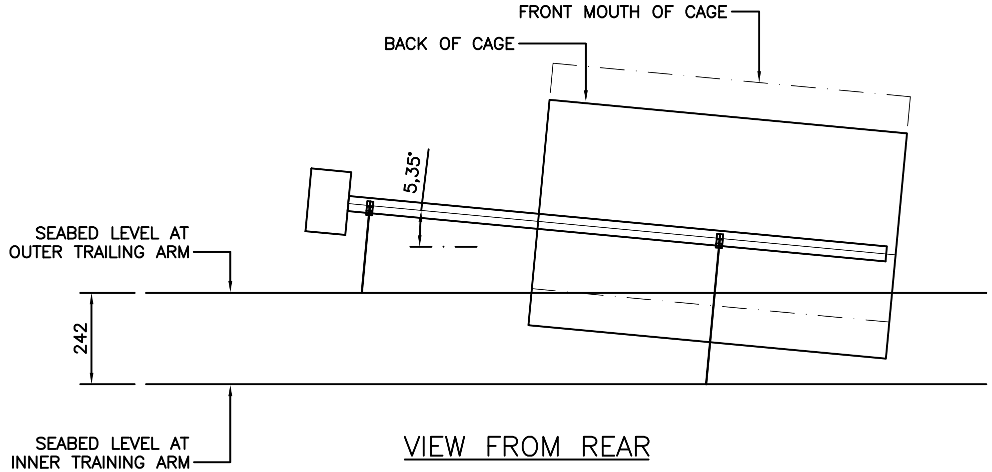
VIEW FROM REAR



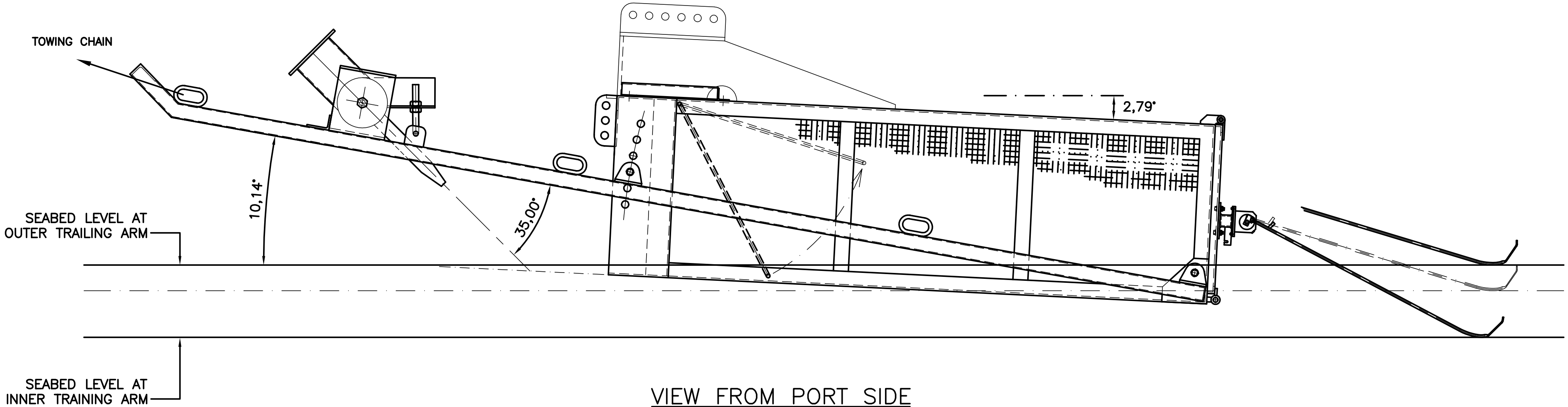
VIEW FROM PORT SIDE

FIGURE 3.12 SEAL SAND:
MEAN PRESSURE 2.47 BAR, SPEED 0.6 KNOTS

SEAFISH	PROJECT RAZOR FISH DREDGE	DWG No.	4950501/04
		SCALE	1:20 @ A4
SEAFISH HOUSE, ST. ANDREW'S DOCK, HULL, HU3 4QE TEL: 01482 327837	TITLE DATA REPRESENTATION 2.47BAR/0.6KNOTS	DRAWN BY	D. DEWICK
		DATE	24-01-06



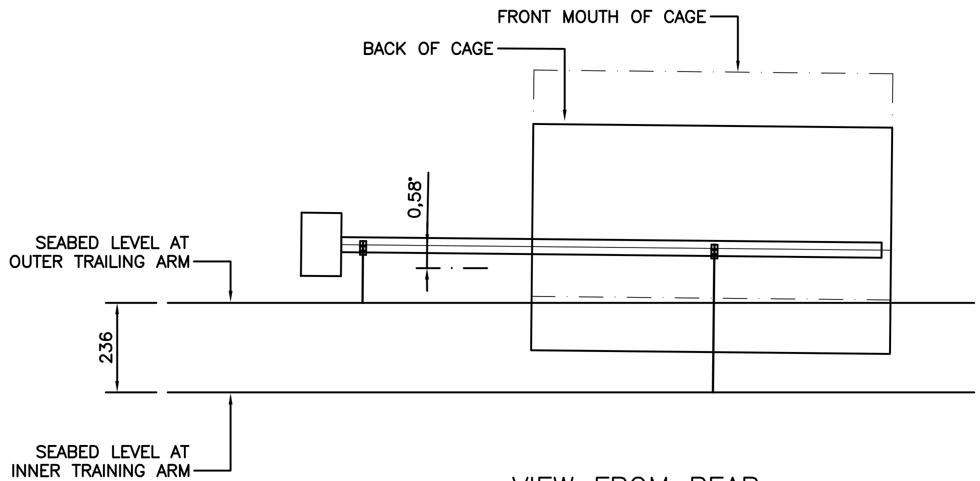
VIEW FROM REAR



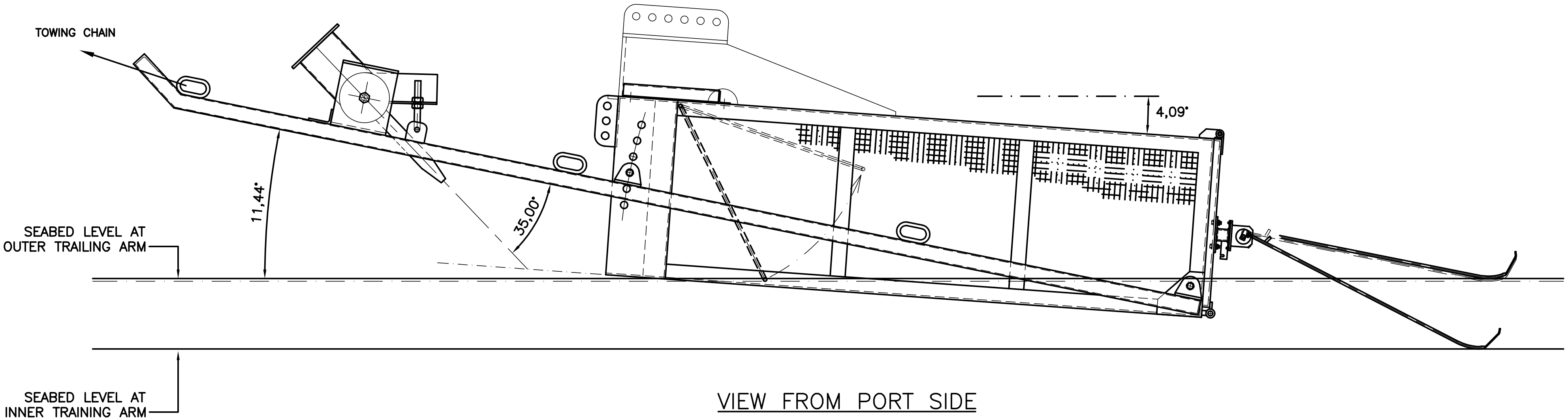
VIEW FROM PORT SIDE

FIGURE 3.13 SEAL SAND:
MEAN PRESSURE 3.74 BAR, SPEED 0.6 KNOTS

SEAFISH	PROJECT RAZOR FISH DREDGE	DWG No.	4950501/05
		SCALE	1:20 @ A4
SEAFISH HOUSE, ST. ANDREW'S DOCK, HULL, HU3 4QE TEL: 01482 327837	TITLE DATA REPRESENTATION 3.74BAR/0.6KNOTS	DRAWN BY	D. DEWICK
		DATE	24–01–06



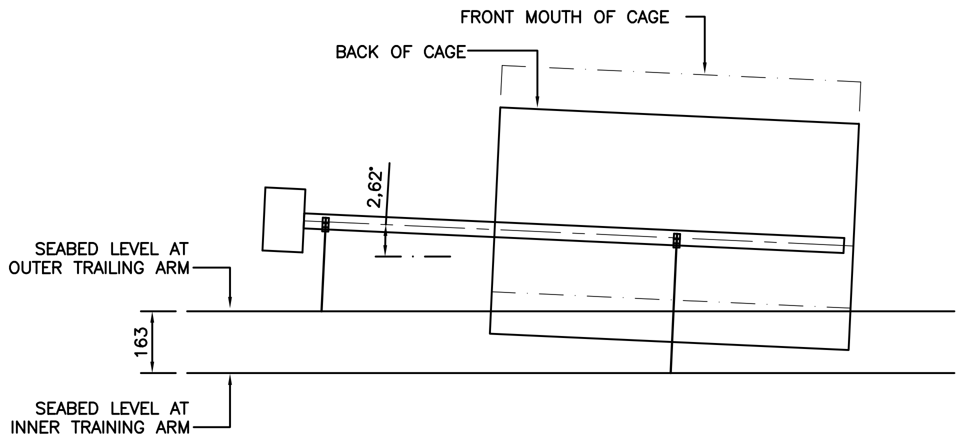
VIEW FROM REAR



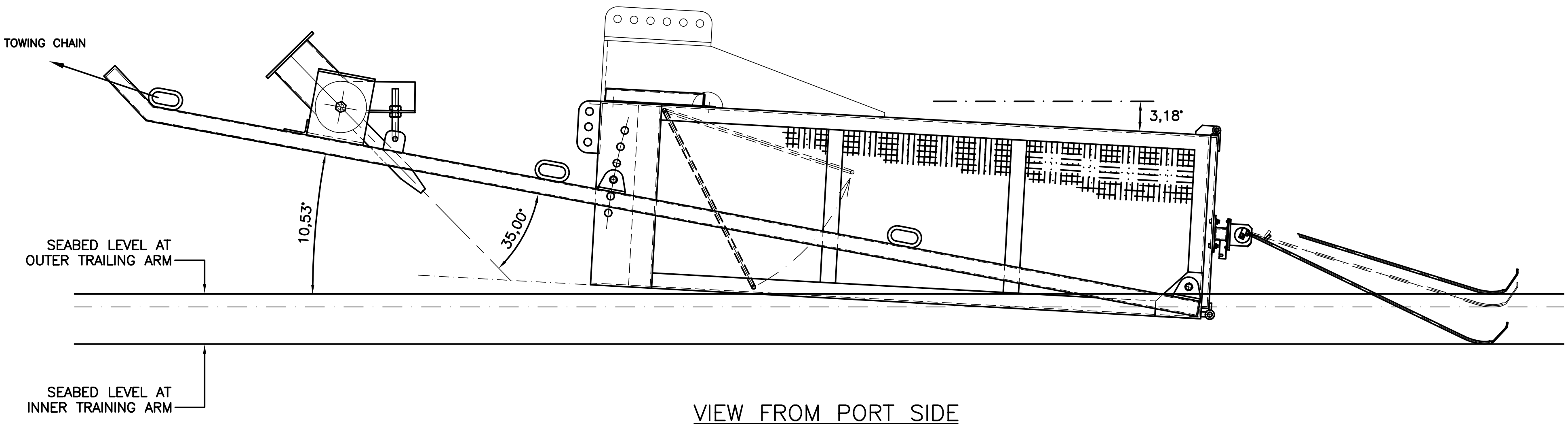
VIEW FROM PORT SIDE

FIGURE 3.14 SEAL SAND:
MEAN PRESSURE 3.7 BAR, SPEED 0.6 KNOTS

SEAFISH	PROJECT RAZOR FISH DREDGE	DWG No.	4950501/06
		SCALE	1:20 @ A4
SEAFISH HOUSE, ST. ANDREW'S DOCK, HULL, HU3 4QE TEL: 01482 327837	TITLE DATA REPRESENTATION 3.7BAR/0.6KNOTS	DRAWN BY	D. DEWICK
		DATE	26–01–06



