Slipper Limpet Mortality Trials
Seed Mussel Project

For:

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Final Report

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Executive Summary

The mussel culture industry is one of the largest and most valuable fisheries in the UK representing almost 90% of total shellfish aquaculture production by weight in England and Wales with a value of around £14 million per year. Continuing productivity is significantly dependant on the movement of mussel seed from wild settlement areas to cultivation areas. Unfortunately, these shellfish movements can also spread pests such as the non-native slipper limpet *(Crepidula fornicata*) which has the potential to have a devastating effect on both fisheries and marine eco-systems as it out-competes other species for food and space as well as depositing pseudo-faeces that builds up to create cohesive 'muds'. An accidental introduction of slipper limpets into the major UK mussel culture area of the Menai Straits, North Wales has recently occurred following a movement of mussel seed contaminated with slipper limpets from the English Channel. This led to urgent remedial action having to be taken by industry which involved removing the infested mussel seed and then smothering of any remaining slipper limpets with new slipper limpet free seed. There is a need therefore for the industry to self regulate and minimise risks in such transfers. Failure to do so will otherwise result in measures being imposed on industry in this respect. Positive action is now currently being undertaken in some regions as can be seen by the development of a Code of Good Practise by the Bangor Mussel Producers.

This study has explored techniques that could be applied to mussel seed after dredging and before subsequent relaying in order to selectively kill slipper limpets whilst leaving the mussel seed largely unaffected. The basis for the trials has been to exploit biological differences between bivalves (such as mussels) which shut their shells during adverse environmental conditions and gastropods (such as the slipper limpet) which cannot remain as well isolated. Brine dipping to kill slipper limpets has been advocated as a control measure for slipper limpets since the 1950's. The trials carried out in the present study have treated slipper limpets and mussels with brine under immersion/soak conditions (5 minutes; 1 hour; 6 hours) as well as through rinse/spray techniques either through a single application or repeated rinse. The treatments were carried out at a variety of temperatures and subsequent exposure times. Data analysis has been performed in order to assess the relative mortality and the size related mortality for both species.

Control tests without the use of brine treatments at ambient and chilled temperatures were designed to emulate the current seed mussel transfer conditions. Mussel mortality for up to 3 days was generally <10% and <5% under ambient and chilled conditions respectively. The highest mussel seed mortality was produced under ambient conditions after 3 days exposure when 17% mortality was found. In contrast, slipper limpet mortality although comparable on Day 0 was elevated relative to mussels on Days 1, 2 and 3. By Day 3 mortality levels were at 30-60% with marginal difference between ambient and chilled conditions. It is also notable that the majority of slipper limpet mortality under Control conditions was within the smaller animals, particularly with increased exposure times. By Day 3 all <20mm slipper limpets, the size predominantly found in surveys of the Menai Straits, were dead within both ambient and chilled conditions.

Brine immersion for periods greater than 5 minutes produced complete 100% mortality of all slipper limpets at all size ranges as shown by the 1hr and 6hr immersion results, even with no subsequent exposure times. However, after Day 3 exposure this immersion period produced a significant increase in mussel mortality of 40-50% under ambient temperatures. Mortality levels after 3 days exposure in chilled mussel samples subject to brine immersion were only slightly elevated over Control levels.

Brine rinsing produced a significant increase in slipper limpet mortality without a marked increase in mussel mortality, even on Day 0. With increased exposure time the slipper limpet mortality increased until nearly 100% mortality was obtained by Day 3. However, few of the larger slipper limpets (>40mm) did survive under chilled conditions. Repeated brine rinsing on a daily basis provided enhanced performance over a single initial rinse without any observable impact on mussel mortality. Although it was relatively easy to obtain 100% slipper limpet mortality in medium and small animals, a few large (>40mm) animals remained alive under chilled conditions. It is probable that increased frequency of rinsing will provide yet more improvements in slipper limpet kill efficacy.

Brine rinsing presents a better operational solution than brine immersion as it would be a more practical to apply to a large mass of mussels. Furthermore, it would greatly reduce the volume of brine required as the same stock could be sprayed or rinsed and the brine re-used in a recirculation system. Further research would be required to assess current industry operational practises with respect to dredging, transporting and relaying of mussel seed

The techniques trialled provide differing mortality levels of slipper limpet kill with only minor impacts on mussel seed viability. It is suggested that treatment levels could be tailored to the sensitivity of the mussel seed movement on a risk assessment basis with respect to the accidental transmission of slipper limpets.

In summary brine rinsing can provide an effective treatment for killing slipper limpets attached to mussel seed. However, before any further work is carried out into developing and testing prototype commercial systems for brine rinsing it is vital that the practical and economic implications for industry of this, or any other treatment methods, are fully evaluated.

1. Overview

1.1 Background

The Slipper limpet (*Crepidula fornicata*) is a species introduced into the UK along with American oyster imports from the United States in the 1800's. This invasive species was first recorded in the UK in 1872 and now extends from Yorkshire to Pembrokeshire (Rayment, 2001). Following transfer from the UK slipper limpets are now also found in Europe with a range covering from the Mediterranean to southern Norway (Sjotun, 1997; ICES, 2005). This has led to the routine screening of mussel imports into Europe for the presence of slipper limpets. In can be seen that this species with its wide environmental tolerances (Rayment, 2001), absence of predators (Thieltges *et al.*, 2004) and the reproductive advantages (Collin, 2001; Rayment, 2001; Richard, 2005 *et al*.) offered by internal fertilisation has proved to be a highly successful invader. Studies over the last 10 years in the Bay of Brest in France have shown that population levels of slipper limpets have gone from isolated pockets of ~400 individuals per m^2 to reports in 2000 of peak concentrations of between 4,000 to 5,000 individuals per m^2 with wide areas covered in >1,000 individuals per m^2 (Guerin *et al.* 2005; Richard *et al*., 2005; CREOCEAN, 2006). These slipper limpets compete for both space and food resources and the pseudo-faeces produced by their filter feeding causes the build up of cohesive 'muds' that have led to devastating changes in marine ecosystems and have in some cases threatened traditional fisheries with complete closure. An example of this is in the Bay of Brest where a major scallop fishery is now estimated to have lost 97% of its harvestable area due to slipper limpets and the remaining grounds are only kept open through intense clearance efforts at considerable cost. Examples of fisheries under threat in the UK include the Fal native oyster fishery (Syvret, 2005) and scallop fisheries around the South West. A detailed review of the potential threat posed by slipper limpets to the UK fishing and aquaculture industries is contained in Appendix C of this report.

Because of the extent of the impact of this invasive species national control measures are needed to ensure that the spread of this species is minimised as far as possible. A study, part funded by Seafish, of the slipper limpet problem in the Fal Estuary has called for a national programme to assess the extent and impact of this species. Of particular concern is the possibility that slipper limpets may be spread through the widespread practise of relaying mussel seed from one area to another. The bottom culture of mussels is by far the UK's biggest aquaculture activity. In terms of shellfish aquaculture in England and Wales, which are dominated by bottom mussel culture, this activity represents almost 90% of total shellfish aquaculture production by weight with a value of around £14 million per year (CEFAS, 2006). The industry is largely based around the movement of mussel seed, often ephemeral in nature (i.e. mussels on offshore beds which are attached more loosely to the substrate in comparison to more permanent, stable intertidal beds), from areas where it may be lost, due to predation or storms, to other areas which are suitable for on-growing and where the stocks can be managed in order to maximise production yields. An example of one of these on-growing areas is the Menai Straits in Wales where mussel seed is regularly dredged from such places as Morecambe Bay or South Wales and then brought back for relaying. The reliance on wild seed for this major industry means that in some years there may not be sufficient local settlement of mussel seed to sustain production. At this stage the mussel farmers will look to source seed from other regions around the UK. There is therefore a danger that seed sourced from areas which may already have slipper limpets such as parts of South Wales or the South coast of England may be transported back to North Wales with slipper limpets attached to the mussels, therefore running the risk that this species will gain a new foothold in another part of the UK.

This current project looks to investigate the extent to which the threat caused by the accidental transport of the slipper limpet can be mitigated or prevented. The trials seek to quantify the time limits of slipper limpet viability once removed from sea water. The conditions under which these investigations have been performed mirror the main environmental conditions experienced during commercial transport of shellfish for relaying. It is hoped that in this way the results emanating from the trials are of direct relevance to the needs of the industry and will therefore be of use in making decisions regarding the extent to which seed stocks from areas affected by slipper limpets can be transported to areas as yet free from this invasive species.

In the summer of 2006 slipper limpets were transferred accidentally with mussel seed to the Menai Strait's mussel fishery. Following discovery in the Spring of 2007 a series of surveys have been performed into the level of the

slipper limpet infestation upon the Menai Straits mussels beds (Morgan, 2007). This study showed that the mitigation efforts to remove slipper limpets from the bed had not been completely successful and that viable animals still remained. A summary of the number and size range of the live specimens found during the April and March 2007 surveys is provided in Table 1.

Table 1 – Summary of Menai Strait Slipper Limpet Size Range

	March 2007 Survey	*April 2007 Survey*
No. <30mm	24	23
No. >30mm	2	3
% <30mm	92.3%	88.5%
% >30mm	7.7%	11.5%
Maximum size	33mm	36mm

In general it should be noted that the size range distribution of the slipper limpets from both surveys revealed that the majority of the specimens were small, with ~90% of animals <30mm in length. The average slipper limpet length on both surveys was 22-23mm in length. The largest specimen found was an empty shell of 39mm. Although the majority of shells found were small and present as single live animals (i.e. not in large 'chains') a high proportion of animals were egg brooding females. As slipper limpets reproduce by internal fertilisation it is clear that many of the slipper limpets (particularly the smaller males at the end of the chains) died during the operation. It is however unknown what proportion died during the dredging or the transfer. It is probable that the combined stress of both operations will have weakened animals within a chain allowing the chain to break up and exposing dead or vulnerable animals to subsequent scavenging or predation.

1.2 Project Outline

As series of mortality trials were undertaken throughout the autumn of 2007 in order to test different variables. An outline of the trials is detailed in Section 2.2 and summarised in Table 2.

Table 2 – Summary of Slipper Limpet and Mussel Mortality Testing

Test	**Dates**	**Species**	**Number of Test Conditions Assessed**	**Variables** ***(Note 1)***	**Details**
A	21/09/07 to 25/09/07	S&M	10	Ranging tests: brine soaking and rinsing	Table 3
B	24/09/07 to 28/09/07	S&M	6	Exposure period and repeated brine rinse	Table 4
C	07/12/07 to 11/12/07	M	6	Temperature and size	Table 5

Note 1: All trials undertook Controls for test conditions

Test A was intended as a ranging trial to assess a number of conditions against the Control whereas the main conditions in Test B were focussed upon assessing and improving the efficacy of brine rinsing as the best overall treatment solution. Test C conditions were aimed at assessing the potential sensitivity of the 'host' mussels to brine rinsing.

1.3 Previous Studies

Walne (1956) undertook an extensive study of the biology and distribution of slipper limpets in Essex estuaries which also included some mortality related components. This paper incorporates comprehensive work by MAFF from 1947-1952 on the slipper limpet including a series of temperature mortality and feeding experiments of relevance to this study.

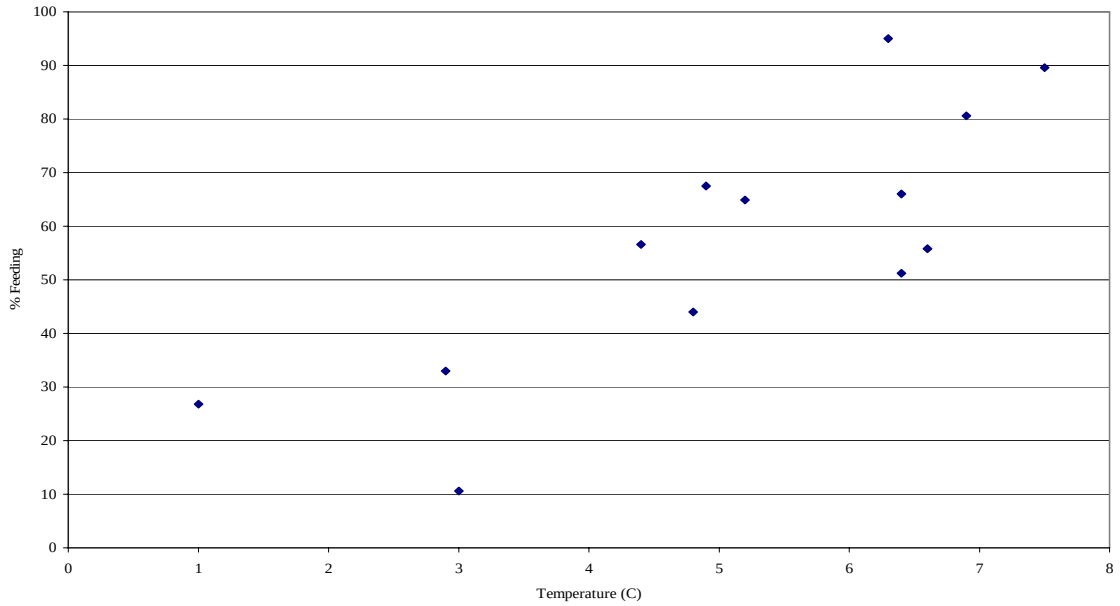
1.3.1 Shell Closure upon Exposure

Mussels and slipper limpets are able to seal themselves shut when removed from the water. Both species however continue to 'weep' water with exposure with some partial shell opening. The basis of any means to preferentially kill slipper limpets over mussels is the assumption that mussels can seal their shells better than slipper limpets and therefore resist exposure longer.

Walne (1956) compared the digestion of slipper limpets and mussels and noted that whilst mussels have a short gut residence time slipper limpets have a much longer digestion period. This means that stored mussels do not excrete faeces into the mantle cavity, whereas slipper limpets continue to excrete faecal pellets. Critically, with the slipper limpet this requires partial opening of the shell thus exposing the slipper limpet and losing some moisture. Furthermore, Walne showed that slipper limpets continue to excrete faeces after removal from the water even at low temperatures. Figure 1 represents Walne's work which shows that feeding took place even at temperatures as low as 1ºC with excretion at air temperatures of 1.1ºC to 7.5ºC.

Figure 1 suggests that even refrigerated slipper limpets will continue to digest food and partially open their shells. As this does not happen with mussels there is a potential mechanism that could be exploited to preferentially kill the slipper limpets.

