Management recommendations for the sustainable exploitation of mussel seed in the Irish Sea

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August 2007

Funded through the Marine RTDI Measure Productive Sector OP 2000-2006

Reference No. ST/02/03

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ISSN: 1649-0053

Marine Environment and Health Series No 31, 2007

NATIONAL DEVELOPMENT PLAN

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EXECUTIVE SUMMARY

Background

The mussel seed fishery in the Irish Sea is integral to the continued viability of the bottom mussel sector in Ireland. The annual value of this sector has increased from €21.6 million in 2003 to €25.7 million in 2005. This report is the outcome of a project funded under the National Development Plan Strategic Marine RTDI Programme 2000-2006 overseen by the Marine Institute. The project was led by University College Cork while partners in the project included, University College Dublin, Queens University Belfast, Letterkenny Institute of Technology, Galway-Mayo Institute of Technology, Aquafact International Service Ltd. and the South East Shellfish Co-op. A steering group for the project comprised of representatives from an Bord Iascaigh Mhara (BIM), the Department of Communications Marine and Natural Resources and the Marine Institute and also included international experts from the UK, NL and USA. The project evolved from concerns raised to the Marine Institute by BIM and Industry representatives regarding the sustainability of the fishery. An overall goal of project was to introduce a science-based management system for the sustainable exploitation of seed mussels in the Irish Sea. A specific goal of the project was to identify drivers governing the distribution and abundance of the seed mussel resources in the Irish Sea. A number of deliverables were provided from this project.

1. Literature search and review of existing biological, fisheries, survey and hydrographic data on mussel populations in the Irish Sea.
2. Studies to estimate adult reproductive cycles and spatfall patterns were implemented. The results were integrated with the output of the modeling exercise in order to verify the models and develop a detailed picture of the reproductive dynamics of the mussels.
3. Hydrographic models predicting areas of mussel recruitment. Models incorporated vertical migration patterns during planktonic life-stages.
4. Draft a management strategy to detail the optimum manner within which to effect the sustainable exploitation of the resource, including an evaluation of the hatchery option as a source of mussel seed.

This report focuses upon the final deliverable above, wherein a series of recommendations encompassing both management and research aspects based upon the scientific outputs of the project are presented.

Project Design and Results

The entire project was carried out as a series of separate work packages that were designed to answer questions relating to each of the expected outputs. A literature review was conducted whereby information, relating to mussels generally and seed mussels from the Irish Sea specifically, was compiled. A number of focused projects were also conducted to identify patterns relating to reproduction and recruitment of mussels in the Irish Sea.

Reproductive patterns were elucidated from monitoring the spawning cycles in mussels at numerous locations along the eastern seaboard. In addition, reproductive output was estimated by calculating broodstock biomass from each of the locations monitored for spawning cycles. The data obtained from the project demonstrate that subtidal locations have the potential to contribute greater numbers of larvae than intertidal areas by virtue of the larger sized mussels found subtidally (and greater output) as well as the fact that they have two spawning events per annum (May-June and October-November), while the majority of intertidal populations appear to spawn only between May-July. As a consequence subtidal beds should be afforded some degree of protection.

Changes in vertical position of larvae within the water column during different tidal states (i.e. flood, ebb, slack water) was coupled with a physical hydrodynamic model of the Irish Sea to estimate larval dispersion from numerous starting points (i.e. spawning beds). The output of the models indicated that larvae remained closely aggregated to each other and are highly associated with estuarine and inshore areas, relatively close to the parental patch. This suggests that beds might be self-seeding or rely on supply of larvae from beds in close proximity. Settlement patterns of mussels demonstrated considerable spatial variation in terms of abundances; however, patterns of settlement indicated that peak settlement generally occurred in July of each year.