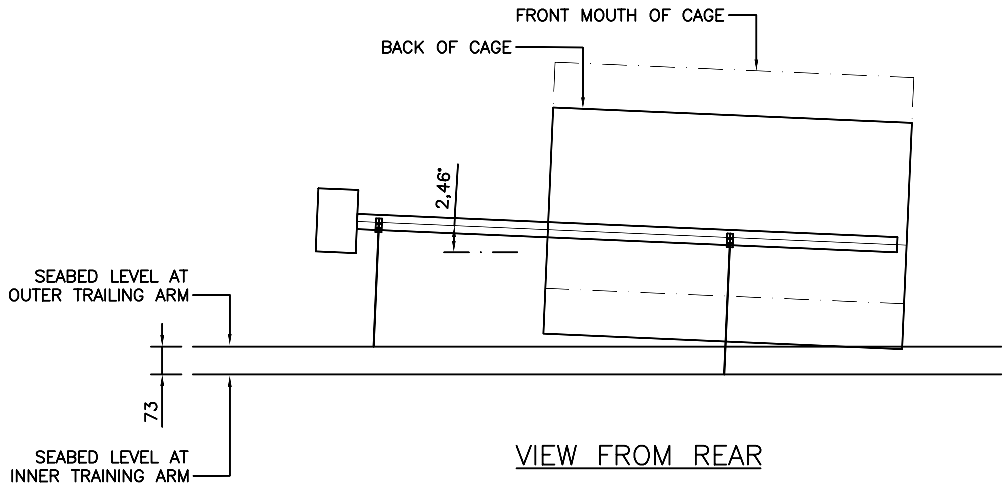
VIEW FROM REAR



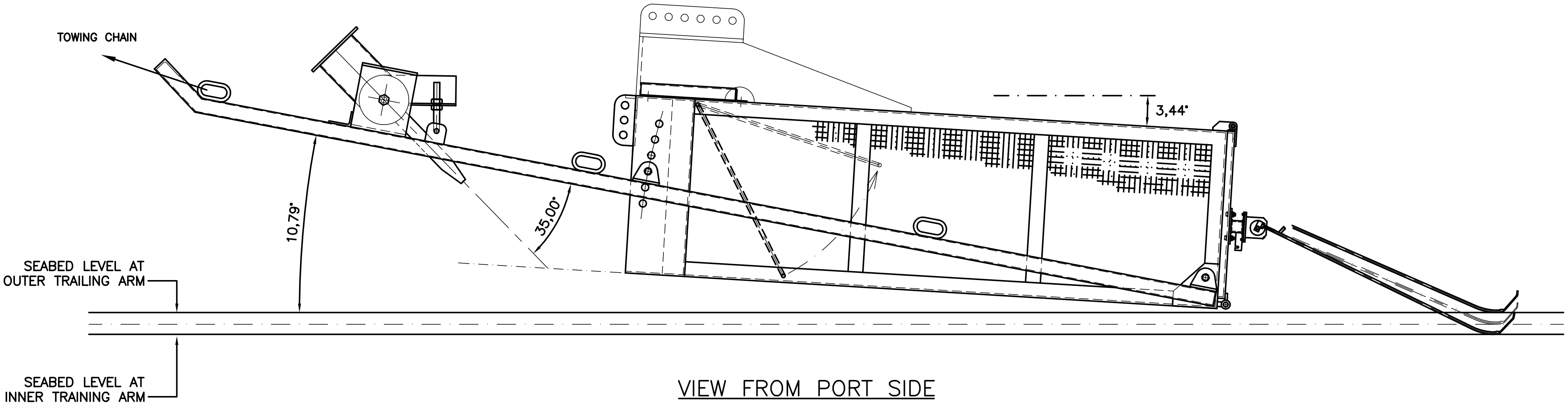
VIEW FROM PORT SIDE

FIGURE 3.15 SUNK SAND:
MEAN PRESSURE 3.57 BAR, SPEED 0.3 – 0.4 KNOTS

SEAFISH	PROJECT: RAZOR FISH DREDGE	DWG No.	4950501/02
		SCALE	1:20 @ A4
SEAFISH HOUSE, ST. ANDREW'S DOCK, HULL, HU3 4QE TEL: 01482 327837	TITLE: DATA REPRESENTATION 3.57BAR/0.3–0.4KNOTS	DRAWN BY	D. DEWICK
		DATE	24–01–06



VIEW FROM REAR



VIEW FROM PORT SIDE

FIGURE 3.16 SUNK SAND:
MEAN PRESSURE 3.72 BAR, SPEED 0.3 – 0.4 KNOTS

SEAFISH	PROJECT: RAZOR FISH DREDGE	DWG No.	4950501/07
		SCALE	1:20 @ A4
SEAFISH HOUSE, ST. ANDREW'S DOCK, HULL, HU3 4QE TEL: 01482 327837	TITLE: DATA REPRESENTATION 3.72BAR/0.3–0.4KNOTS	DRAWN BY	D. DEWICK
		DATE	26–01–06

Table 3.4. Maximum, mean and minimum results for sections of the data from Seal Sand site

	Time		Heel			Inclination top of dredge			Towing Load			Pressure bar			Trailing arms degrees from horizontal					
			deg			deg			kg			bar			Outside trailing arm;			Inside trailing arm		
Stage	**Start**	**Finish**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**
Pressure 1	00:00:00	00:02:15	8	**-1**	-6	7	**-1.06**	-11	747	**511**	90	8.70	**1.63**	0.10	27	**24**	14	44	**29**	9
Pressure 2	00:02:15	00:03:34	1	**-3**	-8	7	**2.33**	-2	747	**707**	422	8.50	**2.47**	0.00	20	**16**	11	30	**26**	19
Pressure 3:1	00:03:34	00:03:42	-2	**-5**	-8	6	**2.79**	0	747	**608**	371	9.60	**3.74**	3.20	15	**14**	12	26	**25**	23
Pressure 3:2	00:03:42	00:04:57	2	**-1**	-6	9	**4.09**	0	642	**377**	246	9.30	**3.70**	1.00	13	**7**	2	28	**23**	19

Table 3.5. Maximum, mean and minimum results for sections of the data from Sunk Sand site

	Time		Heel			Inclination top of dredge			Towing Load			Pressure bar			Trailing arms degrees from horizontal					
			deg			deg			kg			bar			Outside trailing arm;			Inside trailing arm		
Stage	**Start**	**Finish**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**
Pressure	00:00:00	00:01:02	1.9	**-3**	-8	10	**3.2**	-1.1	631	**285**	0	9.10	**3.57**	0.3	19	**14**	12	33	**23**	19
Pressure	00:01:15	00:02:27	1.6	**-2**	-6	8	**3.4**	-2	111	**227**	391	9.80	**3.72**	3.3	26	**20**	16	27	**23**	23

Discussion

In describing the action of the water jet dredge on the seabed, the expectation is that for a given pressure, speed and sediment type the depth excavated will be consistent. Reducing the pressure or increasing the speed will decrease the excavation depth, whereas increasing the pressure or decreasing the speed will increase the depth of excavation because of the relative rate of energy input. Sand of lower relative density will allow a greater depth of excavation because it allows greater penetration of the jet into the seabed. These results are discussed fully in relation to models of sediment properties in Appendix D.

There will also be an upward force on the dredge resulting from the reaction to the water jet. Calculations from modelling studies (Appendix D; also see Figure 3.4) suggest that this could be quite substantial in this system, up to 200 kg force in a vertical direction at full pressure.

The results for the Seal Sand haul are consistent with this and Appendix D. The excavation depth was found to increase with pressure (for a comparison with the model see Appendix D). The front of the dredge was observed to lift with increasing pressure as a result of the reaction to the water jets. The higher towing tension encountered at the Seal Sand site is also consistent with a deeper depth of penetration into the seabed and hence greater friction. The sediments here have been found to be very loose in the upper layers and the sediment observed in the dredge when it was hauled was found to be very loose and shelly.

The results for the Sunk Sand haul were obtained at a slower speed and constant pressure. Here the excavation depth was less although the dredge angle of incidence was similar for the same jet pressures at Seal Sand. Observations of the sediment retained by the dredge suggest that it is at a higher relative density on this site compared with the Seal Sand.

Environmental effects

These results have shown that the dredge sediment interaction is consistent with the modelling approach described in Appendix D. The mean maximum depth of excavation was found to be 240 mm in a location which was shown to be very loose sand as described by the observations with the Mackintosh probe (Appendix D). The shallower depth of excavation which was observed during the Sunk Sand haul is attributed to changes in the sediment properties. In both these locations catches of *Ensis* were well within the expected range.

The results have implications for dredge design and management of the fishery. The pressure used (3.6-3.7bar) was adequate to catch *Ensis* at this speed, and lower pressures were found to result in a higher damage rate. Excavation depths are consistent with depths which the animals would be expected to burrow, as evidenced from grab samples. These results suggest that the excavation depth appears to be limited by the properties of the sediment; areas where the sediment appeared to be denser resulted in less excavation. It is also conceivable that the *Ensis* also burrow less deeply in dense sediments. In environmental terms it would be desirable to limit the impact to the upper loose layers of the sediment since this layer is likely to be mobile and hence more resilient. These results imply that this could be achieved by limiting the pressure developed in the manifold, or possibly by inclining the water jets closer to the horizontal, i.e. tilting up more.

The angle of incidence of the dredge was higher than expected. Underwater video of the original Irish dredges suggests that they are designed to be immersed in the seabed up to the rails. However the species of razorfish at which these dredges are targeted in Ireland dig deeper in to the sand than *Ensis directus* and their cages (blades) are correspondingly set to dig deeper into the sediments than this experimental dredge and this may have a greater downwards force component. The pressure at which the Irish dredges operate is unknown.