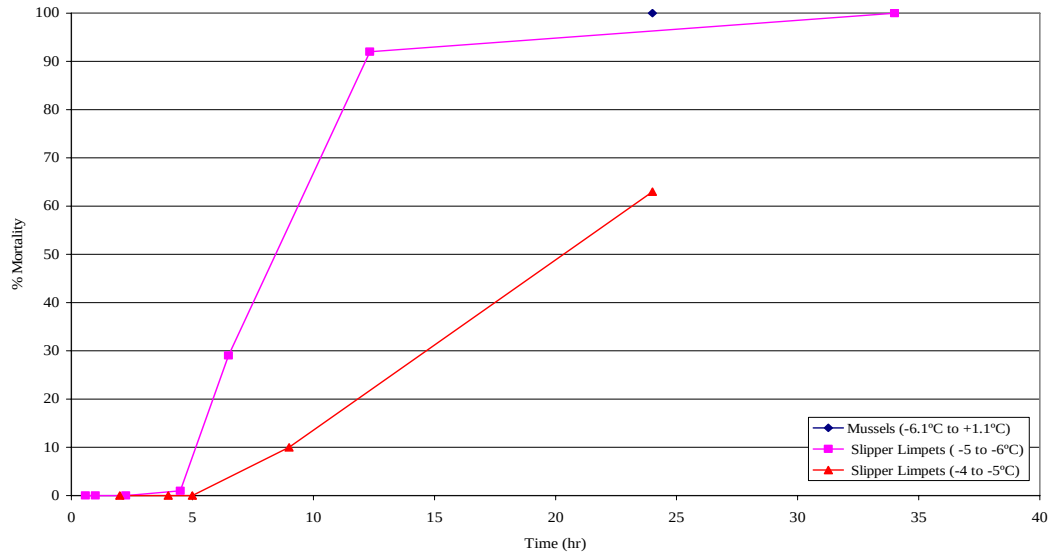
Figure 1: Slipper Limpet Temperature Related Feeding Rates (Walne, 1956)



1.3.2 Temperature Impact on Mortality

Walne (1956) subjected slipper limpets to a series of air exposure tests under freezing conditions to establish survival times. Figure 2 presents the results which show that little mortality is produced in less than 5 hours and that the majority of animals are killed within 24hrs. Walne concluded that mortality was a function of the time taken to freeze flesh contents which was considered comparable to that of mussels. Walne used 'large' slipper limpets for this test as he observed that the smaller slipper limpets were killed more rapidly owing to their thinner shells. Interestingly an ambient temperature Control was run for 7 days after which no mortality was recorded. Although it is probable that smaller slipper limpets would not have survived so well this study showed that large slipper limpets can survive out of water for a significant period.

Figure 2: Slipper Limpet Low Temperature Related Mortality (Walne, 1956)



Observations of natural mortality related to temperature events were also made. The Crouch and Roach Estuaries characteristically suffer cold winter monthly minima of 2-5ºC although the exceptionally cold winter of 1946-47 gave rise to extensive ice covering for several weeks followed by a salinity drop with the snow thaw and a corresponding drop in slipper limpet density with virtual elimination in the upper estuary reaches. It is uncertain to what degree these prolonged low temperatures may have killed the slipper limpets and whether the reduced salinity may have also been a factor.

1.3.3 Active Pesticides

Historically, the use of mercuric chloride has been proposed as an effective means of killing slipper limpets (Cole, 1952). Although this was advocated by MAFF in the 1950's this was prior to the full realisation of the toxic properties of heavy metals and would not be considered today. As the host mussels are ultimately for human consumption it has been decided that no active pesticides will be considered for mortality trials in this study.

1.4 Scope of Report

This study relates previous studies of slipper limpet biology to a series of trials assessing simple cost effective methods to try and kill slipper limpets preferentially to mussel seed. Although this report is set within the context of recent seed mussel transfers with associated slipper limpets it is not intended as a specific risk assessment of the Menai Strait incursion.

Results for a range of test variables from the testing undertaken upon mussel seed and slipper limpets have been presented in a series of summary tables and plots. This report interprets the output with the aim of formulating a system for the treatment of mussel seed to prevent inadvertent slipper limpet transfer. Recommendations have also been provided for the design of a commercial scale trial.

2. Methodology

2.1 Sample Types and Pre-Handling

A seed mussel sample (for Tests A and B) was obtained from Viviers (UK) Ltd. that was sourced from the south coast in a slipper limpet area. Mussel size ranged from >30mm to <60mm with an average of ~45mm and the vast majority of the sample within the 40-50mm size band. The large size of this seed is indicative that these mussels were probably Year 2 stock.

A second seed mussel sample of smaller size (for Test C) was obtained from Deepdock Ltd. sourced from the Menai Strait following a recent introduction of seed mussel. These mussels ranged from >10mm to <40mm with an average of ~25mm with the majority of the sample within the 20-30mm size range. This smaller seed was probably Year 1 stock and was sought in order to test whether this material was less hardy than the Year 2 stock used in Tests A and B.

The low incidence of slipper limpets on the Test A/B mussels (~1:300) prevented use of the mussel seed sample as a suitable source for slipper limpets (see Appendix B; Plate B1). Slipper limpets were therefore obtained from Carrick Roads in Cornwall known for its high slipper limpet density (FitzGerald, 2006).

Testing was performed at Fort Bovisands harbour in a local scallop hatchery with good access to clean full salinity seawater. Both mussel seed and slipper limpets were acclimatised in full salinity seawater prior to testing (see Appendix B; Plate B2).

2.2 Test Variables

Test A experiments were ranging tests with 10 different conditions and just extremes in exposure times (i.e. Day 0 and Day 3). Test B experiments focussed upon a reduced number of test conditions with an increased incidence of samples over a range of exposure times. Test C addressed mussel sensitivity issues with a reduced number of test conditions and an increased number of test samples.

A summary of the testing regime is provided in Table 2 with a detailed overview listed in Tables 3, 4 and 5 for Tests A, B and C respectively.

2.2.1 Rational and Control Conditions

Section 1.3 provides an overview of some of the key biological differences between slipper limpets and mussels that can be used to kill slipper limpets preferentially over mussels. It was known that slipper limpets are highly susceptible to brine soaks whilst it was anticipated that bivalves' ability for extended valve closure in adverse environmental conditions should make them resistant to such treatments. The concept of the testing was therefore centred around exploring this potential differential in mortality under a range of conditions.

All tests were run alongside Controls which used the same exposure and temperature regime but without the test condition. These Controls are also useful guides to consider the potential mortality effect on both mussels and slipper limpets under the current seed transit conditions (see Section 3.1).

2.2.2 Size Range

Tests A and B were performed on pooled samples with subsequent data analysis for different size ranges (see Section 2.3). In contrast, Test C aimed to test the sensitivity of mussel size to mortality and therefore used x4 size bands which were each subjected to the test conditions. A description of the sample size ranges used is provided in Section 2.1.

2.2.3 Air Exposure

Air exposure ranged from 0 to 3 days with the minimum exposure period modelling the impact of the treatment alone whilst the maximum exposure period modelled the expected maximum time for mussel seed transfer. Day 0 exposure (from Test A) was performed during the ranging trials. The test samples were treated before being placed into recovery with no air exposure (other than Controls).

2.2.4 Temperature

Tests A and B were performed at two temperatures: ambient (12-13ºC) and refrigerated (4-5ºC) to emulate representative storage/transport conditions for mussel seed. Test C performed trials at three temperatures: elevated ambient (16-24ºC), ambient (8-12ºC) and refrigerated (4-5ºC) as this trial was focussed on exploring the sensitivity of mussel seed during 'Summer' conditions.

2.2.5 Brine Soaking

Test A included a range of brine immersion times from 5 minutes to 6 hours with subsequent air exposure from Day 0 to Day 3.

2.2.6 Brine Rinsing

Tests A and B included brine rinses with subsequent air exposure from Day 0 to Day 3 on both slipper limpets and mussels. Repeat rinses (daily) were also performed on both slipper limpet and mussel samples in Test B and for mussels only in Test C.

2.3 Experimental Technique

2.3.1 Sample Number

A range of test variables (Section 2.2) were studied using a test sample of x30 mussel specimens and ~x30 slipper limpets for each test condition in Tests A and B. As slipper limpets were present as 'chains' exactly reproducible sample numbers could not be obtained for each sample. Seed mussels for Tests A and B were within a very limited size range presenting little scope for size banding. In contrast, the slipper limpets were of variable age providing a large variation in size distribution. Efforts were made to try and provide a roughly comparable size range for each test sample.

Seed mussels in Test C were present over a wider size range allowing banding into four size ranges (see Appendix B; Plate B3). Each sub-sample of around x30 animals was initially sorted using a visual size grader. Detailed size measurements with vernier callipers were performed on each sub-group following testing.

2.3.2 Sample Containment

All samples were retained in partitioned trays with 0.5mm mesh bases and clip sealable lids also with a 0.5mm mesh (see Appendix B; Plate B4). These trays could be appropriately labelled and stacked either in the test area (for ambient conditions) or within a chiller (at minimum setting for refrigerated conditions). These trays were also used for test animals whilst in recovery as they provide good holding conditions under low stocking densities.

2.3.3 Brine Soaking and Rinsing

A saturated salt solution was made using common salt. Brine soaks were performed by placing the sample trays with their test animals into the solution for the required period before removal and subsequent air exposure (for Day 1-3 tests).

Brine rinses were applied to the relevant test samples using a watering can prior to standing for the appropriate air exposure period. In the case of repeat rinse tests with extended air exposure period further rinses were provided on a daily basis (see Appendix B; Plate B5).

2.3.4 Sample Recovery

Initially recovery was attempted using tanks of clean seawater with bubbled aeration before animal mortality was tested after 1 hour (see Appendix B; Plate B6). In order to ensure that further mortality would not occur in moribund animals the test samples were then returned to the sea overnight before observation of mortality the following day. Although most dead animals were obviously dead prior to recovery a few further deaths were experienced following the extended recovery period. It was therefore decided that all further test samples would be provided with an overnight recovery in the sea (see Appendix B; Plate B7). In order to prevent undue stress from oxygen sag to living animals from already dead specimens, all obviously deceased animals were recorded and removed prior to the recovery immersion.

2.3.5 Sample Measurements and Observations

The size of all animals was measured using vernier callipers to 1mm resolution and recorded directly onto a template spreadsheet (see Appendix B; Plate B8).

Mussel death was registered if the animal could not close its shell upon percussion. Slipper limpet death was registered if an animal could not adhere to its basal connection (see Appendix B; Plate B9). In most cases the slipper limpets were cleanly separated although in some cases dead animals remained 'glued' to a tight fitting base with mucus. If the shells could not be separated with gentle finger pressure they were recorded as still living. In this way it is probable that slipper mortality was in fact under-recorded as it is likely that a number of moribund animals would either be still dying or would not be strong enough to remain attached during mussel seed handling/deployment.

2.4 Data Analysis and Presentation

Mortality rates have been calculated for the total slipper limpet sample as well as the <30mm fraction as this best represents the majority (90%) of the slipper limpets found on the Menai Strait surveys. It should however be noted that only a limited sample number is present in each size band reducing the significance of some results. Furthermore, as it was not possible to provide an equally balanced number of samples over all size bands direct comparison should be treated with caution. However, the differentiation of the sample according to the size banding does provide a good indication of the underlying trends.

Results from Tests A and B have been combined to provide a time series for common conditions using the Day 0 and Day 3 results from Test A and the Day 1, 2 and 3 results from Test B. The two sets of Day 3 results have been averaged. Data for slipper limpets, <30mm slipper limpets and mussels have been presented in Section 3.

Table 3: Test A – Condition Variable Listings

D0 - Initial Ranging, <Day 1 (<24hr)

Condition	Temperature (Note 1)	Brine Exposure	Air Exposure	Test Species (Note 2)	Treatment		Recovery		Comment
					Start	End	Start	End	
1	Ambient	None	6hr	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	Control A
2	Chilled	None	6hr	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	Control B
3	Ambient	Rinse	6hr	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	
4	Chilled	Rinse	6hr	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	
5	Ambient	Soak 5 min	0	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	
6	Chilled	Soak 5 min	0	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	
7	Ambient	Soak 1hr	0	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	
8	Chilled	Soak 1hr	0	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	
9	Ambient	Soak 6hr	0	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	
10	Chilled	Soak 6hr	0	SL & M	21/9/07	21/9/07	21/9/07	22/9/07	

D3 - Initial Ranging, Day 3.

Condition	Temperature (Note 1)	Brine Exposure	Air Exposure	Test Species (Note 2)	Treatment		Recovery		Comment
					Start	End	Start	End	
1	Ambient	None	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	Control A
2	Chilled	None	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	Control B
3	Ambient	Rinse	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	
4	Chilled	Rinse	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	
5	Ambient	Soak 5 min	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	
6	Chilled	Soak 5 min	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	
7	Ambient	Soak 1hr	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	
8	Chilled	Soak 1hr	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	
9	Ambient	Soak 6hr	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	
10	Chilled	Soak 6hr	3 day	SL & M	21/9/07	24/9/07	24/9/07	25/9/07	

Note 1 *Ambient temperature 12-14C*

Note 2 *SL = "Slipper Limpet", M = "Mussel"*

Table 4: Test B – Condition Variable Listings

D1

Condition	Temperature (Note 1)	Brine Exposure	Air Exposure	Test Species (Note 2)	Treatment		Recovery		Comment
					Start	End	Start	End	
1	Ambient	None	1 day	SL & M	24/9/07	25/9/07	25/9/07	26/9/07	Control A
2	Chilled	None	1 day	SL & M	24/9/07	25/9/07	25/9/07	26/9/07	Control B
3	Ambient	Rinse	1 day	SL & M	24/9/07	25/9/07	25/9/07	26/9/07	
4	Chilled	Rinse	1 day	SL & M	24/9/07	25/9/07	25/9/07	26/9/07	
5	Ambient	Daily Rinse	1 day	SL & M	24/9/07	25/9/07	25/9/07	26/9/07	
6	Chilled	Daily Rinse	1 day	SL & M	24/9/07	25/9/07	25/9/07	26/9/07	

D2

Condition	Temperature (Note 1)	Brine Exposure	Air Exposure	Test Species (Note 2)	Treatment		Recovery		Comment
					Start	End	Start	End	
1	Ambient	None	2 day	SL & M	24/9/07	26/9/07	26/9/07	27/9/07	Control A
2	Chilled	None	2 day	SL & M	24/9/07	26/9/07	26/9/07	27/9/07	Control B
3	Ambient	Rinse	2 day	SL & M	24/9/07	26/9/07	26/9/07	27/9/07	
4	Chilled	Rinse	2 day	SL & M	24/9/07	26/9/07	26/9/07	27/9/07	
5	Ambient	Daily Rinse	2 day	SL & M	24/9/07	26/9/07	26/9/07	27/9/07	
6	Chilled	Daily Rinse	2 day	SL & M	24/9/07	26/9/07	26/9/07	27/9/07	

D3

Condition	Temperature (Note 1)	Brine Exposure	Air Exposure	Test Species (Note 2)	Treatment		Recovery		Comment
					Start	End	Start	End	
1	Ambient	None	3 day	SL & M	24/9/07	27/9/07	27/9/07	28/9/07	Control A
2	Chilled	None	3 day	SL & M	24/9/07	27/9/07	27/9/07	28/9/07	Control B
3	Ambient	Rinse	3 day	SL & M	24/9/07	27/9/07	27/9/07	28/9/07	
4	Chilled	Rinse	3 day	SL & M	24/9/07	27/9/07	27/9/07	28/9/07	
5	Ambient	Daily Rinse	3 day	SL & M	24/9/07	27/9/07	27/9/07	28/9/07	
6	Chilled	Daily Rinse	3 day	SL & M	24/9/07	27/9/07	27/9/07	28/9/07	

Note 1 *Ambient temperature 12-14C*

Note 2 *SL = "Slipper Limpet", M = "Mussel"*

Table 5: Test C – Condition Variable Listings

D3

Condition	Temperature (Note 1)	Brine Exposure	Air Exposure	Test Species (Notes 2, 3)	Treatment		Recovery		Comment
					Start	End	Start	End	
1	Elevated Ambient	None	3 day	M (x4 sizes)	7/12/07	10/12/07	10/12/07	11/12/07	Control A
2	Ambient	None	3 day	M (x4 sizes)	7/12/07	10/12/07	10/12/07	11/12/07	Control B
3	Chilled	None	3 day	M (x4 sizes)	7/12/07	10/12/07	10/12/07	11/12/07	Control C
4	Elevated Ambient	Daily Rinse	3 day	M (x4 sizes)	7/12/07	10/12/07	10/12/07	11/12/07	
5	Ambient	Daily Rinse	3 day	M (x4 sizes)	7/12/07	10/12/07	10/12/07	11/12/07	
6	Chilled	Daily Rinse	3 day	M (x4 sizes)	7/12/07	10/12/07	10/12/07	11/12/07	

Note 1 *Ambient temperature 8-12C, Elevated ambient 16-24C*

Note 2 *SL = "Slipper Limpet", M = "Mussel"*

Note 3

Sizes (mm)	Sample Size
0-10	x30
10-20	x30
20-30	x30
30-40	x30

3. Results

3.1 Air Exposure (Control Conditions)

Appendix A lists and plots the mortality results from Tests A, B and C. The ambient and chilled Control condition results, i.e. with no brine exposure, have been extracted and plotted on a common time-base in Figures 3 and 4 below.