Overall, there is clear evidence that mussels over-winter in the Irish Sea, although the patterns and exact locations of over-wintering are somewhat variable. Surveys conducted by BIM confirmed these findings and revealed large mussels (26 mm, and in some cases 40 mm) in May, 2004. Subsequent surveys carried out as part of the project in February and April 2005 revealed that subtidal mussel beds in the Irish Sea had over-wintered. It is extremely unlikely from these examples that larvae could have settled and grown (to the sizes observed) in the winter/spring of both years. Given that concerns were highlighted from the outputs of some sampling efforts in the study that utilised small-scale grabbing equipment, it is clearly better to use carefully structured sampling programmes employing commercial dredges to detail further the extent of over-wintering as well as to survey for seed in the late spring. In addition, the reproductive condition and size was dependent on spatial arrangement within the bed (i.e. edge vs. middle). In order to representatively sample the population as a whole, sampling should take into account the varying structure of a bed and adopt a stratified sampling methodology in addition to operating the dredge in both an east-west direction and north-south direction to determine the overall extent of the bed.

Alternatives to the dredge fishery as a source of seed were also investigated in this project. The use of artificial collectors to capture wild spat has been conducted commercially for the rope-mussel sector. Some operators have relayed rope-caught seed onto bottom plots with mixed results. Growth has been good but survival has been variable. While the technology is available to produce mussel seed from hatcheries, it raises the question as to how hatchery seed will perform in the wild, particularly on the seabed? In addition, to ensure greater survival on the seafloor, it is likely that the mussels would have to be planted at larger sizes (>15 mm) than envisioned for release from hatchery or nursery production (~5mm). Retention of seed in a nursery situation to 15 mm may not be economically feasible. Some benefits of hatchery production could lie in the ability to select for beneficial traits (e.g. faster growth rates or production of thicker shells to resist predation). The use of hatcheries as a source of seed mussels will ultimately be dictated by economics in terms of price to produce seed and how it relates to the price or return on that seed at market. Predation has been indicated as a major problem on newly seeded beds. It has also been reported that direct mortality has been associated with transport and that transport-induced stress may impact upon overall survival in seed mussels from a variety of a sources.

Management Recommendations

There are a number of recommendations that have resulted from the findings of this study. These take the form of direct recommendations towards the management of the industry that can be implemented immediately and others in the form of additional research recommendations that will validate some observations resulting from this project.

Recommendation 1 - Science-based Management Systems- To develop a science-based management system for the sustainable exploitation of seed mussels in the Irish Sea. This should result in the implementation of fishery plans based upon scientific evidence and survey effort involving close collaboration between state agencies and industry. The case study of the Netherlands mussel industry (Appendix IV) is a good working model upon which to base such a management system.

Recommendation 2 - Optimum Time of Year for Dredging to Commence- The results indicate that subtidal populations having originated from over-wintering beds or have settled early in the season can become reproductively active and contribute to the current year settlement. As a consequence, it is recommended that in order to facilitate a complete spawning season and subsequent larval development and recruitment that the southern Irish Sea fishery commences at least two months after the last spawning has been observed. Therefore based upon the information to-date the season should commence in late-July rather than early-June. The exact timing should be informed by weekly surveys of gonadal development and settlement patterns in the Irish Sea. The delay in the season will allow the harvest of larger sized mussels, which will increase the mussel biomass and ensure greater potential survival when relayed.

Recommendation 3 - Closed Areas- This study has deduced that subtidal mussel beds can survive over-winter and may contribute to early season recruitment in subsequent years. As a consequence, it is recommended that the location of stable seedbeds (those that survive for more that one winter) is confirmed and a management plan for each of these beds is established, which might include information such as the minimum viable stock to remain on the seedbed following harvest.

Recommendation 4 - Long-term Monitoring- Annual surveys should be conducted throughout the traditionally fished seedbed areas in order to identify viable mussel seedbeds. These surveys should be carried out in the spring/early-summer (April/May) of each year and consist of an extensive, concerted and coordinated survey effort conducted to agreed standards, involving a commitment from both industry and state agencies. The findings of these surveys would introduce considerable confidence in subsequent management decisions.