It may be possible to alter the dynamics of the dredge to reduce the effects of the upward force due to the towing tension by moving the towing position further aft. However, there will still be a strong upward reaction force from the action of the jets which has to be countered and towing from the forward position of the dredge was found to be the most stable position. One approach would be to add skids under the back end of the dredge to improve stability and design the cage ‘mouth’ to be in the right orientation for capture of the *Ensis*. This appears to be the approach adopted by the Italian dredges designed for *Ensis siliqua minor* (Figure 3.17). These dredges have a manifold which jets water out of the dredge blade which would of course alter the dynamics of the dredge.

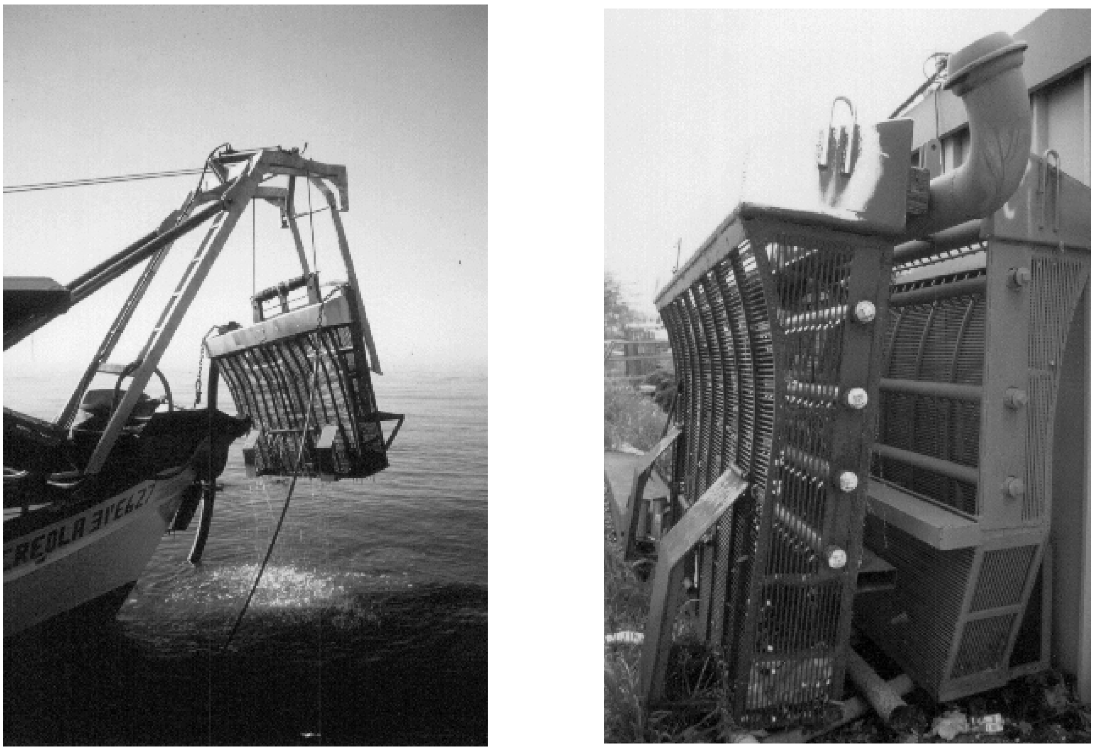


Figure 3.17 Hydraulic dredge for *Ensis siliqua minor* by M. Pellizzato

4 CONCLUSIONS FROM PROJECT AND IMPLICATIONS FOR AN EXPERIMENTAL FISHERY

4.1 Discussion of results of the project

The review of *Ensis* dredge design and operation in various European countries was highly instructive, and led to a rapid identification of a suitable dredge for use in The Wash fishery. Whilst it is recognised that some fishermen use the towed dredge method for Ensis species, in this project we found that it was necessary to tow at a very low speed and this caused significant problems in maintaining both direction and speed. In consequence it was not possible either to obtain any meaningful results from varying operational parameters for the towed dredge or to deploy the instrumentation developed to investigate excavation depth. In contrast the anchor dredge system is used successfully in both Ireland and Italy, and our experiments confirmed that the anchor dredge system permitted good control of direction and speed. This permitted a preliminary evaluation of catch and damage rates under different operational scenarios. In addition the lack of control of the vessel during towing of the dredge means that the anchor dredge system would be favoured on safety grounds.

Comparison of yields from towed and anchor dredge operations suggested that the anchor dredge system consistently achieved significantly greater catch rates. However we should caution that raw catch rate figures from the anchor dredge and towed dredge experiments of 10.8 and 0.8 kg per minute respectively are not directly comparable because operational parameters were not consistent across the two experiments.

Initial analysis of samples to obtain a water classification under the EU Shellfish Growing Waters Directive were very encouraging suggesting that an A classification may be obtained. Additional samples were collected during the annual stock survey in March 2006, and plans are in place to continue sample collection so that a water classification would be obtained prior to the commencement of an experimental commercial fishery.

4.2 Implications for an experimental commercial fishery

4.2.1 Designation of dredge design and operation

The key question remains as to whether it is necessary to set criteria which will minimise any potential impact on the interest features of the cSAC from dredging taking into account likely catch and damage rates of *E. directus*. For example, is it possible to regulate simply by stipulating the level of pressure required to excavate *E. directus* without long term damage to the substrate? In the experimental dredge trials, the optimum parameters for harvesting *E. directus* whilst minimising damage rates were a pump pressure of less than 4.0bar, a vessel speed of approximately 0.3 knots, and an excavation depth of no more than 200 mm. The weight of the experimental dredge used in the project was approximately 600 kg, and our trials appeared to demonstrate that the dredge remained at a relatively constant depth of excavation.

On that basis, any potential environmental impact of the dredging would be self-regulating. The efficiency of any dredge and the potential for high damage rates of the dredge would ensure that individual vessels would regulate the excavation depth and speed of the dredge. High dredge speeds increase damage rates, and depth of excavation is itself self-regulating: shallow excavation depths will cause high damage rates, deeper excavation rates make the dredging process inefficient. Optimum weight of dredge will be dependent upon the design and operation of the dredge, but in general the weight should be sufficient to counter up-thrust and keep it at a constant excavation depth.

The instrumentation employed during these dredge trials provided information from the anchor dredge system trials only. The key issue in relation to potential damage to the interest features of the cSAC is that excavation depths of significantly more than 200 mm are not required to harvest *E. directus* and indeed are inefficient, and this depth is well under the estimate of 650 mm of loose substrate in this area. In other words any likely excavation depth of a dredge will not cause any significant damage to fine sediments in the cSAC, and indeed modelling studies indicated that there would be rapid resettlement of any disturbed coarse mobile sediments.

On that basis, whilst our studies would suggest that the anchor dredge system provides greater control and direction of the dredge, there would not be any *a priori* reason for excluding a towed dredge system from any experimental fishery. Indeed it is likely that vessels with varying designs of dredge will wish to participate in an experimental fishery, and we recognise that our choice of experimental dredge design is not necessarily the optimum design. We suggest that a key aspect of the monitoring of the experimental fishery would be evaluating the catch and damage rates of the various designs of dredge. One obvious major variation in dredge design is whether the dredge involves a “batch” or “continuous” delivery system. Our experimental dredge worked on a batch principle, but there are legitimate concerns within the industry that a batch system causes higher damage rates than a continuous system. There seems to be no scientific reason why an experimental fishery should exclude continuous delivery dredges and it would be instructive to evaluate the relative catch and damage rates of the two systems of delivery. The prime concern would be to ensure that any dredge used in the experimental fishery did not excavate too deep into the substrate. One possibility therefore would be to carry out trials of a continuous delivery system prior to the opening of any experimental fishery using the instrumentation developed in this project to estimate excavation depths.

This project has concluded that any dredge used in an experimental commercial fishery is unlikely to be deployed in such a way that would impact on the interest features of The Wash and north Norfolk cSAC. There is no commercial gain to excavate deeper than about 200 mm and therefore only the coarse, mobile sediments would be disturbed by such dredging activity.

On that basis, we conclude that it is not necessary to adopt fixed criteria for dredge design and operation for vessels that wish to participate in an experimental commercial fishery. Guidelines based on the results of this project can be offered to potential participants, but these will inevitably be modified by individual vessels to maximise catch rates and minimise damage rates of *E. directus*.

4.2.2 Stock status and potential exploitation patterns

Annual stock surveys have shown that, despite irregular settlement and high over-wintering mortality rates of *E. directus* in The Wash, some year classes do survive in significant numbers to provide a potential future fishery. One such year class settled in 2002, and the most recent stock survey in March 2006 showed that this year class has continued to survived in abundance, along with significant numbers of the 2004 year class. Growth rate of *E. directus* is slow (Palmer, 2005) with most individuals not reaching the minimum legal landing size (MLS) of 100 mm length until about 4 years of age. Size distributions of *E. directus* harvested during the experimental dredge trials between October and December 2005 showed that, whilst some of the population had now reached or were about to reach the MLS, there was a significant proportion of the population that was still under the MLS (Figure 4.1). The March 2006 stock survey confirmed that individuals in this year class continued to grow towards the MLS. Stocks of *E. directus* are vulnerable to winter storm damage, and so Autumn 2006 would be an ideal time to harvest this year class when almost all of the individuals will have reached the MLS, and before another winter passes when there is a possibility of high natural mortalities.

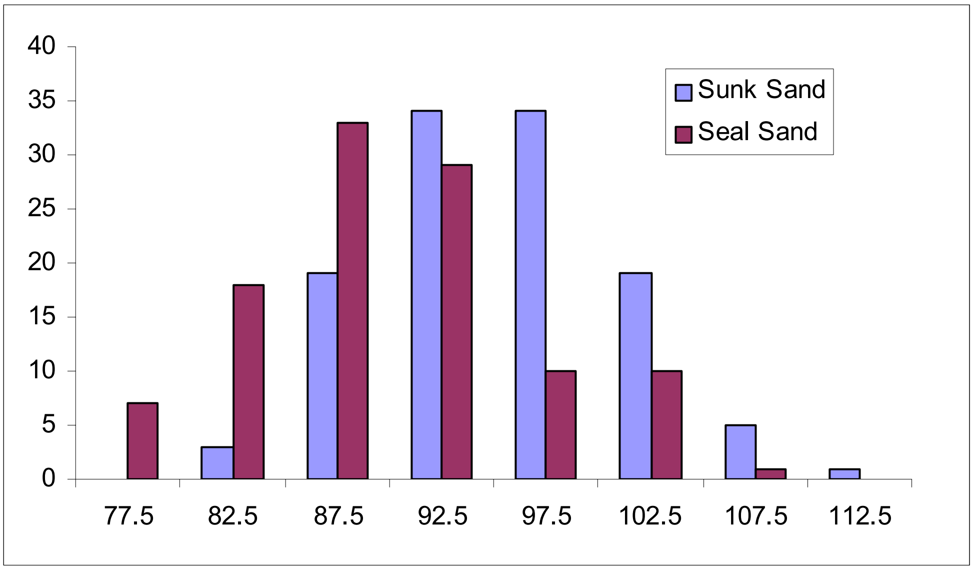


Figure 4.1 Size frequency distributions of *Ensis directus* from the Sunk Sand and Seal Sand experimental plots

4.2.2 Concluding remarks

The experimental results reported in this study and the time series of annual stock surveys now appear to have provided sufficient information to conclude that an experimental commercial fishery could be permitted in the near future. In addition to this report, Cefas has now completed an Appropriate Assessment for an experimental commercial fishery, which is in essence an update of the Appropriate Assessment reproduced in Appendices B and D of this report. If, and when, such an experimental fishery takes place, it will be important to monitor closely the impact of the fishery on both the interest features of the cSAC and on the stock of *E. directus* itself. In relation to the interest features, it will be necessary to monitor the substrate and the benthic community before and after the experimental fishery takes place, and similarly there will need to be stock surveys prior to and after the experimental fishery. It will also be important to monitor magnitude and location of catches of individual vessels during the experimental fishery to evaluate the response to exploitation of the stock over time. Whilst the precise details of the experimental fishery are beyond the scope of this report, we note that it will be important to permit harvesting to occur at a sufficiently intense level within controlled geographical areas in order that there is sufficient statistical power to identify any potential impact. Providing that no adverse impact is identified, the natural progression from an experimental fishery would be to a more general opening of the fishery on a regular basis when sufficient stocks are available for exploitation.