Figure 3: Mortality Time Series Under Ambient Control Conditions

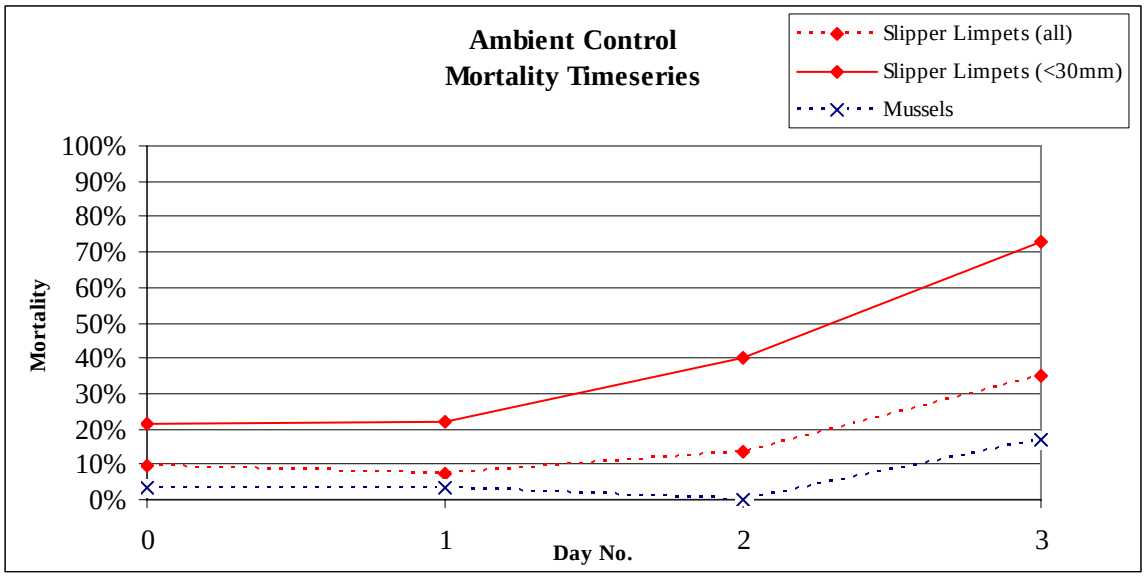
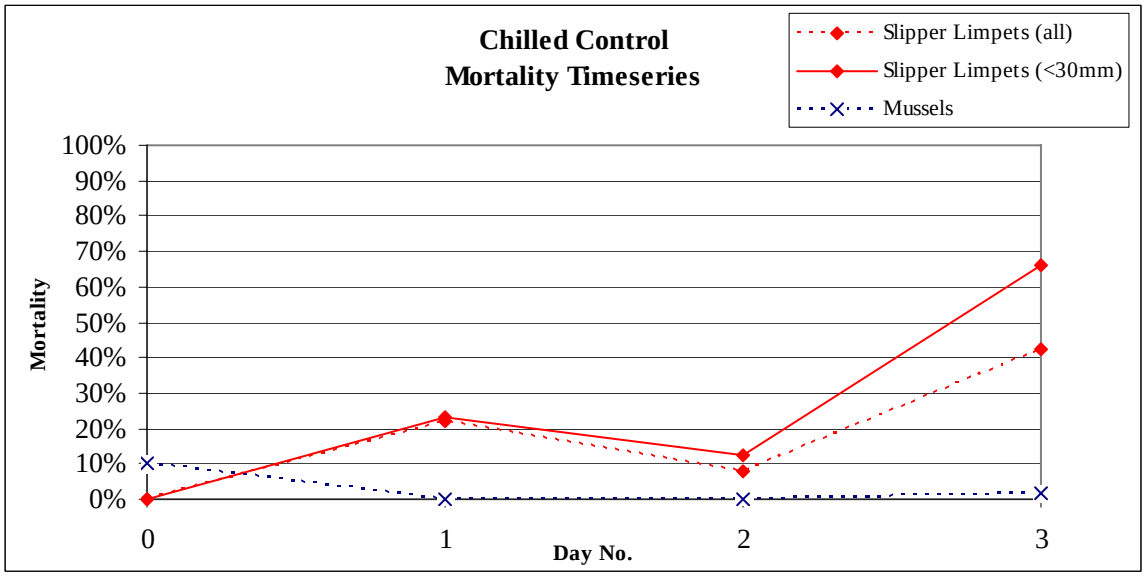


Figure 4: Mortality Time Series Under Chilled Control Conditions



3.1.1 Impact on Mussels

A primary requirement for any treatment for mussel seed will be to minimise mussel mortality. Before the impact of any treatment system on mussel seed can be assessed it is important to have a good understanding of the expected mortality of un-treated mussels under 'normal' seed transfer conditions. As seed can be transported either under ambient or chilled conditions a range of Control trial conditions were run in parallel for all tests.

Figures 3 and 4 show that mussel mortality did not greatly increase over a 3 day test period under both ambient and chilled conditions. Mortality rates within this period were generally <10% and <5% under ambient and chilled conditions respectively.

The highest mussel seed mortality for the test Controls was produced under ambient conditions after 3 days exposure when 17% mortality was found. This suggests some slight disparity between Test A and Test B with increased mortality in the ambient Control sample relative to the chilled Control sample. Test A, Day 3 (Appendix A; Table A2) provided a 17% : 3% mortality (ambient : chilled), whilst Test B, Day 3 (Appendix A; Table A5) produced a 7% : 0% mortality (ambient : chilled) despite being performed under the same conditions. This apparent difference in a 'duplicate' is despite using the same source stock of mussels under similar ambient temperatures. The increased duration of acclimatisation for the Test B stock providing better reconditioning could be an explanation which could have implications with respect to the handling stress imposed by seed transfer operations.

Test C was specifically conducted to test the sensitivity of the host mussel seed to the impact of variable holding temperatures on a variety of size ranges. Table A6 (Appendix A) shows that mussel seed of all sizes ranges experienced low levels of mortality (<5%) at 'Winter' ambient (8-12ºC) and chilled (4-5ºC) temperatures after 3 days exposure. In contrast, mussel seed of all size ranges suffered a marked increase in mortality under elevated ambient temperatures (16-24ºC) after 3 days storage. There was also evidence that the larger size range of >3cm was more hardy than the smaller mussels with 22% mortality as compared with 35-38% mortality for the smaller size test groups.

3.1.2 Impact on Slipper Limpets

Slipper limpet mortality was elevated relative to mussels on Days 1, 2 and 3. Although there was negligible difference between the two species on Day 0 by Day 3 slipper limpet mortality was at 30-60%. It is also notable that the majority of slipper limpet mortality under Control conditions was within the smaller animals particularly with increased exposure times. By Day 3 all <30mm slipper limpets were dead within both ambient and chilled conditions. Comparison between the ambient and chilled results suggests that higher temperature appears to increase mortality. No slipper limpet mortality results are available under elevated ambient temperatures (Test C was only performed on mussels to test the sensitivity of differing size classes to air and brine exposure).

3.2 Brine Soaking

3.2.1 Impact on Mussels

Test A showed a low level of mussel mortality in relation to brine soaking of chilled samples which was only slightly elevated over Control levels at mortalities of <10% within both Day 0 and Day 3 samples for all soak times (5 minutes, 1 hour and 6 hours).

In contrast, mussels under ambient conditions did suffer some adverse effects from brine soaking. This was not observed in the Day 0 when mortality remained comparable to the chilled samples and the Control (<10%). However, by Day 3 mussel mortality at ambient temperatures has increased to unacceptably high levels with 37%, 47% and 41% mortality for 5 minute, 1 hour and 6 hour soaks respectively. This compared to the ambient Control mortality of 17%. As losses were excessively high it was decided that further brine soaking would not be conducted for Test B.

3.2.2 Impact on Slipper Limpets

Brine soaking for periods greater than 5 minutes produced 100% mortality of all slipper limpets at all size ranges as shown by the 1hr and 6hr immersion results (Appendix A; Table A1), even with no subsequent exposure times. However, after

Day 3 exposure all immersion periods including the 5 minute soak produced a significant increase in mussel mortality of approximately 40-50% under ambient temperatures (Appendix A; Table A2).

3.3 Brine Rinsing

Appendix A lists and plots the mortality results from Tests A, B and C. The ambient and chilled brine rinsing results have been extracted and plotted on a common time-base in Figures 5 and 6 below.

Figure 5: Mortality Time Series Under Ambient Brine Rinsing

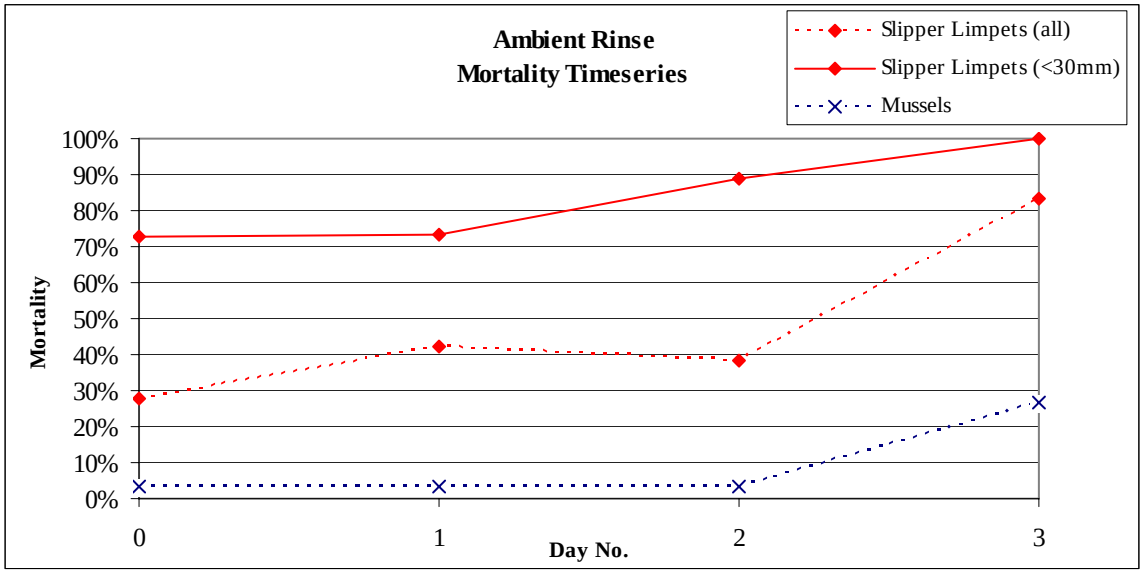
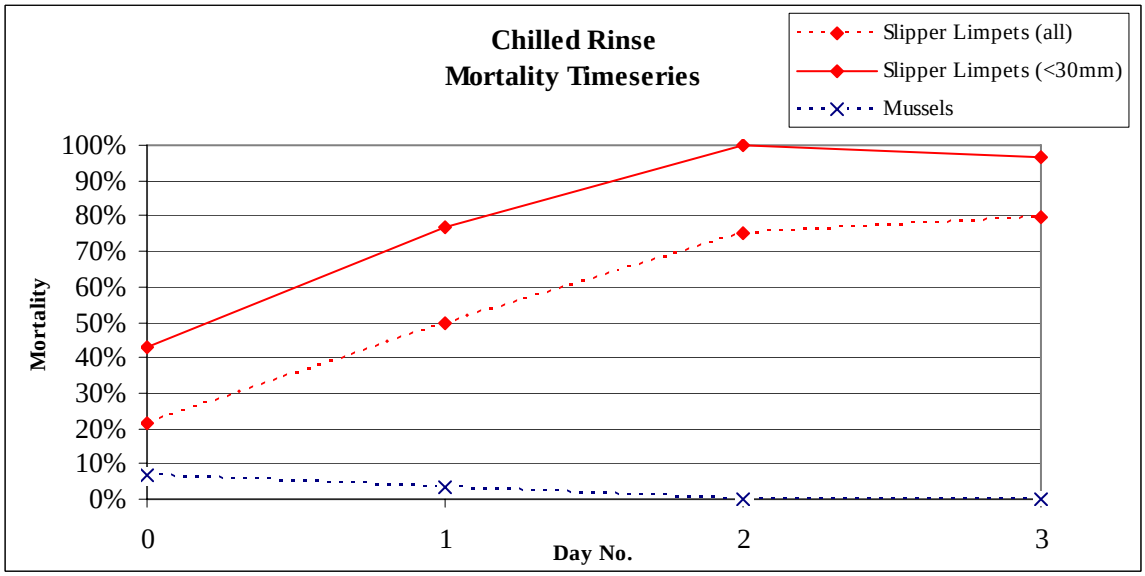


Figure 6: Mortality Time Series Under Chilled Brine Rinsing



3.3.1 Impact on Mussels

Tests A and B showed brine rinsing produced negligible mussel mortality in chilled samples even by Day 3 of exposure. However, there was a low level of mortality for the ambient samples. This was not observed in the Day 0, 1 or 2 samples, yet both the Day 3 exposure Test A and B results showed an elevated mortality. Control : ambient brine rinse mortality ratios of 17% : 30% (Appendix A; Table A2) and 7% : 23% (Appendix A; Table A5) were obtained for Tests A and B respectively.