Recommendation 5 - Future Research- A number of new insights have been provided as a consequence of the research carried out in this study, but in several cases, these need to be refined and have led to a number of new research-oriented recommendations that would require a combination of applied and basic research to address them. Some of the key research issues highlighted include:

- What are the factors that ensure seedbed stability and survival over winter?
- Determining the long-term recruitment patterns for a variety of (subtidal and intertidal) locations in the Irish Sea by establishing a long-term monitoring programme and linking the patterns observed to potential sources.
- Further ground truthing the dispersion models developed as part of this study.
- Investigating if there is a correlation between seabed structure (bottom sediment/hardness) and mussel productivity, i.e. determine habitat suitability.
- Quantifying the effect of predation on seed mortality rates.
- Examining the physical impact of dredging on affected species and the seabed and develop the means to reduce any negative impacts.
- Examining methods to improve handling and transport of stock.
- Developing best practice guidelines to be produced for husbandry of stock which will include appropriate stocking densities and to ensure higher final product to seed ratio.

Recommendation 6 - Funding Opportunities- It is further recommended that industry partners, state agencies and academia (research performers) avail themselves of the funding opportunities provided by both Sea Change[1] and the Cawley Report[2] to develop research programs relating to seed mussel supply and management.

[1] A Marine Knowledge, Research & Innovation Strategy for Ireland 2007-2013. Marine Institute 2006

[2] Steering a New Course - Strategy for a Restructured, Sustainable and Profitable Irish Seafood Industry 2007-2013. Report of the Seafood Industry Strategy Review Group December 2006

FOREWORD

As it currently stands, the management of the bottom mussel aquaculture in Ireland is a complex process that is governed by three overriding factors; these are; 1) Government Policy and regulation, 2) Industry and economics and 3) Science and biology. These three factors are influenced by a range of different issues that influence the implementation of resource management either individually or in combination (see Figure 1) and include, *inter alia*, aquaculture licensing, carrying capacity, company structure and operating practices, animal health legislation, vessel registration and licensing and North/South agreements, prevailing weather conditions and uncertainty of seed supply.

The mussel seed fishery in the Irish Sea, as the primary source of seed, is integral to the continued viability of the bottom mussel sector in Ireland. This report is the outcome of a project funded under the National Development Plan Strategic Marine RTDI Programme 2002, overseen by the Marine Institute and it is the consequence of concerns raised to the Marine Institute by Bord Iascaigh Mhara (BIM) and Industry representatives regarding the sustainability of the fishery. The specific project is entitled a "Resource and Risk Assessment of Mussel Seed in Irish Waters", a goal of which is to develop and implement a science based management system for the sustainable exploitation of seed mussels in the Irish Sea. A specific goal of the project was to identify environmental drivers governing the distribution and abundance of the seed mussel resources in the Irish Sea. A number of outputs were expected from this project;

1. A literature search and review of existing biological, fisheries, survey and hydrographic data.
2. Studies to estimate adult reproductive cycles and spatfall patterns. These were integrated with the output of Workpackage 3 in order to verify the models and develop a detailed picture of the reproductive dynamics of the mussels.
3. Hydrographic models of targeted areas of high mussel population. These models allowed for behavioural characteristics of the larval swimming phases.
4. Draft a management strategy to detail the optimum manner in which to effect the sustainable exploitation of the resource, including the hatchery option.

This report addresses the final workpackage above, wherein a series of recommendations encompassing both management and research aspects, based upon the scientific outputs of the project, are presented.