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Tuck, I.D., Bailey, N., Harding, M., Sangster, G., Howell, T., Graham, N. & Breen, M. 2000. The impact of water jet dredging for razor clams, *Ensis* spp., in a shallow sandy subtidal environment. Netherlands Journal of Sea Research. **43**: 65-81.

Appendix A Dredge trials for the alien razor-fish *Ensis directus* – Appropriate Assessment

After discussion with officers from English Nature, they have provided a series of questions which will need to be addressed: a) prior to dredge trials being carried out; b) before an experimental, commercial fishery should be allowed. The following forms an Appropriate Assessment for the former.

Interest features potentially impacted:

Sub-tidal sandbanks (extent of sandbanks, sediment characteristics, distribution and extent of communities, species composition of communities)

Possibly also Inter-tidal mudflats & sand-flats (cockles), SPA interest (cockle feeding birds)?

Only the first of these will be affected by the dredge trials, as the proposed experimental sites are in the shallow sub-littoral zone.

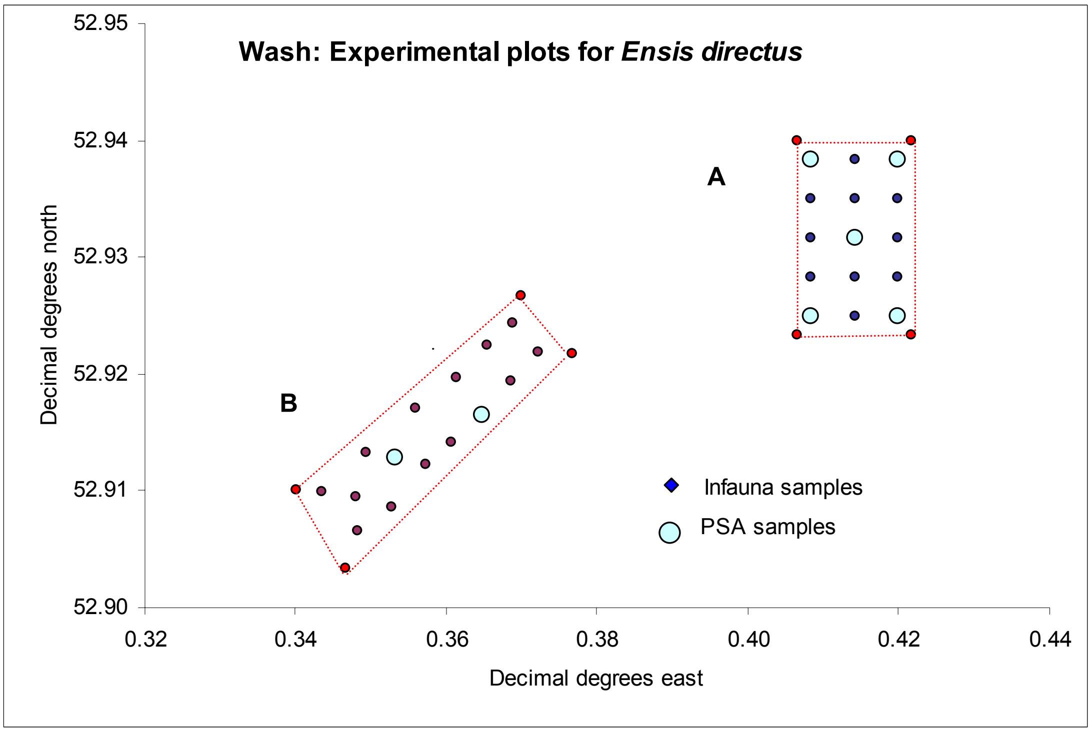
Nature of potential impact:

1. **Sediment characteristics**:

What are the characteristics of the sediment in which E. directus is found (including particle size, organic carbon content)?

E. directus is found in a range of habitats in The Wash, but the intention is to carry out dredge trials and an experimental fishery within two carefully designated fishing areas. Within these sites, 7 PSA samples together with 2 Mackintosh probe measurements have been analysed. A further 3 PSA samples from plot B await analysis. The positions of these samples within the plots are shown below.

Figure A1. Experimental plots including infauna and PSA sample sites



The results characterise the sediment of the experimental plots as mostly fine sand, very loose to about 0.65m, with a small silt fraction. A report by SEtech (Geotechnical Engineers) Limited, which gives details of these findings is appended.

What disturbance does the fishing method have on sediment characteristics e.g. depth/width of dredging operation?

The design for the trials is for a 0.9m wide dredge, which can be adjusted to dig to depths of 20-30 cm. The SEtech report provides details of the likely resettlement time for fluidised sediment. The trials will seek to optimise the depth of operation for effective harvesting of *Ensis directus.* The trials will be carried over ten days at most, from a single chartered vessel. On each of the experimental plots, it is expected that the gear trials will impact no more than about 2000m^2, about 0.1% of the total experimental area.

Does the fishing method alter the characteristics of the sediment? Is sediment structure or stability changed such that it causes significant mobilisation of the feature?

There will be changes to the sediment within dredge tracks. Therefore the dredge trials will be on too small a scale to cause mobilisation of the sandbanks.

If change occurs how long does it take for baseline characteristics to be re-attained? How long do tracks left in sediment persist?

The dredge trials will be used to measure the recovery of dredge tracks and feed into the Appropriate Assessment for the experimental fishery.

2. Benthic communities:

What effect will method of fishing have on benthic communities (species composition, distribution & extent of communities)?

What are recovery rates of communities following fishing?

What are discard rates?

What are likely survival rates of discarded, non-target species?

These can only be answered by monitoring the experimental fishery. Table 1 gives the results of Day grab sampling (0.1m^2) on the experimental sites in May 2005. Poor weather prevented the full survey being completed, and may have affected sampling efficiency at some stations.

Table A1. Fauna sampled by Day grab May 2005. Number per $0.1m^2$ retained on 3mm sieve.

Plot A

Position						*Ophura*	*Nephtys*	*Pagurus*	*Echinocardium*	*Sagartia*	*Lanice*	Total
Lat		Long		Sample	Sediment type	*albida*	Sp.	*bernhardus*	*cordatum*	*troglodyte:*	tubes	
52	56.29	0	25.15	poor	Fine sand	4						4
52	56.296	0	25.193	fair	Fine sand	1		1				2
52	56.119	0	25.157	poor			1				12	13
52	55.89	0	25.165	poor								0
52	55.714	0	25.155	good								0
52	55.491	0	24.84	good							6	6
52	55.489	0	24.816	good	Muddy silt							0
52	55.709	0	24.822	good	Silty fine sand		1				30	31
52	55.912	0	24.826	good	Silty sand	1						1
52	56.1	0	24.817	good							1	1
52	56.311	0	24.462	good	Fine sand							0
52	56.303	0	24.462	fair			1		1			2
52	56.104	0	24.482	good	Fine sand							0
52	55.903	0	24.48	poor		1						1
52	55.693	0	24.47	good	Muddy Sand							0
						7	3	1	1	0	49	61

Plot B

52	55.44	0	22.109	good	Coarse sand and shell	2	1			1		4
52	55.31	0	22.327	fair	Coarse sand and shell							0
52	55.156	0	22.103	good	Coarse sand and shell							0
52	54.848	0	21.601	good	Coarse silty sand	1						1
52	54.735	0	21.415	good	Fine silty sand	1	1					2
52	54.782	0	21.167	good	Coarse sand and shell							0
52	55.32	0	21.874	poor	Coarse sand	1					5	6
52	55.197	0	21.672	good	Coarse silty sand							0
						5	2	0	0	1	5	13

In this case a 3 mm sieve was employed because it was available on board the vessel. Table 2 gives results for mini-Hamon grab samples at four stations close to the experimental plots in February 1999. This grab also samples $0.1m^2$ of the seabed and in this case samples were washed through a 1 mm sieve. A somewhat larger number of species were identified.

Table A2. Fauna sampled by mini Hamon grab, February 1999. Number per $0.1m^2$ retained on 1mm sieve.

	Plot A		Plot B	
Position	52° 56.085 0° 23.909	52° 55.305 0° 24.617	52° 55.004 0° 21.408	52° 55.106 0° 20.682
Anaitides mucosa			1	
Glycera tridactyla	1			
Goniada maculata			1	
Nereis longissima				1
Nephtys caeca	1		1	
Nephtys hombergi	1		1	2
Nephtys longosetosa	5	5		4
Scoloplos armiger		3	1	1
Spiophanes bombyx			3	6
Megelona mirabilis (A)		2		
Caulleriella zetlandica			1	
Notomastus latericus			5	3
Ophelia borealis		1	3	
Lagis koreni			1	1
Pontocrates altamarina		1		
Bathyporeia pelagica		1		
Angulus tenuis				2
Abra alba				1
Ophuira albida				
Ophuira ophuira		1		
Echinocardium cordatum	1			1

Will this method of fishing result in the catch of cockles?

No, the proposed experimental sites are sub-littoral, well below the level of cockle settlement.

If cockles are caught what effect will this have on cockle stocks and the SPA interest that feed on them?

None.

3. Cumulative effects of the proposed fishery in combination with other plans or projects:

Will the proposals have cumulative effects (taking into account existing or proposed plans or projects) on the features of the European marine site eg interactions between the existing shellfisheries and the new fishery for E. directus.