3.3.2 Impact on Slipper Limpets

Brine rinsing produced a significant increase in slipper limpet mortality without a marked increase in mussel mortality, even on Day 0. With increased exposure time the slipper limpet mortality increased until nearly 100% mortality was obtained by Day 3. However, a few of the larger slipper limpets (>40mm) did survive under chilled conditions (Appendix A; Table A2 and A5). These results are discussed more fully in Section 4.

3.4 Repeat Brine Rinsing

Appendix A lists and plots the mortality results from Tests A, B and C. The ambient and chilled repeated brine rinsing results have been extracted and plotted on a common time-base in Figures 7 and 8 below.

Figure 7: Mortality Time Series Under Ambient Repeat Brine Rinsing

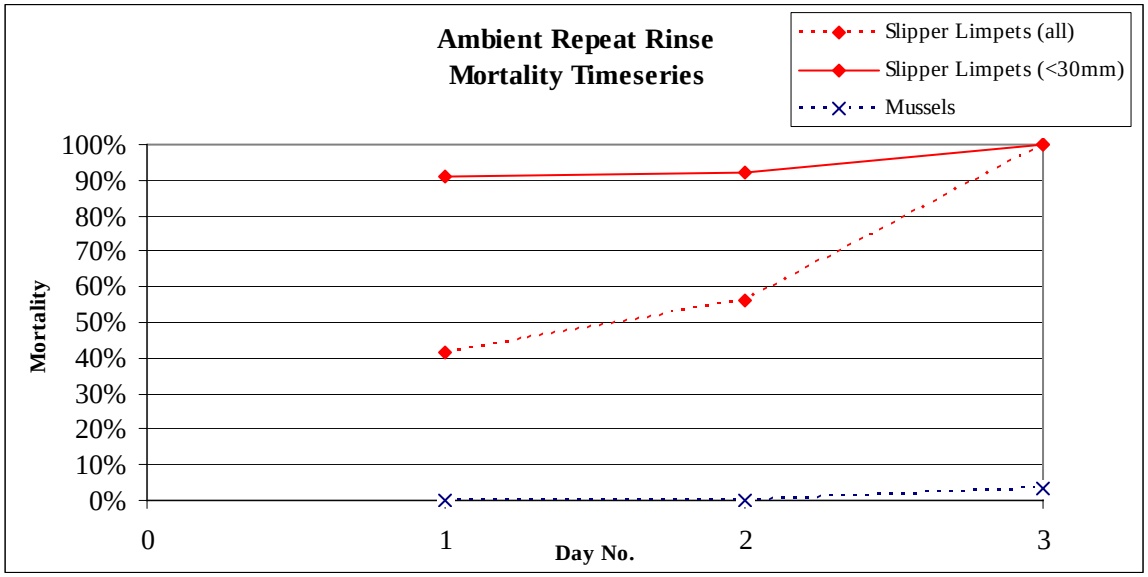
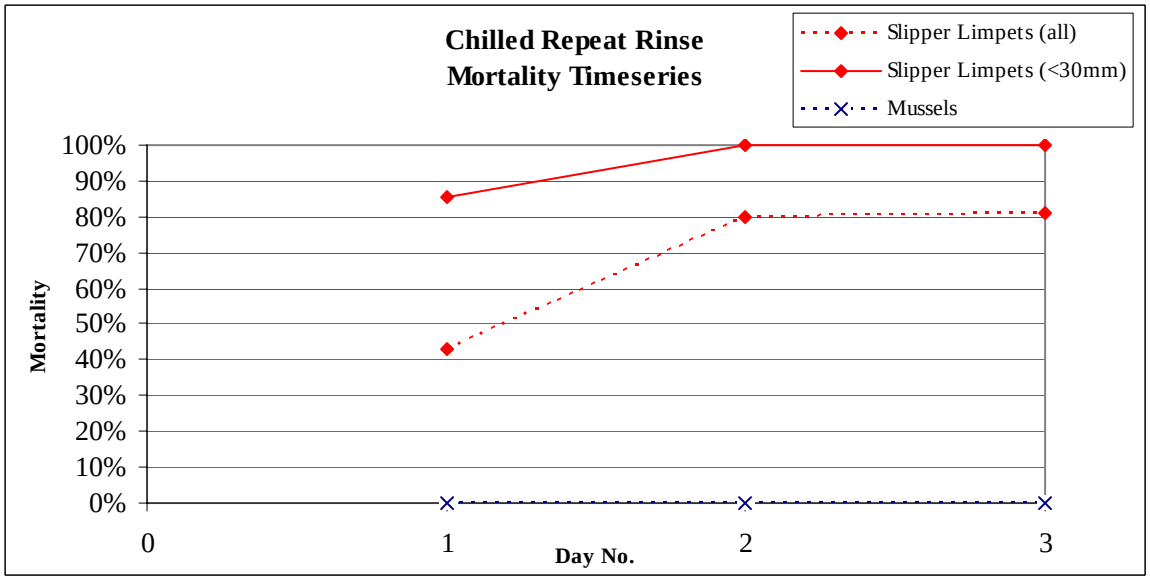


Figure 8: Mortality Time Series Under Chilled Repeat Brine Rinsing



3.4.1 Impact on Mussels

Figures 7 and 8 from Tests A and B show a low level of mussel mortality in relation to repeat brine rinsing over a 3 day monitoring period under both ambient and chilled conditions.

However, mussels subject to elevated ambient temperatures are adversely affected by repeated brine rinsing following a 3 day exposure period. Test C was specifically conducted to test the sensitivity of the host mussel seed to the impact of variable holding temperatures on a variety of size ranges. Table A6 (Appendix A) shows that mussel seed of all sizes ranges experienced low levels of mortality at 'Winter' ambient (8-12ºC) and chilled (4-5ºC) temperatures after 3 days exposure. In common with mussels under 'Control' conditions, mussel seed of all size ranges suffered a marked increase in mortality under elevated ambient temperatures (16-24ºC) after 3 days storage. There was also evidence that at elevated ambient temperatures the larger size range was more hardy than the smaller mussels. In the >3cm fraction, for the Control group, a mortality of 22% was obtained as compared with 35-38% mortality for the smaller size test groups. A similar differential was observed for the repeat rinse group when a mortality of 30% was obtained in the >3cm fraction as compared with 40-48% mortality for the smaller size test groups. The overall repeat rinse mortality averaged 44% as opposed to the Control mortality of 34%.

3.4.2 Impact on Slipper Limpets

Repeated brine rinsing on a daily basis provided enhanced performance over a single initial rinse without any observable impact on mussel mortality. The majority of slipper limpets and virtually all of the <30mm slipper limpets, had been killed by Day 2 under both ambient and chilled conditions (Appendix A; Table A4). However, a few large (>40mm) animals remained alive under chilled conditions even after 3 days (Appendix A; Table A5). It is probable that increased frequency of rinsing will provide yet more improvements in slipper limpet kill efficacy.

4. Discussion

4.1 Potential Risk of Slipper Limpet Survival in Mussel Seed Transfer

A recent transfer of mussel seed to the Menai Strait in 2006 (Morgan, 2007) was subsequently found to have inadvertently introduced slipper limpets. Surveys in 2007 revealed the presence of some living and viable slipper limpets, the majority of which were small (90% <30mm). Remedial action was undertaken to address the removal of infested mussel seed stock followed by the subsequent smothering of any remaining slipper limpets. However, ongoing monitoring is required to demonstrate that this incursion will not lead to a long term population advance of this pest species with its potential for inflicting devastating changes on marine ecosystems (see Section 1.1). The issue has raised concerns about future mussel seed transfers due to the potential viability of slipper limpets following transit.

Although slipper limpets are less hardy than mussels, a significant proportion will survive prolonged air exposure for a number of days particularly if kept cool and dark. Scientific literature (Section 1.3.2) has demonstrated minimal mortality in large animals over several days exposure to air. The results from this trial indicate slipper limpet mortality levels of around one third under both ambient and chilled Control conditions. It should be noted however that the trials were conducted in the late autumn under low ambient temperatures. It is probable therefore that summer ambient temperatures would produce a higher rate of slipper limpet mortality than shown within this study.

This study has also shown that small slipper limpets have a markedly higher mortality level than larger slipper limpets even after only a short duration of exposure to air. In consequence, small slipper limpets directly attached to small mussel seed could therefore be expected to undergo an increased rate of mortality with exposure to air when compared to larger specimens.

Unfortunately, in a slipper limpet infested area, dredged mussel seed could include both small slipper limpets attached to mussels and larger slipper limpets in viable chains. These larger slipper limpets in chains would pose an increased threat due to their ability to carry out the full reproductive cycle.

4.2 Optimal Treatment Regime

There is the potential to reduce the risk of slipper limpet transfer on mussel seed by preferentially killing the pest species without undue loss of the host mussel species by use of an appropriate treatment process. This study has trialled a number of potential treatment regimes using a concentrated brine solution.

A summary of the various treatment options under both ambient and chilled conditions is presented in Figures 9 and 10 respectively.

A brine rinse was effective against most slipper limpets and virtually all <30mm slipper limpets. The repeat rinse provided an increased level of slipper limpet kill with complete removal under ambient conditions. However, even with repeat daily rinsing a low level of survival still persisted in large slipper limpets under chilled conditions. Only the use of brine soaking killed all slipper limpets regardless of size or temperature – this was, however, at the expense of increased mortality in the host mussel seed unless performed under chilled conditions.

Figure 9: Comparison of Mortality Under Ambient Conditions After 3 Days

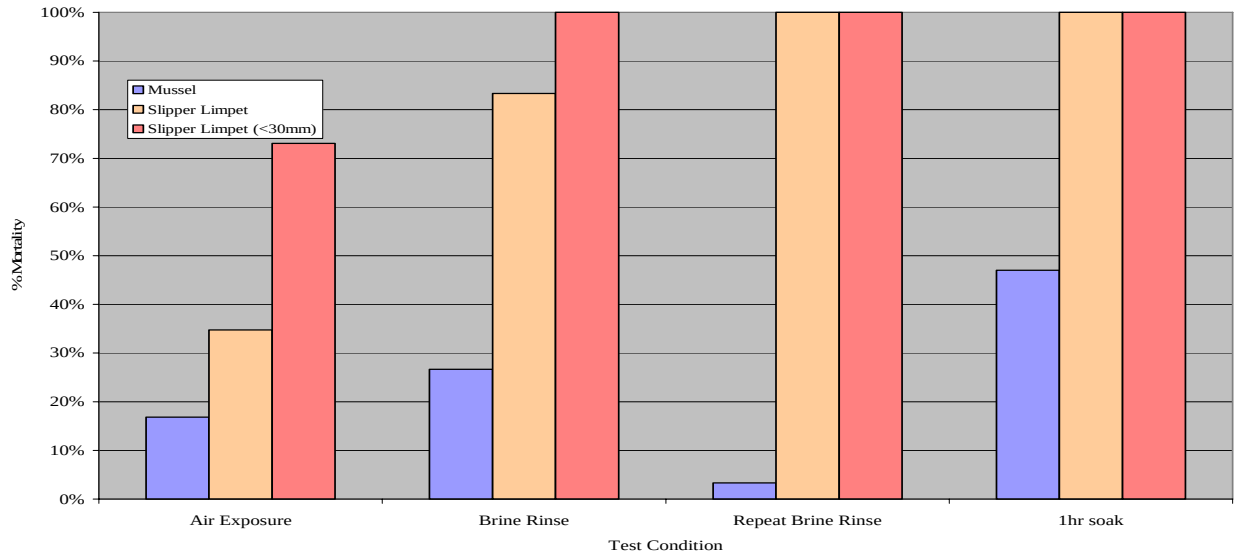
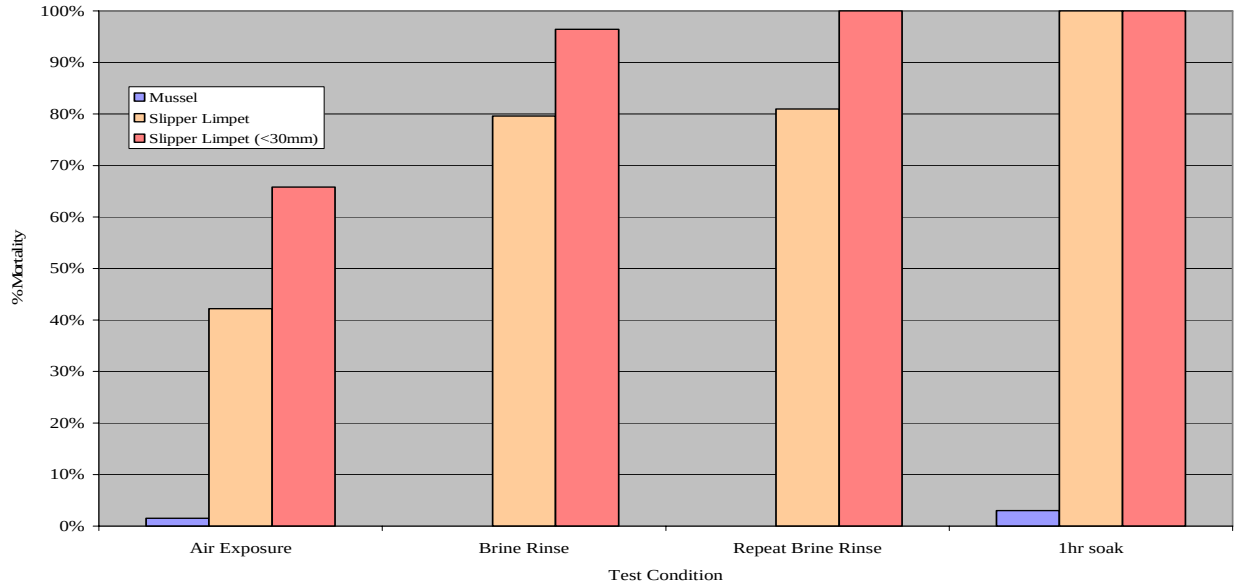


Figure 10: Comparison of Mortality Under Chiller Conditions After 3 Days



Chilling can be used to improve the effectiveness of air exposure mortality on slipper limpets whilst keeping mussel mortality rates at very low levels. Literature studies have shown that slipper limpets are still capable of, and therefore probably still undergo, metabolic activities even at low temperatures. This probably explains why chilling is effective at maintaining mussel condition preferentially over slipper limpets which continue to die.

The potential exists to apply an 'enhanced' repeated brine rinse to provide even greater efficacy if mussel seed is required in sensitive areas. It is probable that performance could be improved for the repeat rinse technique by raising the intensity of rinses from the daily approach used in this study to a more frequent dosing. Alternatively performance could also be improved by pre-screening mussel seed in order to remove larger slipper limpets.