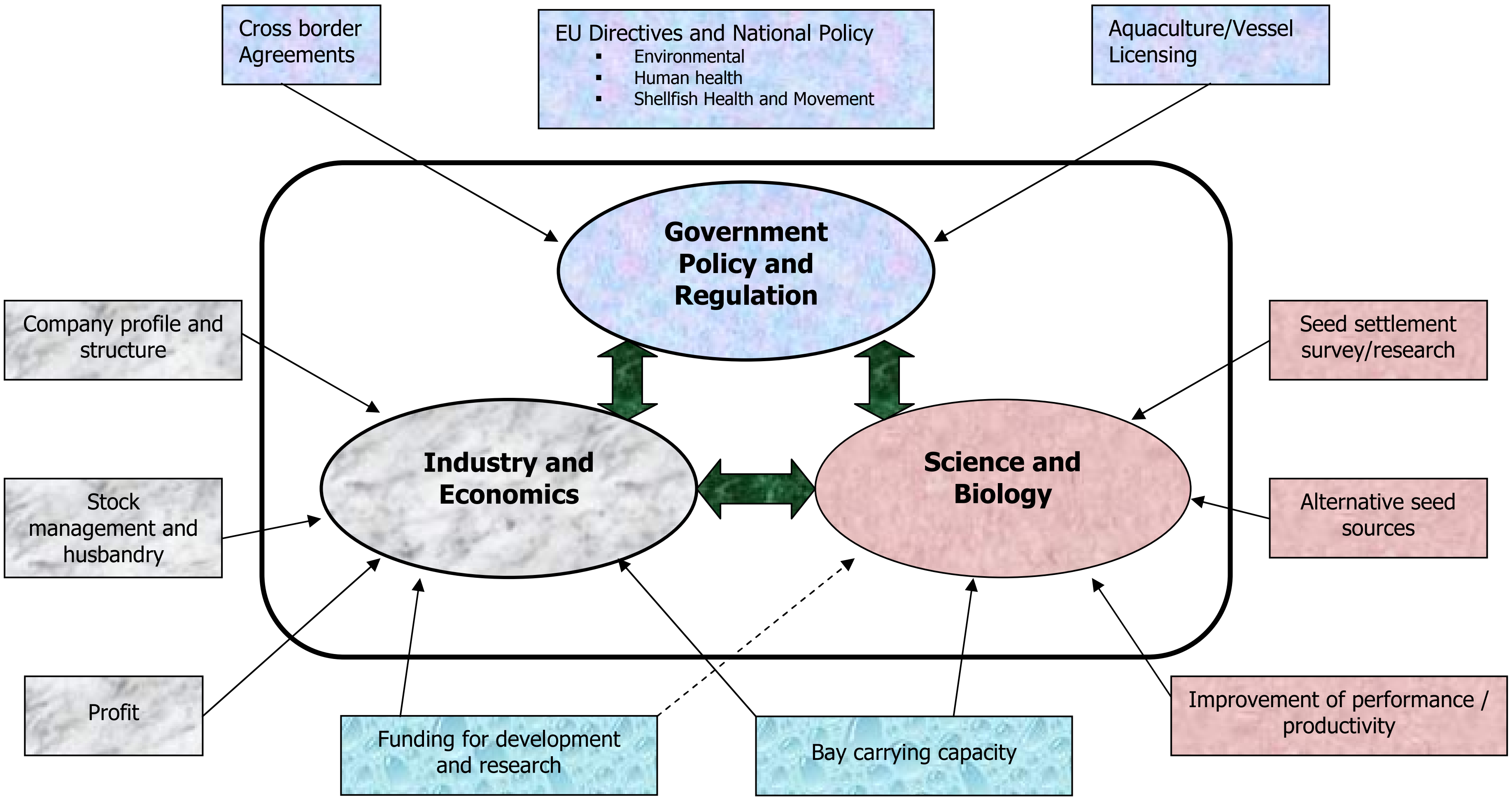


Figure 1. Flow chart depicting factors involved in mussel management structure

1. INTRODUCTION, PROJECT TERMS OF REFERENCE AND GENERAL OVERVIEW OF SECTOR

Mussel seed are on-grown in Ireland by two different methods. Along the west coast of Ireland the rope grown method is preferred. This is where mussel seed is packed into "stockings" that are suspended in the water from longlines. The bottom culture method, which is the larger of the two sectors, is based on the transplantation of wild seed from different natural beds, to culture sites, where the animals are grown to commercial size. Seed is in constant demand. In 2005 the bottom mussel sector applied for 93,526 tonnes of seed. However seed landings yielded less than one fifth of that amount.