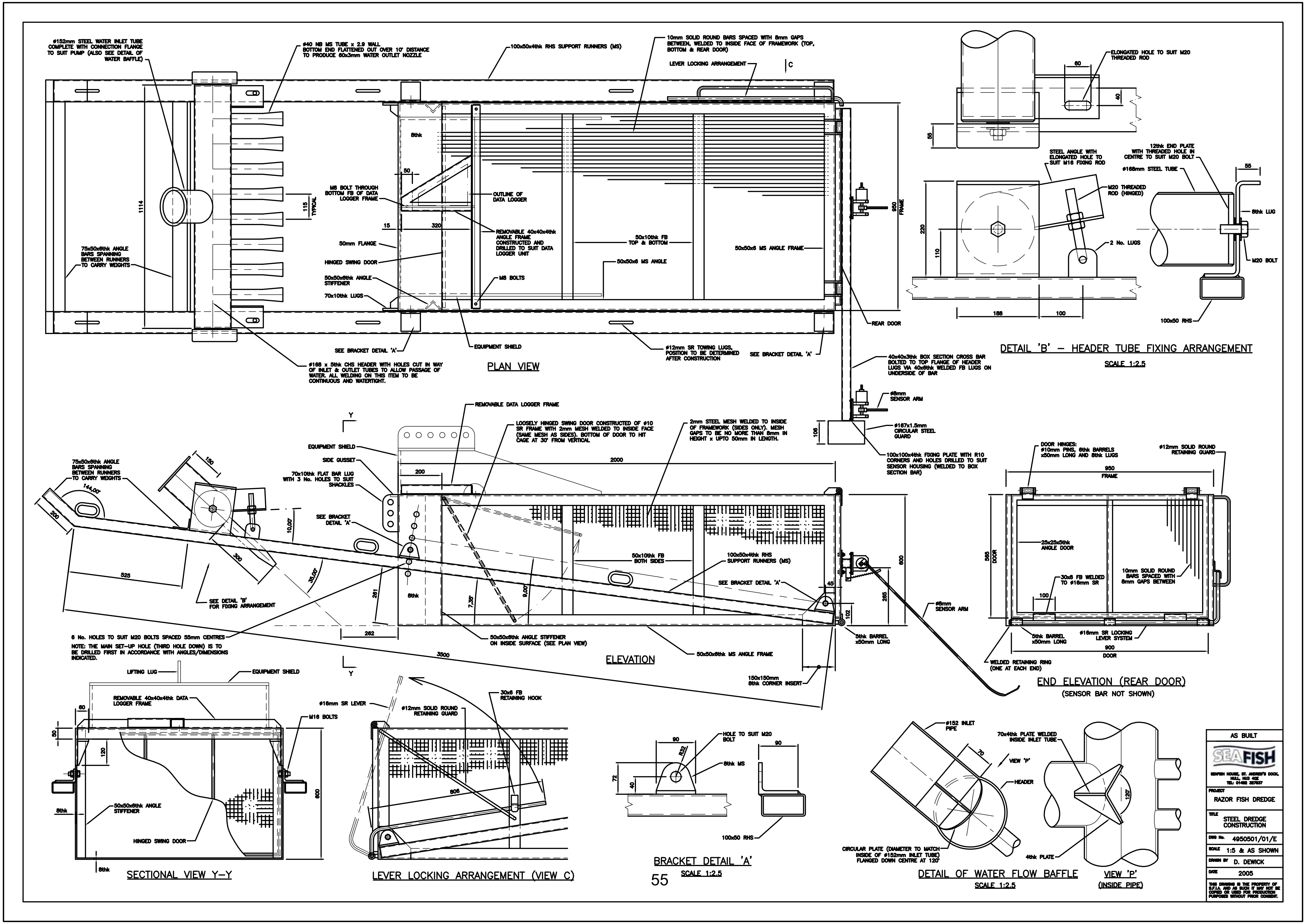
Unlikely if the fishery if confined to specified areas. The grounds are quite separate from existing dredge fisheries.

APPENDIX B DREDGE SPECIFICATION

Full engineering drawings are available from:

Bill Lart
Sea Fish Industry Authority
St Andrew's Dock
Hull
HU3 4QE.

Tel. 01482 327837



PLAN VIEW
ELEVATION
SECTIONAL VIEW Y-Y
LEVER LOCKING ARRANGEMENT (VIEW C)
BRACKET DETAIL 'A'
SCALE 1:2.5
DETAIL OF WATER FLOW BAFFLE
SCALE 1:2.5
VIEW 'P' (INSIDE PIPE)
DETAIL 'B' - HEADER TUBE FIXING ARRANGEMENT
SCALE 1:2.5
END ELEVATION (REAR DOOR)
(SENSOR BAR NOT SHOWN)
ø152mm STEEL WATER INLET TUBE COMPLETE WITH CONNECTION FLANGE TO SUIT PUMP (ALSO SEE DETAIL OF WATER BAFFLE)
ø40 NB MS TUBE x 2.9 WALL BOTTOM END FLATTENED OUT OVER 10' DISTANCE TO PRODUCE 60x3mm WATER OUTLET NOZZLE
100x50x4thk RHS SUPPORT RUNNERS (MS)
10mm SOLID ROUND BARS SPACED WITH 8mm GAPS BETWEEN, WELDED TO INSIDE FACE OF FRAMEWORK (TOP, BOTTOM & REAR DOOR)
LEVER LOCKING ARRANGEMENT
M8 BOLT THROUGH BOTTOM FB OF DATA LOGGER FRAME
OUTLINE OF DATA LOGGER
REMOVABLE 40x40x4thk ANGLE FRAME CONSTRUCTED AND DRILLED TO SUIT DATA LOGGER UNIT
50mm FLANGE
HINGED SWING DOOR
50x50x6thk ANGLE STIFFENER
70x10thk LUGS
M8 BOLTS
50x10thk FB TOP & BOTTOM
50x50x6 MS ANGLE
50x50x6 MS ANGLE FRAME
75x50x6thk ANGLE BARS SPANNING BETWEEN RUNNERS TO CARRY WEIGHTS
SEE BRACKET DETAIL 'A'
EQUIPMENT SHIELD
ø12mm SR TOWING LUGS, POSITION TO BE DETERMINED AFTER CONSTRUCTION
REAR DOOR
ø168 x 5thk CHS HEADER WITH HOLES CUT IN WAY OF INLET & OUTLET TUBES TO ALLOW PASSAGE OF WATER. ALL WELDING ON THIS ITEM TO BE CONTINUOUS AND WATERTIGHT.
40x40x3thk BOX SECTION CROSS BAR BOLTED TO TOP FLANGE OF HEADER LUGS VIA 40x6thk WELDED FB LUGS ON UNDERSIDE OF BAR
ø8mm SENSOR ARM
ø167x1.5mm CIRCULAR STEEL GUARD
100x100x4thk FIXING PLATE WITH R10 CORNERS AND HOLES DRILLED TO SUIT SENSOR HOUSING (WELDED TO BOX SECTION BAR)
REMOVABLE DATA LOGGER FRAME
LOOSELY HINGED SWING DOOR CONSTRUCTED OF ø10 SR FRAME WITH 2mm MESH WELDED TO INSIDE FACE (SAME MESH AS SIDES). BOTTOM OF DOOR TO HIT CAGE AT 30' FROM VERTICAL
2mm STEEL MESH WELDED TO INSIDE OF FRAMEWORK (SIDES ONLY). MESH GAPS TO BE NO MORE THAN 8mm IN HEIGHT x UPTO 50mm IN LENGTH.
SIDE GUSSET
70x10thk FLAT BAR LUG WITH 3 No. HOLES TO SUIT SHACKLES
50x10thk FB BOTH SIDES
100x50x4thk RHS SUPPORT RUNNERS (MS)
SEE DETAIL 'B' FOR FIXING ARRANGEMENT
6 No. HOLES TO SUIT M20 BOLTS SPACED 55mm CENTRES
NOTE: THE MAIN SET-UP HOLE (THIRD HOLE DOWN) IS TO BE DRILLED FIRST IN ACCORDANCE WITH ANGLES/DIMENSIONS INDICATED.
50x50x6thk ANGLE STIFFENER ON INSIDE SURFACE (SEE PLAN VIEW)
50x50x6thk MS ANGLE FRAME
5thk BARREL x50mm LONG
150x150mm 8thk CORNER INSERT
ELONGATED HOLE TO SUIT M20 THREADED ROD
STEEL ANGLE WITH ELONGATED HOLE TO SUIT M16 FIXING ROD
M20 THREADED ROD (HINGED)
2 No. LUGS
12thk END PLATE WITH THREADED HOLE IN CENTRE TO SUIT M20 BOLT
ø168mm STEEL TUBE
8thk LUG
M20 BOLT
100x50 RHS
DOOR HINGES: ø10mm PINS, 6thk BARRELS x50mm LONG AND 8thk LUGS
ø12mm SOLID ROUND RETAINING GUARD
25x25x5thk ANGLE DOOR
30x6 FB WELDED TO ø16mm SR
10mm SOLID ROUND BARS SPACED WITH 8mm GAPS BETWEEN
5thk BARREL x50mm LONG
ø16mm SR LOCKING LEVER SYSTEM
WELDED RETAINING RING (ONE AT EACH END)
LIFTING LUG
REMOVABLE 40x40x4thk DATA LOGGER FRAME
M16 BOLTS
HINGED SWING DOOR
ø16mm SR LEVER
ø12mm SOLID ROUND RETAINING GUARD
30x6 FB RETAINING HOOK
HOLE TO SUIT M20 BOLT
8thk MS
100x50 RHS
ø152 INLET PIPE
70x4thk PLATE WELDED INSIDE INLET TUBE
VIEW 'P'
HEADER
CIRCULAR PLATE (DIAMETER TO MATCH INSIDE OF ø152mm INLET TUBE) FLANGED DOWN CENTRE AT 120'
4thk PLATE
AS BUILT
SEAFISH
SEAFISH HOUSE, ST. ANDREW'S DOCK, HULL, HU3 4QE TEL: 01482 327837
PROJECT: RAZOR FISH DREDGE
TITLE: STEEL DREDGE CONSTRUCTION
DWG No. 4950501/01/E
SCALE 1:5 & AS SHOWN
DRAWN BY D. DEWICK
DATE 2005
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APPENDIX C: AWARD OF TENDERS FOR DREDGE CONSTRUCTION AND VESSEL CHARTER

(For commercial confidence reasons, this appendix is not reproduced in this copy of the report).

Appendix D Report by SEtech

SEAFISH

ENSIS DIRECTUS PROJECT

Issue	Date	Status	Prepared		Checked	
0	15/07/2005	Draft	SW		PGA	
1	31/01/2006	Trial Data Incorporated	PGA		JP	
2	02/02/2006	Client Comments Incorporated	PGA		JP	

Title

Ensis directus Dredge Study

Report No.

8342 / 2

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EXECUTIVE SUMMARY

The Centre for Environment Fisheries and Aquaculture Research (Cefas) at Lowestoft are leading a Financial Instrument for Fisheries Guidance (FIFG) project to introduce a dredge fishery for *Ensis directus* in the Wash. Cefas, with the collaboration of the Sea Fish Industry Authority (Seafish), have investigated the performance of the hydraulic dredges commonly used for shell fish.

The project is considering two trial sites, as illustrated in Figure 1. SEtech has been commissioned by Seafish to provide assistance with the project by:

- Investigating the geotechnical characteristics of the seabed in the study areas.
- Theoretical modelling of the interaction of the dredge with the seabed, including:
    - Assessing the depth to which the water jetting process fluidises the seabed.
    - Assessing the time taken for sediment to settle out of suspension.
- Assisting in the development of a trial programme.
- Comparing the theoretical results with those obtained during the trial programme.
- Commenting on, and making recommendations for the operations of the dredge.

The work found that the sediments at the site are uniform sand, possibly sorted by transportation of mobile sediments. Probing of the seabed indicated the sands to be very loose at the seabed to approximately 0.65m depth, where it becomes loose to medium dense.

The depth of penetration of the water jets is limited to the upper sediments, with the sand that has been fluidised anticipated to settle out of suspension relatively quickly.