4.3 Potential Treatment System

Although this study has provided a framework of suitable conditions to propose for use in a treatment system, it should be recognised that any technique would need to be easily and cost effectively applied to stock. An overly onerous operational and economic burden on industry has a reduced chance of implementation. For this reason brine soaking is not considered a

practical treatment option as it would require massive volumes of brine, extensive contact tanks and extended seed transit times. In contrast, brine rinsing could be applied to a large stock of mussels either prior to shipment or even whilst in transit using only a small volume of brine via a suitable recirculation system.

A potential brine rinse system would require a spray bar applicator, containment sump to collect drained liquors and a filtered return to a pump. The system could be further enhanced with a repeated rinse option with basic timer controls to the pump. However, the exact configuration of such a system may well need to be tailored to both land based and sea based transfer operations.

Initial investigations into industry practices have been undertaken in order to assess the practicality of utilising a brine rinse system. Land based transfer could offer opportunities for treatment either prior to loading or during lorry transfer. Unfortunately, sea transfer of mussel seed is highly variable in its methodology making it difficult to design a 'standard' system that could be used in this respect. Some operations have in-board holds with drains that could possibly be modified to operate a recirculation system. However, other operators hold mussel seed directly on deck in order that it can be washed off once the vessel has reached the relaying area. Although such transfer vessels could perhaps operate a single pass brine wash they would not be suitable for a more effective brine rinse recirculation system.

The duration of the seed transfer and the holding temperature (ambient Summer/Winter or refrigerated) are significant variables for slipper limpet mortality which require better characterisation before any system design could be produced.

The pre-screening of mussel seed remains another option to remove the hardier larger slipper limpets. Although mussel dredges frequently operate with coarse screening, the use of a finer screen would need careful consideration in order to prevent blinding and operational difficulties.

4.4 Further Requirements

As indicated in the previous section it is recommended that a two stage study is performed that would first characterise industrial seed transfer practises and then assess the economic viability of treating mussel seed to remove slipper limpets. This could then be followed by trials of commercial scale treatment systems if thought worthwhile. The objectives of such a study might include the following:

1. To review current industry practises with respect to dredging of mussel seed and then direct relaying. This aspect of the feasibility study would include a review of the equipment and vessels used; volumes of seed dredged; range of geographic movements of seed; timing of seed movements.
2. To review current industry practises with respect to dredging of mussel seed and then transporting for relaying.
3. To design and suggest possible options for prototype treatment equipment that can be applied to the differing methods/practises with respect to movement of mussel seed. These prototypes would be designed to allow multiple rinses with brine where possible and practicable.
4. To suggest a possible strategy for differing levels of treatment following risk assessments of infestation levels and range.
5. To analyse the economic impacts and cost implications of treating mussel seed in order to remove slipper limpets based upon the treatment options identified by the feasibility study.

Any proposed commercial treatment systems might well require adaptation to both land based and ship seed transfer. Large scale treatment efficacy could be tested on larger slipper limpet samples immersed in the middle of a bulk mussel seed shipment which may yield slightly different results to the current test trials reported here. The potential exists for increased slipper limpet mortality by the use of an enhanced brine rinse with a more frequent dose than the daily repeat rinse reported in this study. Enhanced brine rinsing efficacy could also be achieved through mussel seed pre-screening although this technique would also require sea trials.

In addition to the technical issues outlined above, management options (Section 4.5) will be strongly influenced by the level of perceived risk posed by mussel seed movements. For a meaningful risk assessment it is vital to review and monitor the geographical distribution and density of slipper limpets within UK waters. This could include baseline monitoring of offshore ephemeral mussel deposits once stocks have been located. The report covering work on the slipper limpet infestation in the Fal (FitzGerald, 2006) called for a National Slipper Limpet Study to address this issue as anecdotal / sighted slipper limpet occurrences exceed current reported findings. For a review of the potential impact of slipper limpets on UK fishing and aquaculture industries and recommendations for further work in this respect see Appendix C of this report.

4.5 Management Options

Treatment of mussel seed would have time and cost implications for industry. Furthermore, more aggressive treatment strategies with higher kill certainties will impose greater losses to the host mussel shipment. In consequence, any potential management option to treat mussel seed would need to be appropriate to the level of risk posed by the shipment. It is suggested that a possible hierarchy of risk could be based around the presence/absence of slipper limpets and the designation of the receiving waters. A discussion template is suggested below:

Table 6: Potential Mussel Seed Transfer Management Options to Address Slipper Limpet Infestation

Condition	*Risk*	*Dredge Source*	*Relay Destination*	*Management Option*
1	Low risk	SL free	SL present	No action
2	Low risk	SL free (Note 1)	SL free	No action
3	Intermediate	SL present	SL present	Brine rinse
4	Intermediate	SL present	SL present (+SAC)	Brine / Enhanced rinse (Note 2)
5	Moderate	SL present	SL free	Enhanced rinse (Note 3)
6	High	SL present	SL free (+SAC)	Movement restricted (Note 4)

Note 1: 'SL free' status is subject to knowledge of the source area (i.e. could still pose some risk).
Note 2: Enhanced rinse is likely to provide a higher SL kill rate but with either greater collateral damage to mussel seed or greater costs.
Note 3: Subject to individual risk assessment. Risk relative to SL abundance.
Note 4: Subject to individual risk assessment. Seed movement from SL free possible (Condition 2).

5. Summary

Brine soaking and brine rinsing were tested as treatments against Control conditions on slipper limpets and mussels in order to test differential mortality. Temperature and exposure times were varied and mortality measured for a number of size ranges.

The use of brine soaking effectively kills all slipper limpets, although it would present operational difficulties in application and potentially an unacceptable burden of loss in the mussel seed. Brine rinsing is effective in killing slipper limpets (particularly smaller animals) and might be a technique that is possible to cost effectively apply in a commercial context.

Potential brine rinsing treatment protocols could be developed to preferentially kill slipper limpets on mussel seed (Section 4.2). Subject to the resolution of outstanding trial needs (Section 4.3) this technique could be an effective management tool for mussel seed movements in order to limit slipper limpet movements and introductions. In order for any such protocols or prototype systems to be developed further research would be needed to identify the different operational practises used by industry to dredge, transport and then relay mussed seed.

Discussions with industry have highlighted their concerns as to the economic and practical implications of adopting treatment methods such as brine rinsing. As mentioned in Section 4.4 careful consideration would therefore have to be given as to the economic impacts of introducing treatment methods to remove slipper limpets from mussel seed prior to or during transport to a relaying area.

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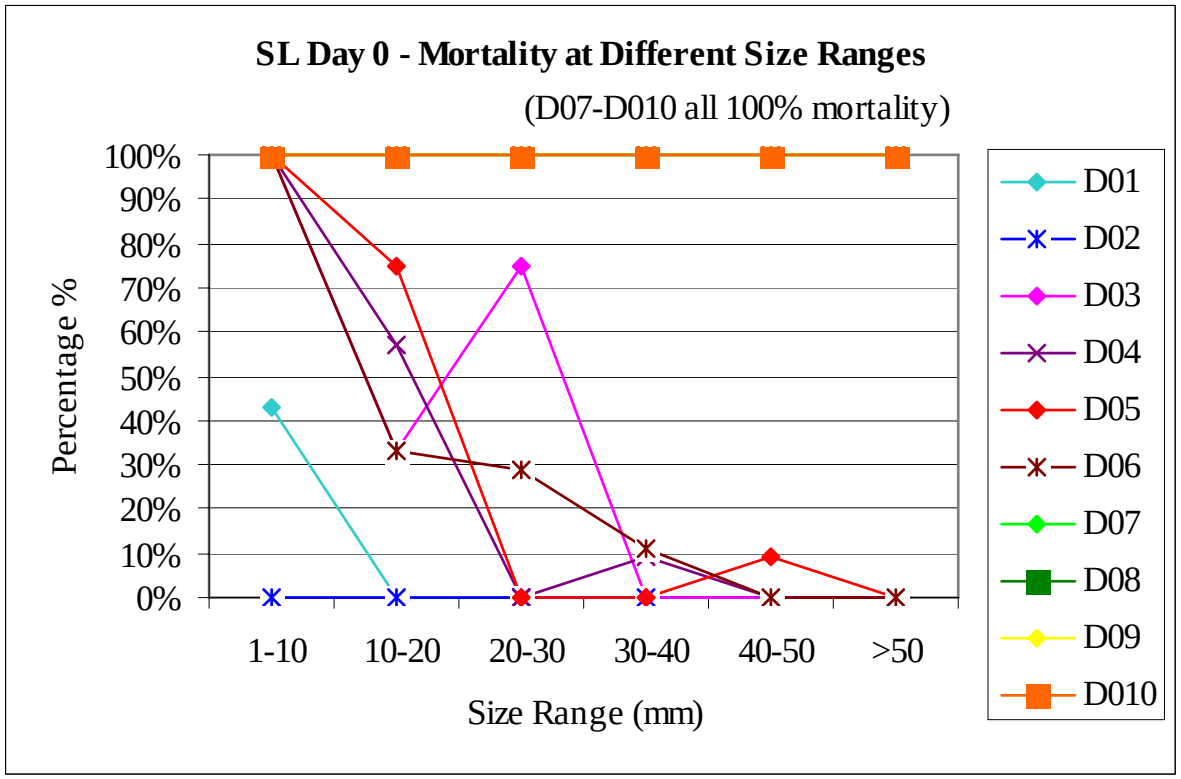
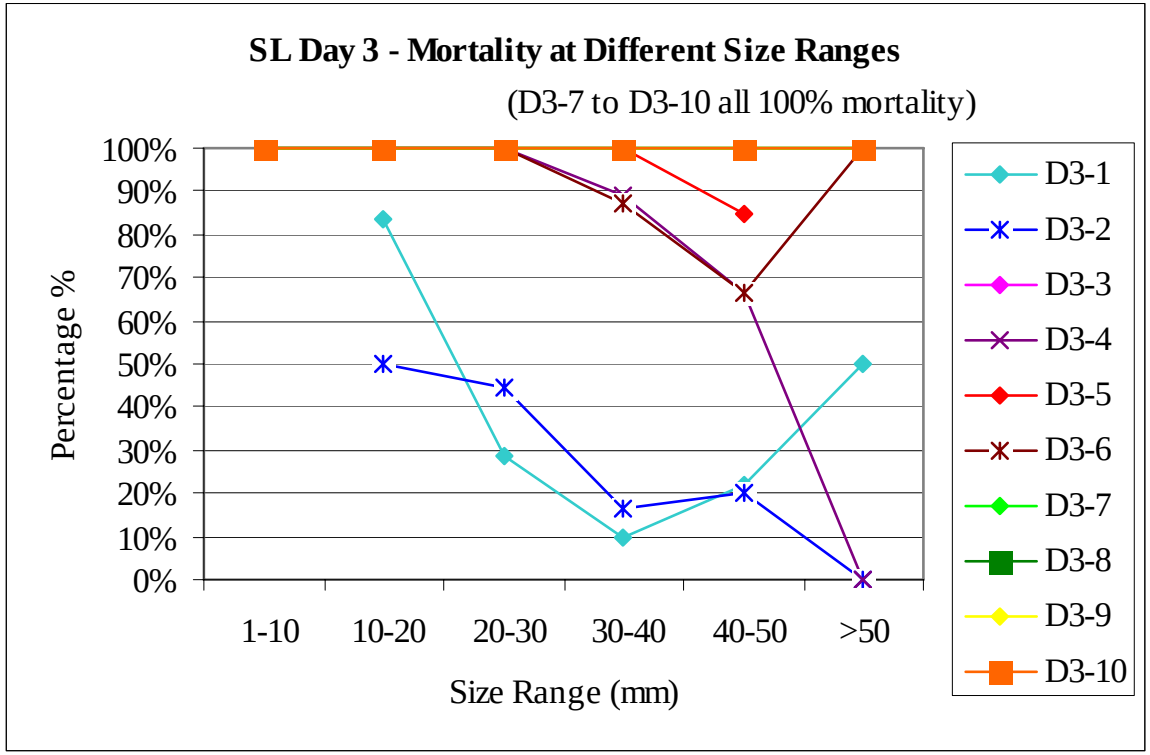
Appendix A : Test Results: Table A1 – Test A, Day 0 (D0) Summary Results

Condition	D01	D02	D03	D04	D05	D06	D07	D08	D09	D010
Temperature	Ambient	Chilled	Ambient	Chilled	Ambient	Chilled	Ambient	Chilled	Ambient	Chilled
Brine Exposure	None	None	Rinse	Rinse	Soak 5 min	Soak 5 min	Soak 1hr	Soak 1hr	Soak 6hr	Soak 6hr
% Slipper Limpet mortality	9%	0%	28%	21%	24%	22%	100%	100%	100%	100%
% Mussel mortality	3%	10%	3%	7%	7%	10%	3%	10%	10%	0%
Slipper Limpet All Av. (mm)	29.1	29.3	29.7	29.6	31.2	30.5	27.5	30.5	27.1	31.4
Slipper Limpet Live Av. (mm)	31.4	29.3	35.2	33.3	36.5	34.3	N/R	N/R	N/R	N/R
Slipper Limpet Dead Av. (mm)	7.2	N/R	15.4	15.7	14.9	16.9	27.5	30.5	27.1	31.4