Sourcing seed from natural settlement areas has also been problematic for the industry and regulatory agencies. BIM and DARD have been conducting a mussel seed surveys for a number of years and have found that recruitment is extremely variable both temporally and spatially (*See Section 1.2.2*). Therefore, the quantity of seed available for harvest is highly variable. As a consequence, it is deemed important to understand fully the recruitment process and the factors that govern it. The primary factors thought to affect variation in recruitment include adult reproductive output, hydrodynamic processes, larval survival and behaviour, availability of settlement substrata and post-settlement mortality (e.g. Butman, 1987 and Underwood and Keough 2001). *Mytilus edulis* are generally dioecious, although a small number of hermaphrodite mussels have been found (Brousseau, 1983). Spawning patterns vary according to location. King *et al* (1989) described two spawning periods, spring and summer, on the west coast of Ireland. Wilson and Seed (1974) described a similar pattern in Carlingford Lough, however extended spawnings may continue into winter. Rodhouse *et al.* (1984) showed that in Killary Harbour only large mussels >74mm spawned in spring whereby all sizes spawned in summer. Additional research is needed to characterise patterns of spawning in the Irish Sea.

Ocean currents primarily move mussel larvae. The hydrodynamics of the Irish Sea are driven primarily by tides and wind and consist of a general northerly flow of water (Bowden, 1980). The time-averaged circulation of the Irish Sea is relatively weak, with no coherent directionality over large areas (Proctor, 1981). Stratification of the water column can occur during the summer and recent studies have highlighted a summer gyre in the western Irish Sea (Hill *et al.,* 1997). More detailed models of circulation patterns in the area of the seed fishery would greatly aid in attempting to predict patterns of movement of larvae. These models will also allow for the behavioural characteristics of different larval swimming phases.

Several environmental factors, such as temperature (Seed, 1969), food concentration (Pechenik *et al.,* 1990), physical mechanisms (Richards *et al.,* 1995) and predation (Young and Chia, 1987) may affect bivalve larval growth and mortality rates. In laboratory experiments some of these factors can be controlled but their influence in natural habitats is almost impossible to ascertain. Mussels may delay settlement for up to 10 weeks due to environmental factors (Bayne, 1964) and can spend up to 8 months at various settlement stages (Burnell pers. comm.).

Plantigrade mussels initially may settle onto filamentous substrata such as algae, hydroids or other structures in the water column and detach and reattach themselves onto several substrates before selecting a site of permanent attachment (Bayne, 1964). However, McGrath *et al.* (1988) and McGrath and King (1991) found that mussel larvae settled directly onto adult beds on Irish shores without any primary settlement phase. The mechanisms by which juvenile mussels arrive at sites of permanent or semi-permanent attachment are not therefore clear i.e. there may be several phases of movement or only one.

The question of whether mussels that have settled into seed beds in the Irish Sea survive over winter is also critical. It is possible that the seed beds are ephemeral and are quickly disrupted by predators or winter storms. If so, then they are simply 'sink' populations derived from a remote 'source' and fail to contribute to their own replenishment. If this is the case, exploitation of mussel seed beds would be fully sustainable as long as the source populations are conserved. If, on the other hand, the beds do survive to contribute to subsequent harvests of seed, then steps must be taken to exploit the beds themselves in a sustainable manner.

There is a clear dearth of knowledge regarding mussel recruitment and population dynamics in the Irish Sea. This project aimed to investigate the reproductive patterns of adult mussels in identified beds, larval movement through hydrographic models and behavioural studies, distribution and settlement of larvae and survival of beds of mussel seed. The information derived from this research would be used to provide a scientific basis for predictions of the location and tonnage of mussel seed in the Irish Sea. In addition, the feasibility of hatchery production of mussels would be assessed. All findings would be integrated in the formulation of a strategy for the sustainable management of the resource.