Trials were performed with an instrumented dredge and the results analysed by Seafish. These results have been compared to the theoretical model and the general trend of deeper fluidisation with increasing pressure has been followed. However, the model has under predicted the depth of fluidisation of the seabed at one of the trial sites. This is thought to be due to the very loose nature of the seabed sands at this location.

1 INTRODUCTION

The Centre for Environment Fisheries and Aquaculture Research (Cefas) at Lowestoft are leading a Financial Instrument for Fisheries Guidance (FIFG) project to introduce a dredge fishery for *Ensis directus (E. directus)* in the Wash. Seafish and Cefas propose to carry out trials of hydraulic dredges for this species at two selected sites.

The purpose of this project is to review dredges currently available for razor clam fishing, and to conduct field trials in The Wash, with the expected outcome being the designation of appropriate gear for use in a controlled fishery for *E. directus* in The Wash.

1.1 Background

The four species of razor fish found in British waters are *Ensis arcuatus*, *E. siliqua, E. ensis* and *E. directus.* The first 3 are native, whilst *E. directus* is an alien from N. America which has become established in European waters over the last 20 years.

The fishery for razorfish *(Ensis directus)* in The Wash was still in an experimental phase in 1998 when, following advice from English Nature, Defra introduced an Order prohibiting dredge fishing for razor shells, trough shells and carpet shells in The Wash area, specifically the area designated as a candidate Special Area of Conservation (cSAC) under the European Habitats Directive.

Since then CEFAS has undertaken a series of resource surveys, which suggest that, in some years, individual year classes of *Ensis directus* survive in sufficient numbers to be harvested in a sustainable manner. Much of these stocks are found in highly mobile sediments which contain little other benthos, and which may be subject to periodic storm damage. The quantities available are variable dependent on year class strength but current estimates indicate that there may be around 2000+ tonnes available this winter.

1.2 Objectives of SEtech Study

SEtech is a geotechnical engineering consultancy with particular expertise in the field of seabed sediment mechanics. Since an important aspect of the dredge's environmental effect is its mechanical action on the seabed then it is important to focus expertise on this aspect.

The objectives of this study are to:

1. Investigate the geotechnical characteristics of the seabed in the study areas and reviewing the theoretical, numerical models available for describing the action of the dredge.

2. Theoretically model the interaction of the dredge with the seabed, including:
    a. Estimation of the depth to which the water jetting process fluidises the seabed.
    b. Estimation of the time taken for sediment to settle out of suspension.

3. Compare the theoretical results with those obtained during the trial programme.

4. Comment on, and making recommendations for the operations of the dredge.

1.3 Trial sites

The project is considering two trial sites, A and B as illustrated in Figure 1.

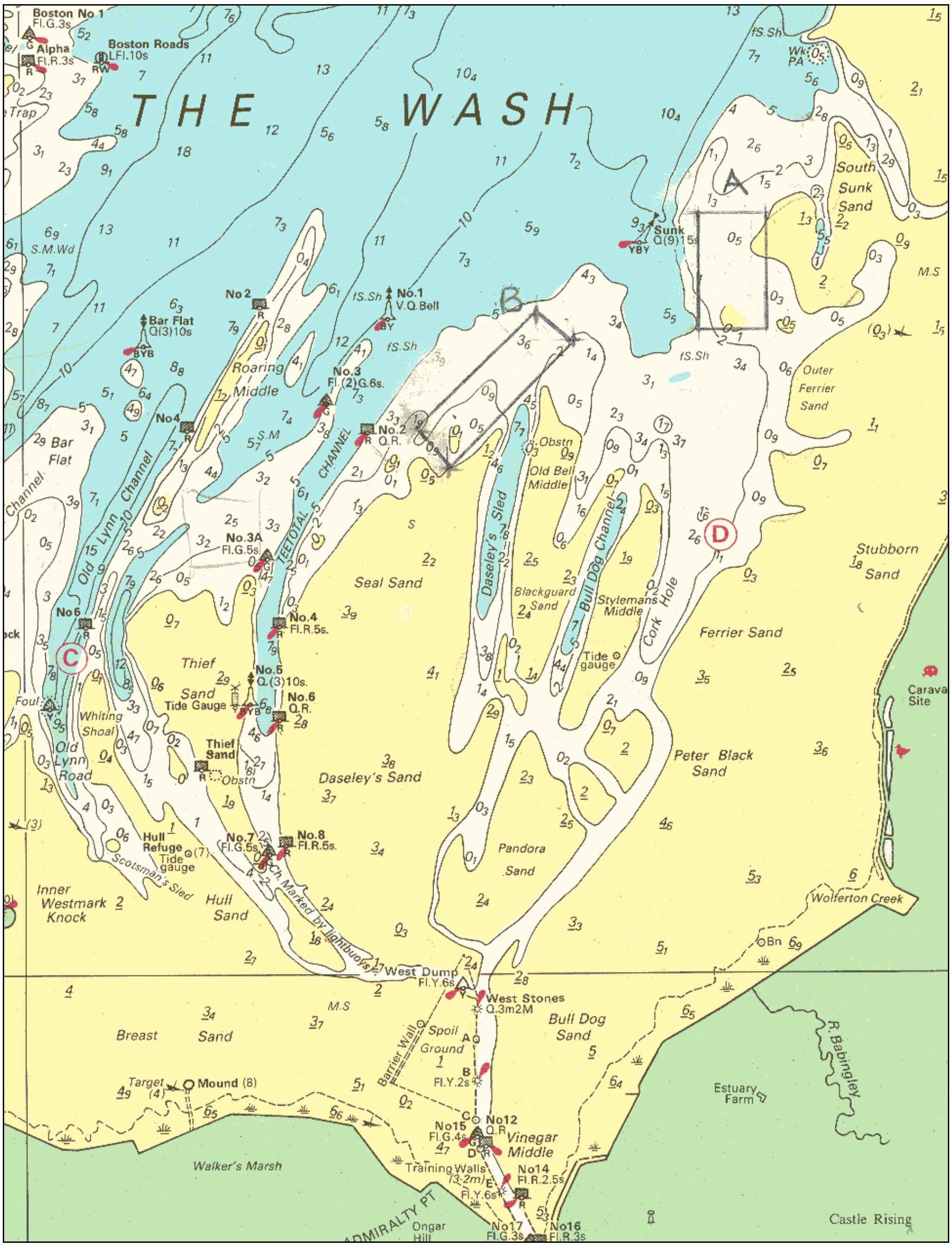

Figure 1: Location Plan

2 SEABED CONDITIONS

2.1 Regional Context

The British Geological Survey (BGS) indicate the sediments at the sites, as shown in Figure 2 to be composed of sands, with minor slightly gravelly or gravelly patches. The BGS indicate some of the areas will become exposed during extreme low water spring tides. Occasional sand waves are also noted to occur within the Wash.

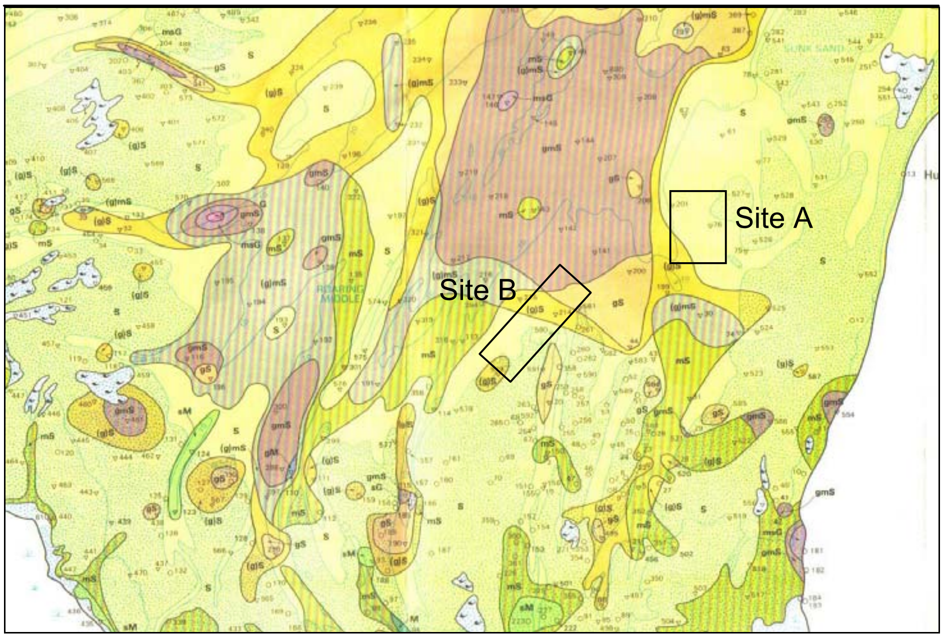

Figure 2: Seabed Sediments

Most of the sediments within the Wash are thought to be derived from offshore areas with the sediment load from rivers being relatively small. Deposition of sediment occurs largely in the intertidal zones, with erosion being dominant in the sub tidal zones. Tidal currents carry sediment onto the intertidal flats, differentiating the load as they advance, resulting in a series of coast-parallel belts of sediments which fine shorewards, cut across by deposits associated with tidal creeks or river channels.

2.2 Geotechnical fieldwork and testing

Fieldwork for the project was undertaken in May 05 from RV "Three Counties". During the survey, in situ testing in the form of two Mackintosh probes was carried out, and seven samples were taken by means of grab sampling.

A Mackintosh probe is a tool used to determine ground density by penetrating a probe into the ground by a drop weight falling through a given height. The number of blows for each 100mm depth increment is used to assess the relative density of a sand or strength of a clay. Time and tide limitations dictated that the tests were only performed at Site B.

The Mackintosh probes indicate the sands to increase in density with depth and to be predominantly very loose to loose with no measurable resistance to penetration over the top 0.1m. Below this depth, results indicated a very loose sand to greater than 0.5m below seabed. The results of the tests are presented in Figure 3. Loose sands may be anticipated at Site A, however this has not been confirmed.

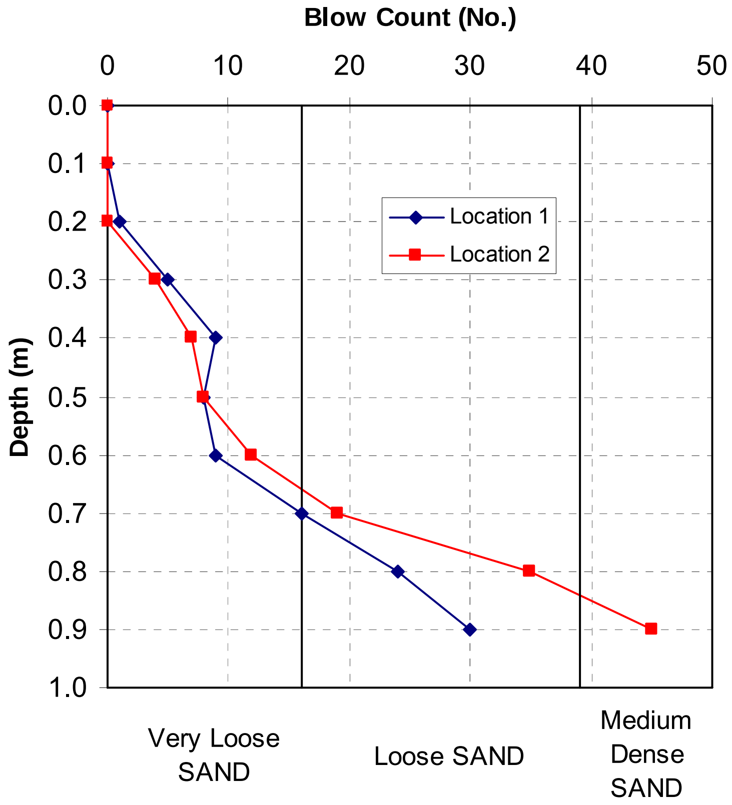

Figure 3: Mackintosh Probe Results

Particle size distribution tests have been carried out on the samples recovered, with the results plotted in Figure 4. These results indicate the sediments to be predominantly silty fine to medium grained sand, with one sample grading as medium to coarse sand.