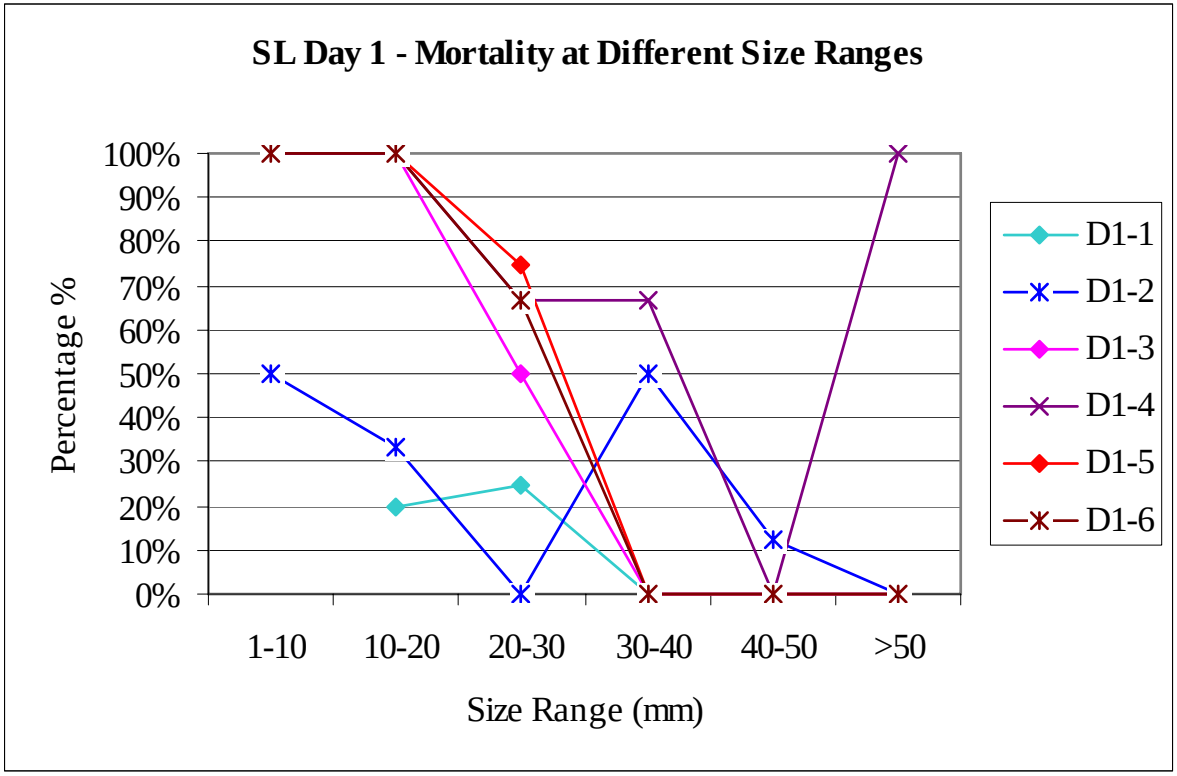
Appendix A: Table A2 – Test A, Day 3 (D3) Summary Results

Condition	D3-1	D3-2	D3-3	D3-4	D3-5	D3-6	D3-7	D3-8	D3-9	D3-10
Temperature	Ambient	Chilled	Ambient	Chilled	Ambient	Chilled	Ambient	Chilled	Ambient	Chilled
Brine Exposure	None	None	Rinse	Rinse	Soak 5 min	Soak 5 min	Soak 1hr	Soak 1hr	Soak 6hr	Soak 6hr
% Slipper Limpet mortality	32%	31%	100%	84%	93%	88%	100%	100%	100%	100%
% Mussel mortality	17%	3%	30%	0%	37%	3%	47%	3%	41%	10%
Slipper Limpet All Av. (mm)	32.5	32.8	28.3	31.7	33.7	30.0	32.4	35.5	34.0	33.9
Slipper Limpet Live Av. (mm)	36.2	34.4	N/R	45.0	45.4	44.0	N/R	N/R	N/R	N/R
Slipper Limpet Dead Av. (mm)	27.1	26.8	28.3	29.2	32.9	28.1	32.4	35.5	34.0	33.9



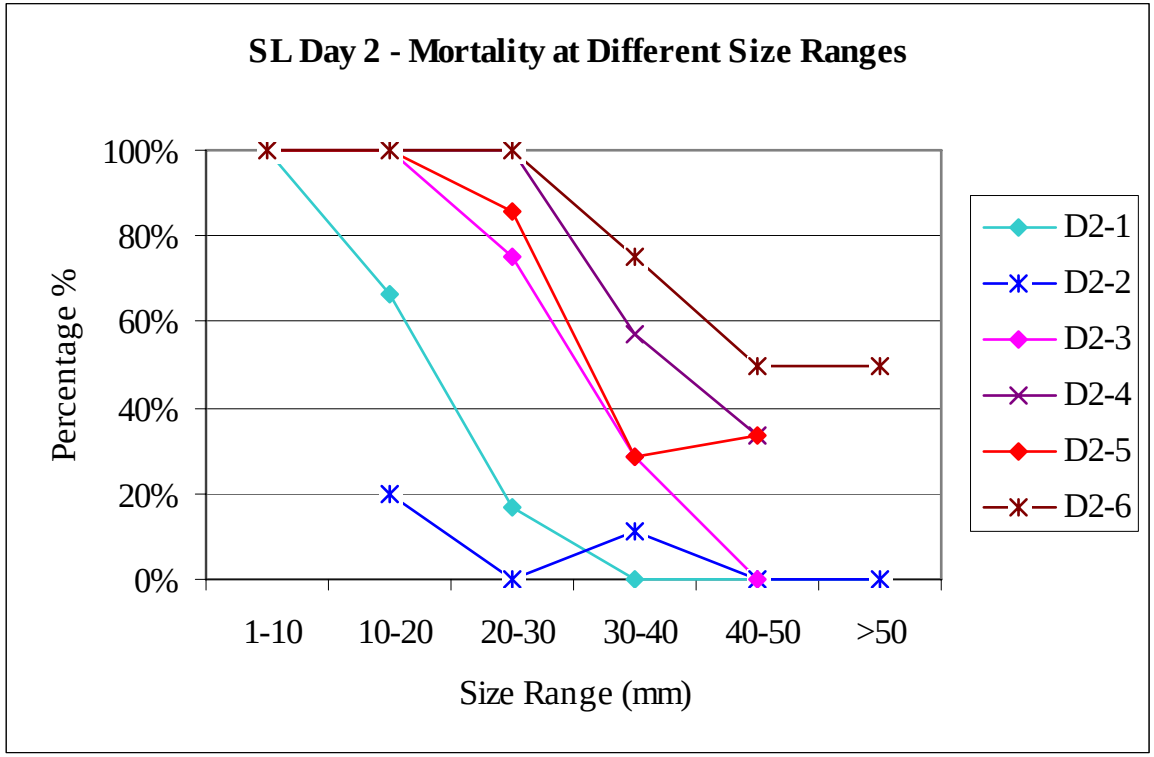
Appendix A: Table A3 – Test B, Day 1 (D1) Summary Results

Condition	D1-1	D1-2	D1-3	D1-4	D1-5	D1-6
Temperature	Ambient	Chilled	Ambient	Chilled	Ambient	Chilled
Brine Exposure	None	None	Rinse	Rinse	Rp Rinse	Rp Rinse
% Slipper Limpet mortality	7%	22%	42%	50%	42%	43%
% Mussel mortality	3%	0%	3%	3%	0%	0%
Slipper Limpet All Av. (mm)	33.6	30.9	29.9	32.1	32.6	29.5
Slipper Limpet Live Av. (mm)	34.6	32.5	38.9	39.9	42.1	38.6
Slipper Limpet Dead Av. (mm)	20.2	25.3	17.7	24.3	19.3	17.4



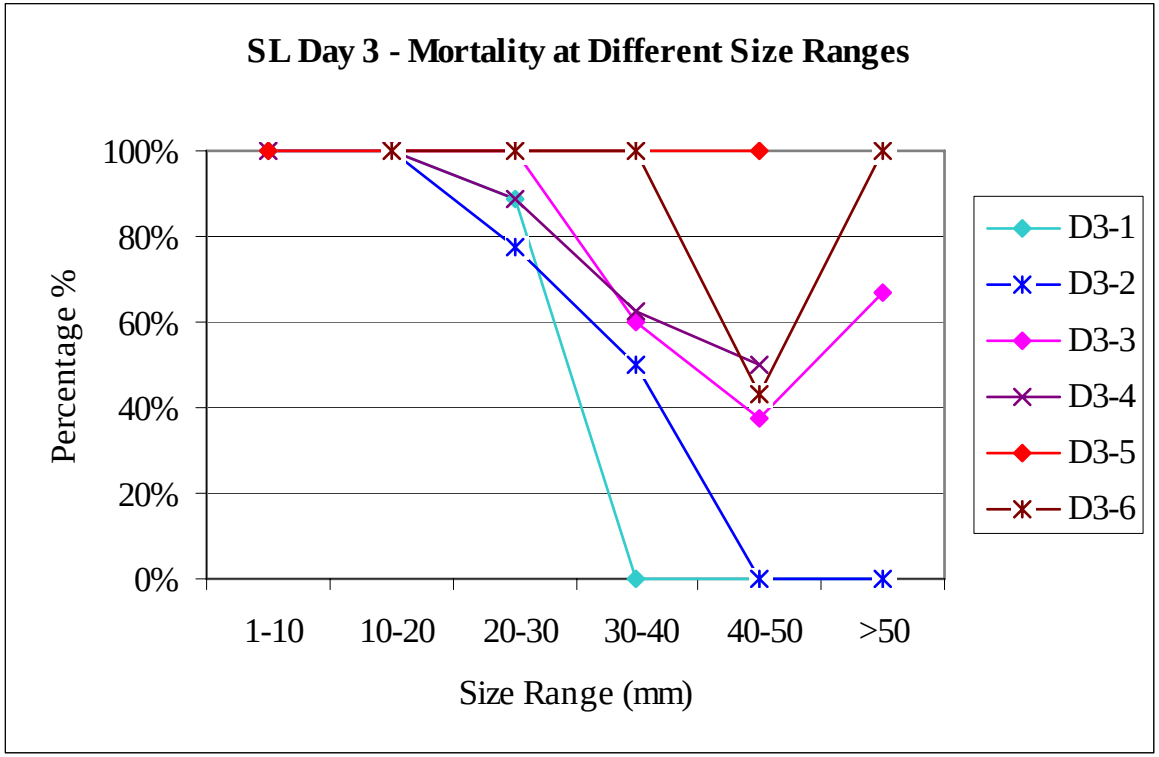
Appendix A: Table A4 – Test B, Day 2 (D2) Summary Results

Condition	D2-1	D2-2	D2-3	D2-4	D2-5	D2-6
Temperature	Ambient	Chilled	Ambient	Chilled	Ambient	Chilled
Brine Exposure	None	None	Rinse	Rinse	Rp Rinse	Rp Rinse
% Slipper Limpet mortality	14%	8%	38%	75%	56%	80%
% Mussel mortality	0%	0%	3%	0%	0%	0%
Slipper Limpet All Av. (mm)	32.2	32.2	33.0	26.3	30.6	30.5
Slipper Limpet Live Av. (mm)	35.0	33.0	40.8	37.8	38.0	44.4
Slipper Limpet Dead Av. (mm)	15.0	23.0	20.7	22.5	24.8	27.0



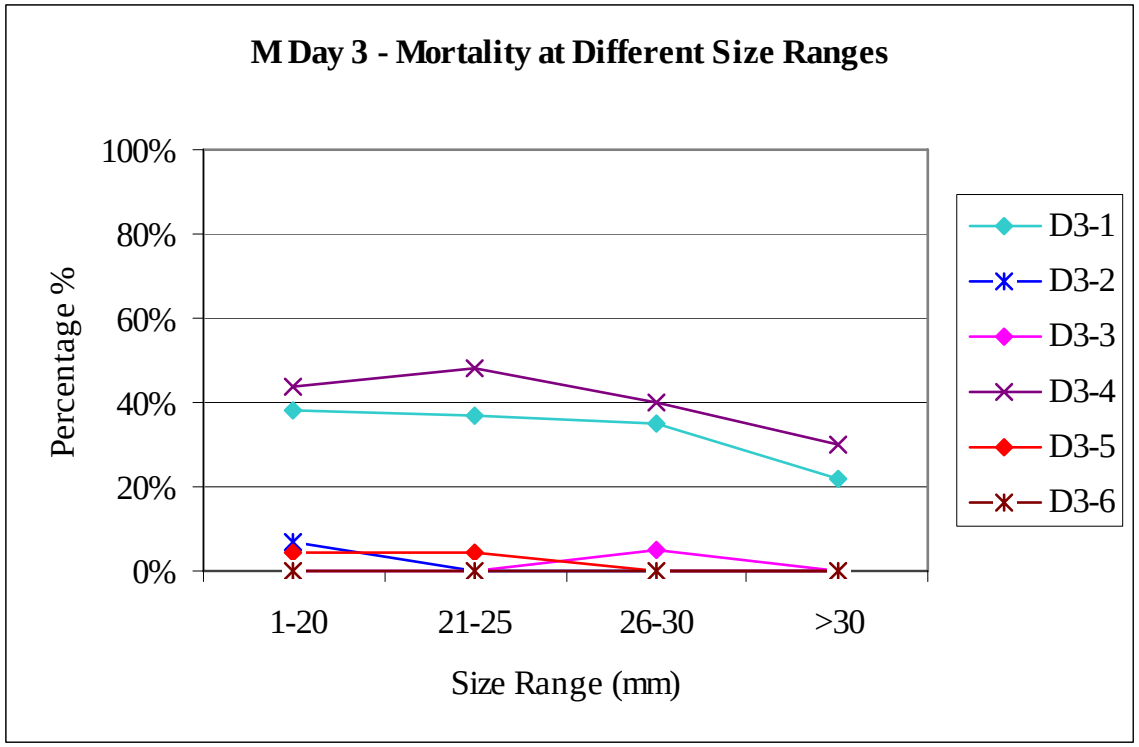
Appendix A: Table A5 – Test B, Day 3 (D3) Summary Results

Condition	D3-1	D3-2	D3-3	D3-4	D3-5	D3-6
Temperature	Ambient	Chilled	Ambient	Chilled	Ambient	Chilled
Brine Exposure	None	None	Rinse	Rinse	Rp Rinse	Rp Rinse
% Slipper Limpet mortality	38%	54%	67%	75%	100%	81%
% Mussel mortality	7%	0%	23%	0%	3%	0%
Slipper Limpet All Av. (mm)	33.4	30.5	33.7	29.3	30.6	33.2
Slipper Limpet Live Av. (mm)	41.4	39.4	44.8	37.1	N/R	44.3
Slipper Limpet Dead Av. (mm)	20.0	22.9	29.2	26.7	30.6	30.6



Appendix A: Table A6 – Test C, Day 3 (D3) Summary Results

Condition	D3-1	D3-2	D3-3	D3-4	D3-5	D3-6
Temperature	E. Ambient *16-24ºC*	Ambient *8-12ºC*	Chilled *4-5ºC*	E. Ambient *16-24ºC*	Ambient *8-12ºC*	Chilled *4-5ºC*
Brine Exposure	None	None	None	Rp Rinse	Rp Rinse	Rp Rinse
% Mussel mortality	34%	2%	1%	44%	3%	0%



Appendix B : Trial Photographs

Plate B1; Example of slipper limpet found on mussel seed during Tests A/B	**Plate B2; Mussels and slipper limpets being acclimatised in full salinity seawater**
Plate B3; Example of one size band (26 – 30mm) of seed mussels from Test C	**Plate B4; Example of partitioned trays used in trials**

Plate B5; Trays containing mussels and slipper limpets during trials	**Plate B6; Tank used for initial recovery of treated mussels and slipper limpets**
Plate B7; Treated trays ready for overnight recovery in seawater	**Plate B8; Example of slipper limpets after treatment**

Plate B9; Dead slipper limpet following treatment

Appendix C : Overview of UK Slipper Limpet Impact

Status of & Threat to the UK Fishing & Aquaculture Industries Posed by the Slipper Limpet

C.1 Overview

The current status and threat posed by slipper limpets to UK fisheries was reviewed by FitzGerald (2006). This study assessed the UK slipper limpet data in the context of the population dynamics and impact observed in France over the last couple of decades. The following section summarises the FitzGerald (2006) report and includes some recent developments in this respect.