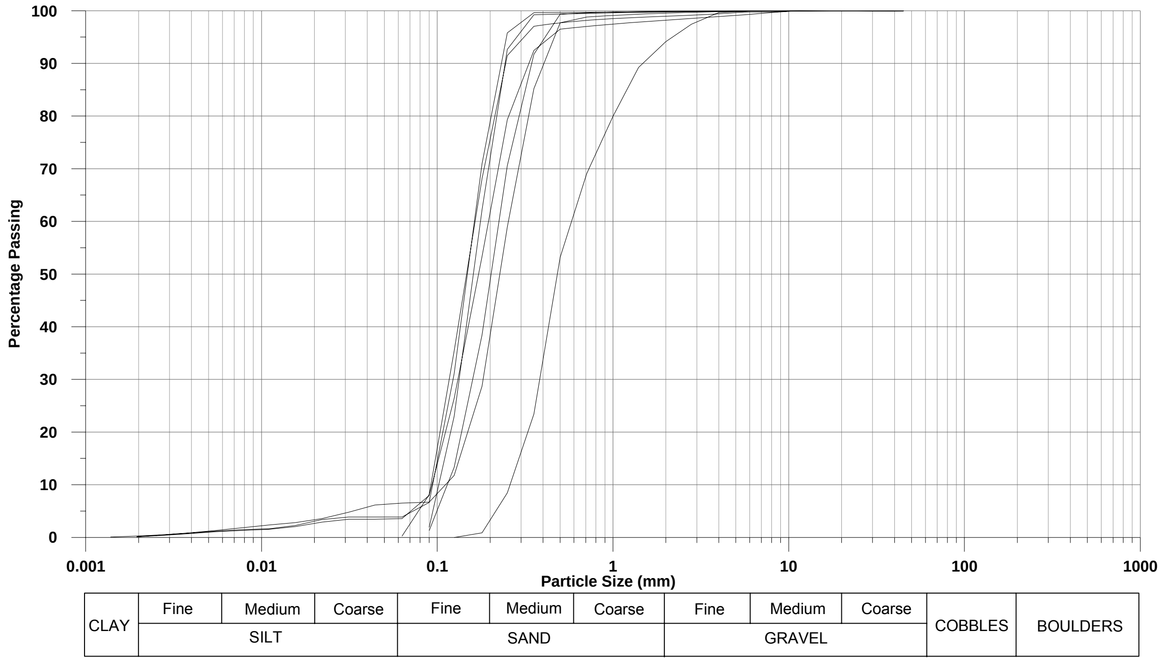

Figure 4: Grab-sampled Particle Size Distribution Results

2.3 Results of Geotechnical Observations

The majority of the sediments at the site are considered to be uniform, fine to medium grained sand, in the size range 0.1 to 0.3mm grain diameter. The sand has possibly been sorted by transportation and tidal currents. The sand is indicated to be very loose and unconsolidated at seabed to approximately 0.65m depth, where it becomes loose to medium dense.

3 THEORETICAL CONSIDERATIONS

Seafish have investigated typical dredges and provided representative dimensions, these are:

- Overall width of dredge 0.9m
- 8 no nozzles directed at approximately 45° to axis of dredge cage
- Nozzle size 45mm x 10mm (plus semi circle at ends)
- 1 to 6bar pressure at nozzle considered
- Dredge speeds of 0.25, 0.5 and 0.75kn considered
- Sediment settlement calculations based on mean particle size of 0.2mm

3.1 Jetting

Jetting of water into sands embraces a number of different components. Firstly it is necessary to investigate the capacity of a water jet to remove sand particles from the seabed and then lift them into suspension. The trench formed by the jet tool is assumed for ease of modelling to be vertically sided.

Once fluidised by the passage of the hydraulic dredge, the sand may be assumed to have become mixed with the jet water and hence be fluidised. In this state, the fluidised /water mixture will behave in a manner more akin to a fluid and solid/particulate mechanics theories cease to be valid. The main changes will be an increase in density and viscosity when compared to water. Almost immediately after the passage of the hydraulic dredge, the sand will begin to settle out of suspension. The main factor to consider at this stage is the rate at which sand, settling out of suspension, infills the trench.

3.2 Ability of Jet to Fluidise Sand

An assessment of the ability of a water jet to erode sand may be approached from a simple sediment mechanics perspective of water velocity required to entrain seabed sand, or the combined hydraulics and sediment mechanics work performed on the scouring action of a jet directed across the surface of a sand bed.

This study has made reference to work carried out by Wakefield, 1994. Wakefield presented a curve for water jet cutting for water pressure at nozzle against a coefficient, which allows the weight of soil fluidised per second to be calculated.

The depth of the trench produced is influenced by the volume and pressure of jet water, the speed of the hydraulic dredge, and the size of the jet nozzles. Figure 5 presents the results of the calculation carried out to determine the theoretical trench depth. As the speed of the hydraulic dredge decreases and the water jet pressure increases the depth of the trench increases.

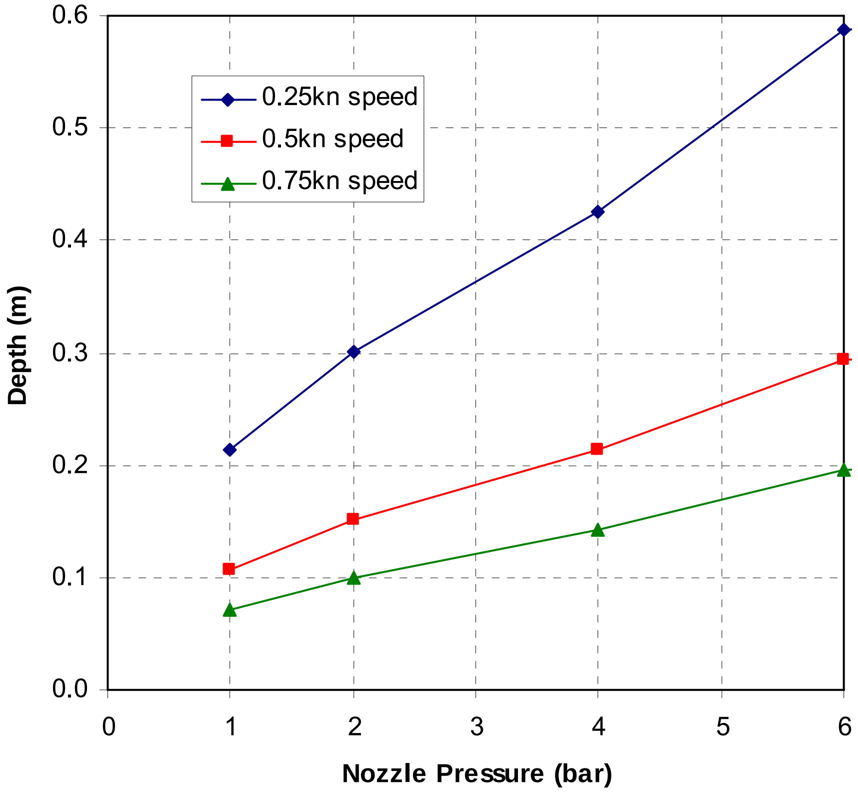

Figure 5: Depth of Scour

3.3 Settlement Velocity of Sand

Once sand from both the trench cross section and that due to (trench sidewall) collapse, has been fluidised and entrained, it will disperse with the jet water as a turbulent homogenous fluid. Based on the speed of the water jet and the volume of water delivered, it is possible to idealise this dispersion as a semicircle centred on the trench. In the absence of other currents, eg tidal currents, some of the sand will settle out of suspension and into the base of the trench. The remaining sand will settle out of suspension beyond the trench profile

Several factors are found to influence the settlement velocity of sand. These factors include, particle size, concentration of sand grains, and speed of the hydraulic dredge. The findings of the calculations for the speed of settlement of the grains are given in Figure 6.

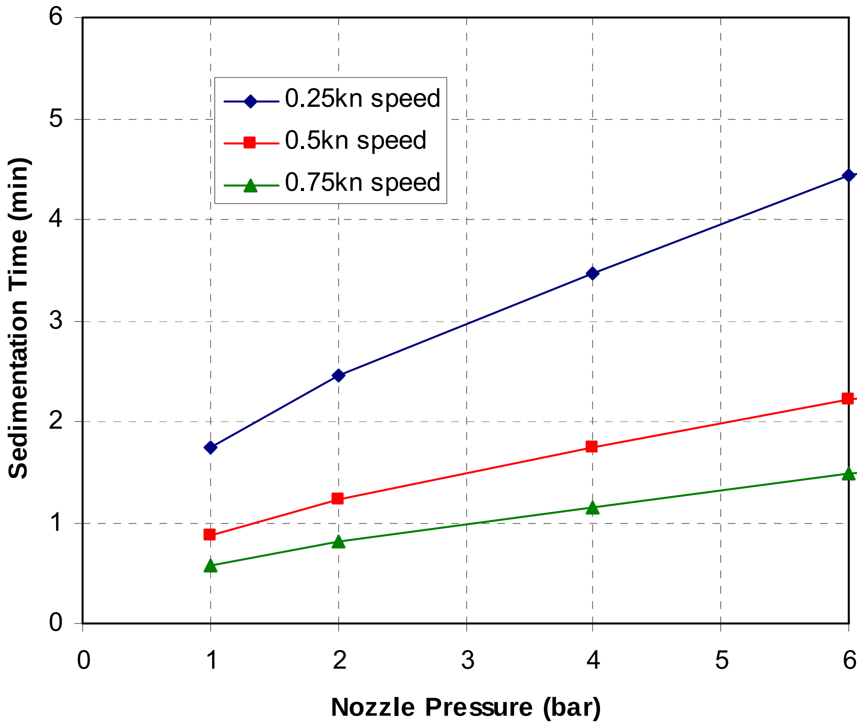

Figure 6: Average Sedimentation Time based on D_{50}

The grain size used was based upon the mean grain size (D_{50}) of the samples recovered. The particle size distribution of the sand is uniform, and hence this is considered to be a reasonable assumption. The rate of sedimentation is a function of the volume of water used to fluidise the sand, and hence the height to which the sand is lifted above the seabed, and the volume concentration of the sand. The graph illustrates how, as the speed of the hydraulic dredge increases the time taken for the sand to settle decreases, and as the nozzle pressure increases, the time taken for the sand to settle increases. Longer settlement times will be observed in the fine (silt) fraction, however as silt is a relatively small percentage (less than 10%), this fraction may be anticipated to be dispersed by currents.

4 INSTRUMENTED DREDGE TRIALS

4.1 Introduction

Following preliminary dredge-towing trials, the fully-instrumented dredge trials were performed on 20th December 2005. Time limitations restricted this to one dredge on each site. The instrumentation fitted to the dredge comprised trailing arms to measure the depth to which the seabed sands had been fluidised, accelerometers to measure the inclination and heel of the dredge, a load shackle on the towing chain to measure the towing tension and a pressure transducer to measure water pressure in the jet supply system (see Seafish report for full details of setup and results). The dredging operation was performed by deploying an anchor and pulling the fishing vessel along on the anchor wire whilst towing the dredge astern of the vessel on a fixed tow-chain. This gave a more consistent towing speed and directional control than when operating under the vessel's own propeller propulsion.

The first trial was performed at Site B, and the second at Site A. The locations and length of the tow are presented in Table 1.

Site	Latitude (dd° mm.mmm')	Longitude (dd° mm.mmm')	Length of tow (m)
A (Sunk sand)	52° 55.911' N	00° 24.738' E	55
B (Seal)	52° 54.567' N	00° 21.123' E	50

Table 1: Summary of Instrumented Trial Locations

At Site B, the trial was conducted at a constant speed of 0.6knots and the water jet pressure was increased during the tow. At Site A, the speed and pressure were constant at 0.35knots and 3.6bar throughout. This had been established in previous trials as the optimum operating conditions of the dredge in terms of minimising damage to the catch.

4.2 Trial Results

Data from the trials has been processed by Seafish and the results presented on a series of diagrams. The results are summarised in Table 2 and graphically on Figure 7:

Site	Trial Data Set	Pressure (Bar)	Speed (Knots)	Trench or Depth (m)	Inclination (°)	Tow Tension (kg)
B	Pressure 1	1.63	0.6	0.086	1.1 forward	511
B	Pressure 2	2.47	0.6	0.192	2.3 aft	707
B	Pressure 3:1	3.47	0.6	0.242	2.8 aft	608
B	Pressure 3:2	3.7	0.6	0.236	4.1 aft	377
A	Pressure 1:1	3.72	0.35	0.073	3.4 aft	285
A	Pressure 1:2	3.57	0.35	0.163	3.2 aft	227

Table 2: Summary Dredge Trial Results (relate to Part III main report)

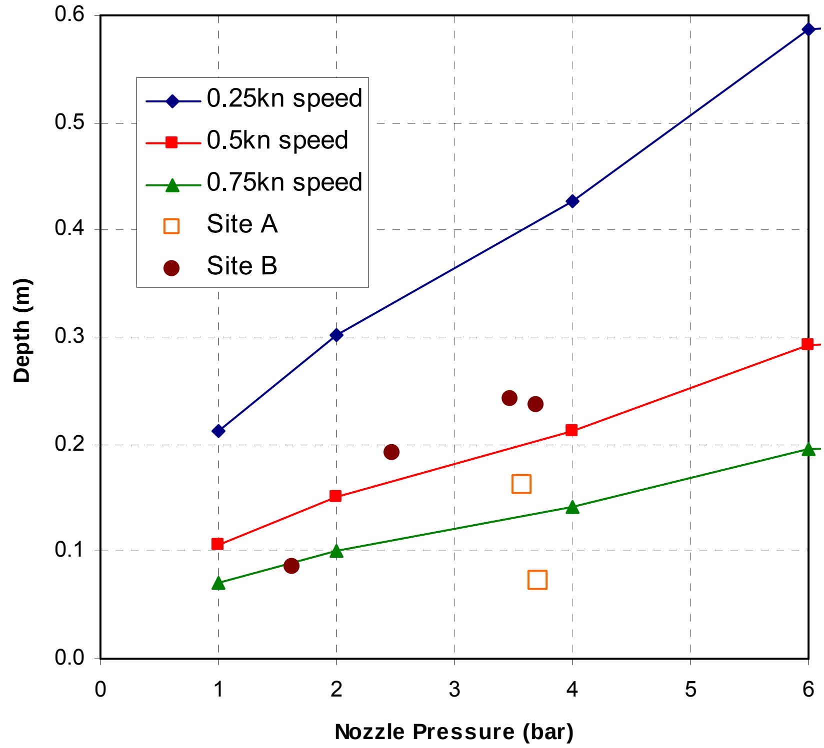

Figure 7 : Depth of Fluidisation – Trial Data and Theoretical Results.

4.3 Discussion

The results of trials at Site B follow the general trend line established by the theoretical model, and are slightly higher than the depth of fluidisation / speed relationship would suggest. However at Site A, the depth of fluidisation was significantly shallower than indicated by the theory when allowance is made for the slow speed used at this site.

The explanation for variation in the results obtained may relate to the relative density of the seabed sands. The Mackintosh probing performed at Site B indicated the seabed sands to be very loose in the top 0.2m, suggesting they would fluidise easily. Experience during the trial, while only circumstantial, gave the impression that the soils at Site A were denser than at Site B.

Some further indication of the relative density of the sand is given by the tow tensions which were in the range 250 to 700kg. The lower values (both from Site A) are consistent with a friction coefficient of 0.5 for steel on a sandy seabed. However, at Site B, the tow tensions were much higher (average 600kg) suggesting either that there was either a much higher friction coefficient of approximately 1, or that the dredge was digging in to the seabed. The assumption that the dredge was digging into the seabed at Site B would be consistent with the sand being much looser than at Site A.

The trial data indicated the dredge cage to be pitching aft or at best only slightly forwards. This would suggest that the dredge is sitting in the 'trench' formed by the water jets. However the dredge side bars are inclined approximately 10° to the horizontal with the nominal objective of keeping the dredge cage pitched forwards.

The attitude of the dredge on the seabed suggests that the water jets are fluidising the sand beyond the profile of the dredge cage. This implies that the width and hence volume of sand fluidised is greater than actually required. In practice, this is unavoidable due to dispersion of the water from the jet nozzles and the sandy seabed forming the trench side not being able to stand vertically. As the side runner bars are relatively narrow, it is probable that they are insufficiently wide to reach beyond the trench side onto undisturbed seabed.

A further contribution to the tendency for the dredge to run with an approximately horizontal attitude is the uplift from to the tow chain and the reaction from the jet nozzles as illustrated in Figure 8. This assumes that the system is operating at a jet pressure of 3.5 bar and that the tension in the tow chain is between 250 and 600kg, with a layback to depth ratio of 3 : 1.

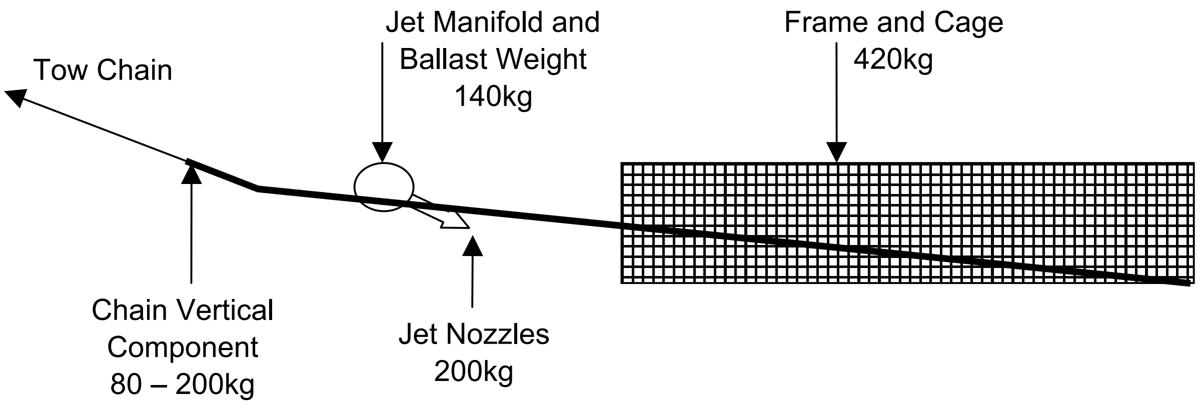

Figure 8 : Weight and Vertical Forces Acting on the Dredge

Inspection of Figure 8 indicates that the vertical uplift forces acting on the dredge total between 280 and 400kg, compared to a total weight of 560kg. As both the chain and the nozzles are forwards of the centre of gravity of the dredge, this would be sufficient to lighten the leading edge and contribute to maintaining the dredge on a horizontal attitude to the seabed. This may be undesirable as it could contribute to the leading edge of the cage running above the depth of the jetted sand.

No monitoring of the sediment plume developed was performed and hence this has not been discussed further.

4.4 Recommendations

From the available data, it would appear that the pump and nozzle area are well matched and able to fluidise the seabed sands to sufficient depth to enable the *E. directus* to be caught with apparent efficiency.

The main observations from the operation of the dredge are that the depth of fluidisation is sensitive to the relative density of the sands. This may be beneficial if the *E. directus* burrow to shallow depth in dense sand seabeds, but go deeper in loose sands.

Consideration could be given to fitting large skids to the cage. Possible locations include outboard to the cage with an ability to adjust the height to suit the seabed soils, or on the underside of the cage. Positioning skids on the underside of the cage may be preferable as it would allow the dredge to run at an equilibrium depth according to the seabed conditions, while preventing the dredge digging in and high tow forces being experienced.

The length of the draw bar on the dredge contributes to the uplift. However reducing the length would reduce the directional stability and the configuration of the nozzles relative to the cage. It is therefore probable that there is little scope to reduce this length.

5 CONCLUSIONS

1. The sediments at the site are considered to be uniform fine grained sand with a small silt content (less than 10%), probably sorted by transportation of mobile sediments. The sand is indicated to be very loose at seabed to approximately 0.65m depth, where it becomes loose to medium dense. The very loose nature of the sand, and its uniformity suggests a high level of sediment mobility may be occurring.

2. The theoretical interaction of the proposed hydraulic dredges with the seabed sands has been considered for a range of water pressures and speeds. These models suggest that at low speeds (0.25knots) and high pressures (4bar) seabed penetration could reach 0.4m. The estimated average time for the fluidised sand to settle out of suspension is anticipated to be between 3 and 4 minutes, however some finer particles such as silt will remain in suspension for longer and may be dispersed by currents. No actual observations of sediment dispersal were made.

3. The pattern of the results of the trial conducted is consistent with the theoretical model. The depth of excavation on Site B was comparable with the model, but was underestimated on site A. The variation is attributed to changing relative density for the sand.

   The maximum depth of penetration observed was 0.24m within an area identified as very loose sand based geotechnical observations using a probing tool. The results showed some variation from the theoretical model, which is thought not to adequately allow for the changing relative density of the sand.

4. Operational factors which may be concluded from the trial data include the tendency of the dredge to incline upwards. This may be undesirable, but could be compensated by adding additional weight to the front of the dredge, or by shortening the front bar length, however this latter option may compromise directional stability.

5. Consideration could be given to placing skids on the underside of the dredge cage, preventing the dredge digging in and reducing friction over the seabed. This would help reduce and maintain tow forces at a minimum level.

6 REFERENCES

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