At first impression the slipper limpet does not appear to be a significant threat to UK fisheries – it does not directly kill the target species and has been present in UK waters for over a hundred years. This perception is however flawed in two respects:

> -The unusual reproductive biology of the slipper limpet is its weakness in initially becoming established but its strength when spreading once it has become established. It therefore takes time before a 'critical mass' is obtained.
>
> -The past is not an indicator for the future. Climate change with the potential for warmer summer temperatures in nearshore waters gives the slipper limpet a significant advantage over broadcast spawners such as the commercial bivalves. Furthermore, there is some evidence that water quality improvements are more likely to benefit slipper limpets than bivalves.

These two features in harmony coupled with anecdotal reports from a number of fisheries would suggest that the slipper limpet population in the UK is increasing. To obtain an objective assessment of the threat posed by slipper limpets to UK interests it is insufficient to only consider the current level of infestation and its impact. It is therefore necessary to review the UK status in the context of European case studies from Brittany and the Waddensea where slipper limpets reach super-abundance levels in order to consider the potential impact that the UK could experience.

The temperature regime of much of the southern UK falls within the same temperature regimes experienced between Brittany and the Waddensea suggesting that the pattern of colonisation experienced off mainland Europe could be repeated in UK waters.

Table C.1 – Overview of Nearshore Temperature Ranges in UK and Europe

Area	Location	Temp Range
Eastern Channel	UK – Essex Estuaries	~2C° to 20°C, (Walne, 1956)
	Europe – Waddensea	2.7C° to 18.1°C, (Thieltges *et al*., 2003)
Western Channel	UK – Carrick Roads	9.1°C to 17.2°C (FitzGerald, 2003)
	Europe – Bay of Brest	~8.5°C to ~17.5°C (2002), (Richard *et al*., 2005)

C.2 Threat to Commercial Fisheries

Impact on commercial fisheries can be significant in reducing income and ultimately threatening fishery viability. The impact of slipper limpets upon different commercial species varies as described in the following sub-sections.

Table C.2 – Overview of Slipper Current Limpet Impact in UK and Europe

Impact on commercial species	Current Impact in UK (given generally low abundance)	Current Impact in some European Sites (super-abundance levels)
Survival / Reproductive Success	Limited*	Limited*
Reduced Growth	Unlikely	Probable
Handling/Processing Difficulties	Limited	High
Dredging Difficulties	Limited**	High

* - *Species specific*

** - *Limited for un-powered vessels and manual hauling*

C.2.1 Survival / Reproductive Success

Generally, slipper limpets, unlike boring drills or tingles, are not perceived as a direct pest as they do not kill commercial species. In some cases slipper limpets have been implicated in reduced success for competitor species by increasing stress and through loss of habitat.

Scallops

Scallops employ an escape response by flapping their shells to swim away if under threat. Slipper limpet settlement upon scallop shells (see figure C.1 below) is likely to significantly compromise the effectiveness of this response.

Figure C.1 – Slipper limpet coverage on scallop shells

Source:
Slipper Limpets on Dredged Scallops – Lower Salcombe Estuary
(Photo: Kevin Oakman)

Scallops occur on sandy bottom sediments where they can partially bury themselves and thus hide in the sediment but can also escape if attacked. Once the seabed is covered with slipper limpets there is nowhere for the scallops to hide leaving them exposed with a resultant increased risk of predation. In consequence, their natural habitat is reduced and their density drops. If scallop biomass is significantly reduced relative to slipper limpet biomass then there is also a risk of reduced scallop reproductive success. A drop in scallop broodstock density (and corresponding spawning success) coupled with a high rate of larvae ingestion by the slipper limpets will limit new recruitment to the fishery.

Mussels

Thieltges (2005[A]) reports that slipper limpet attachment in the Waddenzee reduces mussel (*Mytilus edulis*) survival and growth rates. Reduced growth was attributed to disruption of the benthic boundary layer by slipper limpets thus affecting feeding rates. Growth and mortality levels were also possibly compromised by the increased resources needed in terms of byssus production as the stressed shellfish struggle to maintain attached to their substrate due to the weight of slipper limpet chains on their backs.

Conversely, the same workers in this area showed that the presence of slipper limpets on mussels could

actually reduce the rate of loss through predation (Thieltges, 2005[B]). This was attributed to the shielding of the mussel by the slipper limpets, (although the workers accepted that on a commercial bed if a starfish struggled to open a mussel with a slipper limpet chain on its back it could just move onto an adjacent mussel).

Nehls *et al.* (2006) showed that although increasing numbers of slipper limpets may seem to correspond to decreasing numbers of mussels, both trends were in fact related to increasingly mild winters and that climate change was the function affecting both trends.

Oysters

The Pacific oyster (*Crassostrea gigas*) has a complex external shell structure and is often cultured inter-tidally which places it outside of the slipper limpet's normal habitat range. The native oyster (*Ostrea edulis*) however with its smoother shell and sub-tidal habitat is much more susceptible to slipper limpet coverage. Unlike scallops as mobility is not a significant factor in their survival the attachment of slipper limpets to oyster shells does not impact on oyster survival in the same fashion. Disease resistance was considered a potential conflict yet immuno-competence studies performed on oyster spat in the presence of slipper limpets showed no specific detrimental effect on adult oysters (Hawkins, undated).

There is a complex relationship between slipper limpets and native oysters which is hard to assess in terms of relative reproductive success. For example, it has been observed that while native oyster larvae will settle on empty slipper limpet shell (hence it has been advocated as an oyster cultch) – they are not seen to settle on live slipper limpet shells. In contrast, slipper limpets will settle on oyster shells whether dead or alive. This raises the question as to whether juvenile slipper limpets may graze over newly settled oysters, particularly in heavily infested areas, and therefore directly impact on recruitment to the oyster fishery. This may relate to the differing feeding strategies of the two species which is considered further in Section C.2.2. Further research will be required to properly evaluate these interactions.

Finfish

Slipper limpets have been implicated as a threat to finfish nursery grounds through the loss of habitat. Le Pap *et al.*(2004) describe the threat of slipper limpets on the Bay of Biscay sole fishery which is valued at 40M Euros per annum with a 2003 landing figure of 4,000 tonnes. This paper considers that slipper limpets reduce the availably of soft homogenous sediments for the young sole to feed on and bury themselves in. Trawl studies have shown that 60% of annual recruits for this fishery have nursery grounds in three shallow (<5m depth) coastal areas in southern France which are all infested with slipper limpets. Other commercial species such as bass also use shallow estuarine waters as nursery grounds although it is not known how slipper limpet infestation may impact upon these species.

C.2.2 Reduced Growth

Slipper limpets are widely viewed as a trophic and habitat competitor species. In areas where slipper limpets have become well established their biomass can greatly exceed aquaculture biomass creating direct competition for space and food.

Studies have shown that the particle size range removed by slipper limpets in the filtering process is comparable to that of oysters. This suggests direct trophic competition with bivalves. Indeed the IFREMER research station at Aarchion runs a major study programme to evaluate the degree of trophic competition within the Bay of Mont St Michel where major quantities of slipper limpets are found alongside mussels, Pacific oysters and flat oysters (Blanchard & Hamon, 2006). The IFREMER research programme seeks to assess the trophic balance between 5,000 tonnes of oysters, 10,000 tonnes of mussels and 100,000 tonnes of slipper limpets (now increased to 150,000 tonnes). With x10 greater slipper limpet biomass than commercial species there is concern that growth rates will be reduced.

Analysing competition for food is more complex than just a direct comparison of biomass between

commercial species and pest species – the feeding strategy is also important. Although the slipper limpet is a gastropod, complete with a grazing radula, it is unusual in that it is well known as a sedentary filter feeder. However, unlike bivalves who are filter feeders throughout their life the newly settled slipper limpet is free to roam and graze in a manner similar to many other gastropods. It is probable that only when forced to settle down by its needs for reproduction that the balance of food acquisition switches from grazing to filtering.

Orton (1914) provides a comprehensive account of the filter feeding mechanism within the slipper limpet. The gill creates a cilia driven current allowing food particles to be captured by a mucus sheet before being swept into a sausage-like pellet which is then pushed towards the mouth where it is grazed. Orton describes how the slipper limpet can select other larger detritus which can also be grazed.

It therefore seems apparent that although the majority of its nutrition may be provided through filter feeding the adult slipper limpet retains its ability to graze with its radula. It is possible that the gregarious nature of slipper limpets allows each animal to continue to graze its immediate substrate which, complete with mucus layer, would tend to form a good culture medium. In this way chains of slipper limpets could actually 'watch the back' of their neighbour and graze off other epiphytic growth that may interfere with the normal feeding process of the chain. Furthermore, anecdotal observations from oyster fishermen suggest that although slipper juveniles frequently settle upon oysters the converse is rarely true (Mike Parsons pers. comm.) unless the slipper limpet shells are empty.

Another feeding aspect of interest is the capacity for filter feeders to consume both their own and competitors larvae. Pechenik and co-workers explored this aspect and showed that not only do adult oysters consume larval slipper limpets and adult slipper limpets consume larval oysters but adult slipper limpets also consume their own young (Pechenik *et al.*, 2004). Although this may sound a disadvantage it should be noted that in the presence of phytoplankton this consumption rate was reduced and in certain cases large slipper limpet larvae were actually rejected by the adults. It is possible that this strategy may allow slipper limpets to either re-absorb this biological resource if environmental conditions are limiting, or reduce the level of cannibalism if conditions are not.

In summary, slipper limpets are likely to be able to out-compete bivalves as they can adopt a number of differing feeding strategies.

C.2.3 Dredging Difficulties

Slipper limpets are considered to have a major impact on dredged fisheries once a significant level of bed coverage has occurred (Fresard & Boncoeur, 2004 & 2005; Fresard *et al.*, 2005).

Impacts on the fishing/processing industry include:

-Loss of fishing areas; The Bay of Brest is estimated to lose 25% of harvestable area/yr (Fresard & Boncoeur, 2004). This represents a 97% loss of harvestable area in 12 years with a predicted destruction of the fishery unless management options are exercised. Heavily infested beds with pseudofaeces deposition convert a soft sandy bed into cohesive sediment as solid as concrete that is impossible to dredge.

-Dredging difficulty; Dredging is hard work in areas where slipper limpets outweigh oysters. The level of impact varies from fishery to fishery not only as a function of slipper limpet density but also according to the capture technique used. Mechanised vessels and dredges can work more highly infested beds that un-powered vessels and manually hauled dredges. The increased load retained within dredges is of particular relevance to hand dredge fisheries such as the native oyster fishery in Carrick Roads.

The deposition of muddy pseudofaeces associated with superabundant slipper limpets is also a particular

problem in St Brieuc Bay in Brittany. Here 'hot spots' occurrence with 70-100% seabed coverage on the Eastern side of the region has increased reducing available dredging areas (Michael Blanchard pers. comm.). French authorities under the ARVAL programme have removed 30,000t/yr from St Brieuc Bay and Mont St Michael Bay using large scale suction dredging at considerable expense. The St Brieuc Bay area is a major scallop fishery landing 20,000t/yr – yet the slipper limpet population is now estimated at over 450,000 tonnes and growing. Mont St Michael Bay was reported to have a slipper limpet population of 100,000 tonnes in 1995-1996 which increased to 150,000 tonnes by 2005 despite the removal of 44,000 tonnes of slipper limpets during this period (Blanchard *et al*., 2006).

Oystermen operating on the 12 designated beds or 'Parcs' in Mont St Michael Bay are significantly affected by slipper limpets. Because of this they now work with public authorities to try and combat the problem and following the close the season in April-May actively manage the beds by removing slipper limpets which are then dumped in two spoil grounds to the north of the harvest areas for subsequent collection by the suction dredger. This is a considerable burden on both public authorities and the fishing sector with a prospect of a worsening outlook as slipper limpet populations continue to rise.

C.2.4 Handling / Processing Difficulties

As scallop, mussel and oyster shells frequently form the settlement substrate for the slipper limpet a large proportion of commercial catches of these species can become covered with the pest species. Walker (2007) showed that 80-90% of slipper limpet settlement occurred on shells. Although half of shell settlement occurred on other slipper limpet shells, oyster shells attracted around a third of total shell settlement.

In addition to the physical difficulties presented during dredging operations (see previous section) economic impacts are also felt by the shellfishermen and processors throughout all aspects of handling. Impacts to the fishing/processing industry include:

-Increased time required to sort the catch.

-Market acceptance can be compromised by the presence of attached slipper limpets meaning they must therefore be removed incurring more time costs.

-Knocking slipper limpets off can damage stock.

-Reduced quality of catch; Scallop landings can be adversely affected by the presence of slipper limpets. Scallop divers in Lyme Bay have reported ~10kg of slipper limpets to every 50kg of scallops in some areas (Paul Fivian pers. comm.).

-As with oysters and mussels the presence of slipper limpets on scallops can increase processing time as slipper limpets need removing if the animal is to be sold on the half shell (Peter Tierney pers. comm.). This is also the situation in the Bay of Brest (Fresard & Boncoeur, 2004; Fresard *et al.*, 2005) where a shell cleaning time of 15.5hr/t was estimated.

-Slipper limpets on scallop shell increase the mass (and odour problems) of waste requiring expensive disposal following processing.

C.3 UK Status

C.3.1 National Overview

Prior to the recent incursion of slipper limpets into the Menai Strait, North Wales, the UK slipper limpet range was reported to extend from Pembrokeshire to Yorkshire. The main historic 'hot-spots' of concentration were in the Solent and the Essex estuaries which formed the major population centres prior to WWII. Following WWII a number of vessels were laid up in these contaminated areas prior to being

moved around the country to various ports for breaking – this was the biggest single boost to the spread of the slipper limpet. By the early 1950's a number of reported slipper limpet incidences were reported from around the UK coast.

The Conchological Society of Great Britain and Ireland have initiated a new project (reported on their website) to try and map the extent of slipper limpet coverage (www.conchsoc.org). This society has provided data collected by their members to the NBN Gateway/MARLIN website which provides an on-line geographic data base from a number of sources.

FitzGerald (2006) reported on the difficulties in establishing the current status impact on UK fisheries. Sea Fishery Committees around the coast were contacted from South Wales Sea to Sussex in order to try and ascertain the perception of impact upon the fisheries and whether any formal management techniques are in place. Generally, there was little exact knowledge of the population status or whether specific fisheries were affected. However, a number of fishery respondents on the ground were aware of certain areas where stocks had been spotted in their personal areas of operation. This could be a valuable data source if consolidated and verified.

Recently some Sea Fisheries Committees have become involved with slipper limpet issues relating to scallop fisheries and have initiated their own monitoring programmes by analysing levels of infestation upon the catch displayed within fish markets and noting the capture location (T. Robins pers. comm.).

C.3.2 Regions

C.3.2.1 Essex

The estuaries of Essex have long been considered the main seat of slipper limpet proliferation within the UK and are also key native oyster fisheries. Essex Sea Fishery Committee confirmed that all of the estuaries in its area were heavily infested although there were no formal management techniques in place (Joss Wiggins pers. comm.).

A number of studies were conducted in Essex estuaries in the 1950's by MAFF workers from the Burnham-on-Crouch laboratory (Walne, 1956; Mistakidis, 1951). These comprehensive reports provided details on the slipper limpet density and population growth and were the first comprehensive studies carried out when the population impact became apparent.

FitzGerald (2006) undertook a cross comparison between differing data sources in order to obtain a rough inter-comparability. The 1950 dredged surveys (Walne, 1956) obtained peak slipper limpet densities of >1,000ind./50m dredge. Assuming an area of 30.5m^2 and a dredge efficiency of 16% this equates to >205ind./m^2. Recent grab sample data (1998-2000) shows that populations have probably increased still further with a maximum count of 2,350ind./m^2 (averaged from two samples).

C.3.2.2 Solent

The Solent has also long been recognised as a major seat of slipper limpet population within the UK. The primary reference work detailing chain densities was undertaken in 1973 (Barnes *et al.*, 1973). This research showed that within the study area the major area of slipper limpets was located in the eastern approaches to the Solent whilst the deep channel with boulder field and high current velocity on the western approach was much less affected. Consideration of the slipper limpet density for the Solent is provided in Section C.4.2.

Data from the NBN Gateway available via the web shows some population data for slipper limpets although there is insufficient data coverage to allow a quantitative assessment of biomass in the area. More importantly the 1973 study showed that the major area of slipper limpets did not correspond to a major new find of oysters identified off Calshot and Stanswood to the west of Southampton. Since this time the oyster fishery has been developed although knowledge of the level of slipper infestation and its impact is limited (Ian Carrier pers. comm.). FitzGerald and Walker (2007) reported a limited data set availability through

slipper limpet landings associated with oyster monitoring by CEFAS although a targeted monitoring programme was recommended to provide a more comprehensive evaluation of the slipper limpet status in this area.

C.3.2.3 English Channel

The Solent has formed the main centre of slipper limpet population levels within the English Channel as described in the previous section. Abundance listings from the NBN Gateway show high populations to both the east and west of the Solent. High counts to the east were obtained off Hastings and Newhaven whilst to the west large numbers were also encountered off Bournemouth and Poole. Poole Harbour has been subject to a massive level of population growth in recent years. Dyrynda (2001) reported a population biomass estimate for slipper limpets in 1984 of ~32 tonnes whereas recently ~1,000t of slipper limpets were dredged off the oyster beds and removed suggesting a significant rate of growth (Ian Davies pers. comm.).

Slipper limpets have been encountered in Portland Harbour and off Weymouth which would appear to be ideal areas for colonisation (Rayment, 2001).

The initial extension of the slipper limpet range into Lyme Bay was reported in 1950 (Walne, 1956). At the time individual specimens were obtained from a number of sites along the coast with ages estimated from growth curves placing initial settlement at about 1946. Nowadays slipper limpets are regularly found on scallops from the bay (Paul Fivian and Peter Tierney pers. comm.). These observations concur with the data available on the NBN Gateway which also show stocks of slipper limpets off Beer, Exmouth and Brixham.

The MARLIN database also records the presence of slipper limpets in the Salcombe Estuary as logged by the Marine Conservation Society survey (1977-1982). As with Portland Harbour and the Salcombe estuary, Plymouth Sound would appear to be a prime area for future population growth. From personal observation mid-reaches of the Salcombe estuary already support a high number of chains which are visible at extreme low water springs. The recent University of Plymouth MSc work by Alexandra Mack records high slipper limpet densities from a number of stations in the lower estuary (Emma Jackson pers. comm.), whilst the Salcombe conservation officer has reported a slipper limpet reef off Ox Point mid-estuary (Nigel Mortimer pers. comm.). Inshore scallop dredgers within the lower estuary are concerned that the slipper limpet may threaten fishery viability (Kevin Oakman pers. comm.).

Data from the NBN Gateway show low counts of slipper limpets in Plymouth Sound and the adjacent Yealm and Tamar estuaries. Observations by shellfishermen suggest a significant population in association with mussel beds on the Lynher estuary (Dave Hancock pers. comm.).

The Port of Truro oyster fishery has experienced large fluctuations in its landings within the native oyster fishery. Licence uptake has fluctuated significantly in the recent decades as a result of many problems such as *Bonamia*, pests such as drills and tingles in addition to slipper limpets (Syvret, 2005). However, the rapidly increasing number of slipper limpets was stated to be the "single biggest problem faced by the Oyster Fishery" (SW Pesca, 2002). Oystermen have historically attempted some management with limited removal and killing utilising brine dipping but efforts have been inconsistent and unfocused. A recent review of management options by FitzGerald (2006) advocated a trial season to target a 25t/yr slipper limpet removal with a variety of utilisation options for both flesh and shell. It is hoped that this approach could be adopted once the potential for funding through the European Fisheries Fund becomes available.

C.3.2.4 South Wales

The first report of x6 individual slipper limpets in Milford Haven was given in 1953 (Cole & Baird, 1953). Now significant levels are found north of Neyland (Phil Coates pers. comm. & NBN Gateway). The recent incursion of slipper limpets within the Menai Straits in North Wales is considered more fully in the main body of the report.

C.4 Potential Future Threat of the Slipper Limpet to UK Fisheries

C.4.1 European Cases Studies – Methodology Difficulties

Case studies from different areas can help to assess population dynamics in order to try and gauge whether the extreme impact observed in some mainland European fisheries may also be experienced in the UK.

A major problem in trying to cross compare slipper limpet data from different areas is the variety of methodologies used (FitzGerald & Walker, 2007). French studies of super abundant populations use different techniques to UK studies of lower populations. Slipper limpet coverage can be assessed by grab samples, dredged samples, diver survey and remote sensing. All methods have their own relative advantages and disadvantages and tend to give somewhat differing results. Grab samples are good to obtain quantitative data from a fixed position but are so limited in area covered that they are likely to miss hotspots – especially in the case of slipper limpets where there may be great heterogeneity on the seabed. Dredge samples are good in that they provide a more representative sample over a longer tow area, yet under-estimate biomass as smaller slipper limpets are not retained. Diver surveys can be useful but are expensive and limited in the area that they can effectively cover. Remote sensing can cover large coastal areas of uniform seabed but requires ground truthing and is less reliable in shallow nearshore waters with differing substrates.

It is understandable that such a variety of techniques are employed as differing levels of resources may be available at different stages of the invasive process. Initial monitoring may only be initiated after anecdotal reports of slipper limpet occurrence, whilst the comprehensive expensive monitoring conducted in France with remote sensing, grabs and diver surveys on an annual basis has been driven by the high level of impact.

Unfortunately, because slipper limpet density is initially so patchy it is very hard to get an objective assessment of UK status with the data currently available. Assessment of the slipper limpet population in the 1990's in Mont St Michael showed that over half the slipper limpet biomass occurred in just 15% of the total area. Ideally, all infested areas would have slipper limpet biomass density mapped so that the extent of hot-spots could be monitored and the rate of biomass growth estimated.

C4.2 Slipper Limpet Density

Population growth in the Bay of Brest provides a stark illustration of how a slowly developing slipper limpet population can appear to reach a 'tipping point' beyond which population growth is rapid. Guerin *et al.* (2005) provide an illustration of this process with a review of the slipper limpet population estimates made in recent years for the Bay of Brest. In 1995 peak slipper limpet densities were ~400 ind./m^2 in a few restricted upper estuary sites whilst the majority of areas had <200ind./m^2. Within the space of 5 years however the extent of the agglomerations had spread significantly with peak densities of >1,000's ind./m^2.

For Essex, FitzGerald (2006) undertook a cross comparison between differing data sources in order to obtain a rough inter-comparability between the 1950 dredged surveys (Walne, 1956) and recent grab data (1998-2000). This suggested that the peak population of >205ind. /m^2 in the 1950's may have increased significantly with a maximum count of 2,350ind. /m^2 (averaged from two samples) from the recent survey. Although this peak count is comparable to the high levels found in the Bay of Brest (>4,000 ind./m^2) the majority of sites had levels <1,000ind. /m^2.

For the Solent, FitzGerald (2006) used the 1973 dredge survey data (Barnes *et al*., 1973) which he then recalculated on a density basis indicating a density of 200 to 400ind. /m^2. Even allowing for only a low 5% population growth this will have increased slipper limpet levels to >l,000ind. /m^2 densities by the present.

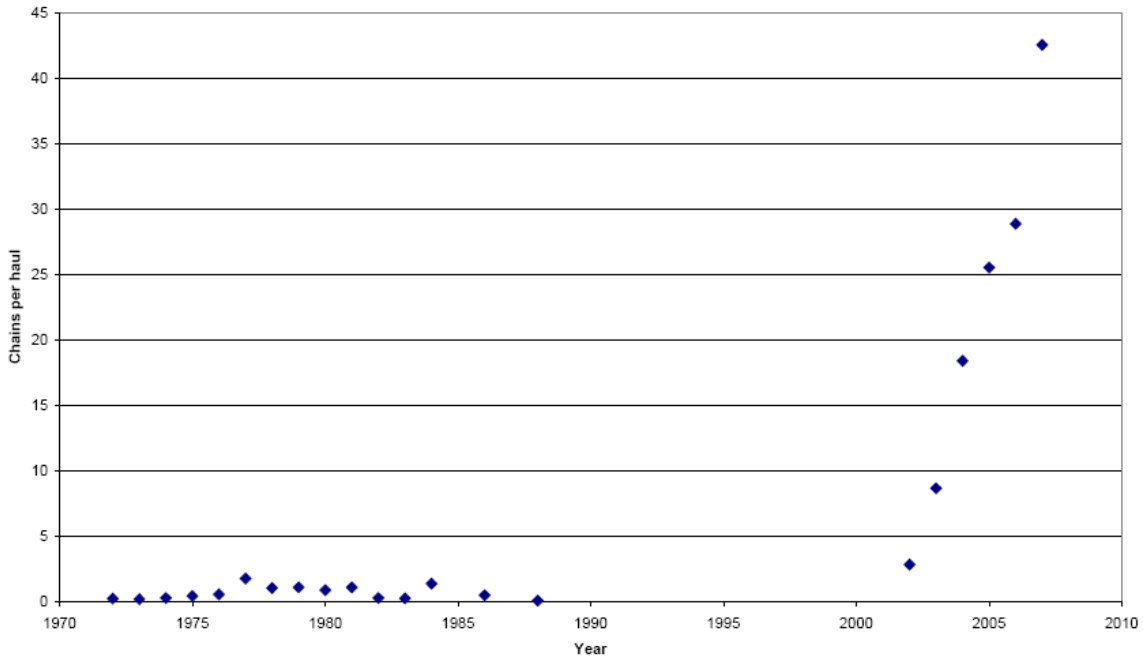
In contrast, the Carrick Roads native oyster fishery currently has densities of ~20 to 60 ind. /m^2 yet even these levels could reach superabundance in the middle term at the current growth rates measured (see Section C.4.3). Offshore slipper limpet densities remain an area of great uncertainty and there is an urgent

requirement for identification and characterisation of 'hot-spots'.

C4.3 Rate of Population Growth

Dupont (2004) reviews the dynamics of slipper limpet invasion which shows a low rate of initial growth, a rapid population explosion followed by a decreased rate of growth when an area approaches saturation. Clearly, the expected rate of growth for any slipper limpet population will vary according to the stage of the invasive process.

Figure C.2 - Catch rate of slipper limpet chains – Truro Oyster Fishery 1972 - 2007 (Walker, 2007)



The figure above (from Walker, 2007) shows how the slipper limpet population in Carrick Roads, Falmouth showed little apparent rise over many decades before a rapid increase in landing rates over recent years. This apparent 'tipping point' in rapid population growth was also observed in French waters in the late 1990's.

FitzGerald (2006) reviewed French slipper limpet growth rates for St Brieuc Bay and Mont St Michel Bay and arrived at an estimate of ~10%/yr in recent years, whereas the Bay of Brest growth rate is probably closer to ~30%/yr.

For Carrick Roads, FitzGerald (2006) calculated a slipper growth rate of 26%/yr based on 2004-2006 survey data. This was confirmed by a more detailed analysis performed by Walker (2007) using mapped slipper limpet density and growth in three individual beds between 2006-2007 which also showed an overall population growth rate of 26%/yr. FitzGerald calculated that if the current 26% population growth in Carrick Roads is maintained without check then it would be possible that the peak density of slipper limpets could reach super abundant levels (>1,000 ind./m^2) in 10-15 years.

C.5 Recommendations

1. Slipper Limpet Audit and Monitoring

Much of the UK slipper limpet data available is old and unrepresentative. Before any control and management options can be considered it is important to ascertain the current extent and density of slipper limpet beds. A programme using common measurement techniques could provide a baseline to help assess ongoing developments and identify key zones under threat.

Some qualitative monitoring of slipper limpet infestation is now being undertaken by Sea Fisheries Committees using catch observations. Although this is a qualitative measure and will under report early stages of infestation, it is a cost effective monitoring technique with which the industry can be directly involved. A broadening of this approach with perhaps some harmonisation in technique and recording could provide a valuable monitoring tool in identifying 'hot-spots.' It may be possible to couple this qualitative industry monitoring with additional quantitative techniques in order to better evaluate slipper limpet biomass. It is suggested that industry and conservation bodies should consider working in co-operation on such a programme and in this way share costs thus making best use of available funding sources.

Following a UK national monitoring programme it may be possible to model rates of growth for specific water bodies. Numerical modelling of the financial impact/costs such as that conducted by French researchers (Fresard & Boncoeur, 2004 & 2005; Fresard *et al.*, 2005) will help better inform fisheries management.

2. New Developments

Certain pest control techniques being used in other countries could offer a technical solution in certain settings if developed further for the slipper limpet. FitzGerald (2006) considered the potential for the use of pheromone traps which have been effective for a number of species and could be appropriate for the slipper limpet. CEFAS currently has resources and personnel skilled in this field of work and would be well placed to develop this technique. 'Horizon scanning' of new techniques and cost-benefit assessments should be considered.

3. Slipper Limpet Strategy

UK conservation bodies have adopted the Convention on Biological Diversity approach to non-natives i.e prevention, control, eradication. Historically most effort has been placed upon 'prevention' but this is now too late for the slipper limpet in the UK. 'Control' efforts may be of increasing importance especially if intervention is carried out early when cost implications are significantly lower. These control efforts could well of course have implications for fisheries management. Eradication methods in cases of super abundance are both expensive and have little real impact – however, targeted removal in certain fisheries could still be effective. It is suggested that industry and public bodies should work together to form a strategy as a matter of urgency for both fisheries and conservation interests.

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