Therefore the project was broken down into various component aims:

1. *To investigate the reproductive patterns in identified adult beds.*
   This involved an investigation into the reproductive annual cycle of mussels in the Irish Sea. An assessment of whether mussels reproduced once or many times per annum and the identification of the age of first spawning in the Irish Sea. Also the biomass of mussel beds was correlated to their recruitment output.
2. *To investigate larval distribution and recruitment in the Irish Sea.*
   This involved an investigation of the distribution both temporally and spatially of larvae in the water column. Also it investigated the time and location of larval recruitment, the settlement substrate and primary, secondary and tertiary attachment of larvae. Also an assessment of seed survival over winter was carried out.
3. *To investigate the hydrographic patterns of the western Irish Sea.*
   This involved an assessment of the bathymetric currents of the Irish Sea in order to predict larval movement and settlement.
4. *To conduct a feasibility study on the potential of large-scale hatchery production of mussel seed.*
   This involved a desk-top study of the potential for large-scale production of mussel seed in hatcheries. Also a preliminary field trial of mussel seed collection and immediate growout were carried out.
5. *To analyse the output of the scientific investigations to draft initial management strategies for the sustainable exploitation of the mussel resource.*

1.1 Definition of seed mussels

The definition of "mussel seed" varies widely (See Table 1). In this study seed is defined as

"Any mussels deemed suitable for relaying under current Irish legislation and not placed directly on the market for human consumption."

Table 1. Definition of seed in the literature

Location	*Description of seed*	*Reference*
Britain	20-40mm in length	Dare P.J. and Edwards D.B. (1976)
Dutch Wadden Sea	20mm or almost 1 year old	Dankers N. and Zuidema D.R. (1995)
Maine, USA	<2 inches (51mm) or >106 mussels/2Quarts (~55 pieces L^{-1})	http://www.maine.gov/sos/cec/rules/13/188/188c012.doc.
Canada (Gulf Region)	Any small mussel usually around 15mm	http://www.glf.dfo-mpo.gc.ca/pe-pe/es-se/mussel-moule/mussel-moule-e.pdf

1.2 Data of seed production outputs

1.2.1 European bottom mussel industry

The production volume of mussels (*Mytilus edulis* and *Mytilus galloprovincialis*) within the EU grew from 368,851 tonnes in 1993 to 597,589 tonnes in 2003, 75% of which was *M. edulis*. Table 2 shows the countries involved in the production of *M. edulis*.

Table 2. Total European production of *M. edulis* in 2003 (www.fao.org)

Country	*Total Tonnage*	*% Bottom Culture*	*Tonnes Bottom Culture*
Spain	248,827		
The Netherlands	55,200	100%	55,200
France	55,000		
Ireland	39,289	76%	29,976
Germany	28,549	100%	28,549
UK	19,218	66%	12,812
Sweden	1,742		
Norway	1,367		
Channel Islands	108		
Iceland	4		
Total European M. galloprovinicalis production	148,274		
TOTAL European M. edulis production	449,315	28%	126,537

In Europe, a number of different methods to culture mussels are employed. In France, where Bouchot, or pole culture, is practiced, seed is collected on man-made substrates. In areas with shallow seas such as in parts of the UK and Ireland, the Netherlands, Germany seed is relayed on bottom plots. In Spain, western Ireland, Sweden and Norway, where the sea is too deep for bottom culture, raft and long-line systems dominate. This involves placing seed mussels, in stockings attached to horizontally suspended ropes. With the exception of Spain, collecting sufficient and predictable amounts of mussel seed is extremely difficult. Dredging wild beds or scraping mussels from intertidal hard surfaces such as rocks are the traditional sources of seed. However, in some countries wild spat is collected on artificial substrates.

The Netherlands

Mussel farming in the Netherlands is based on the culture of mussels on bottom plots in the Wadden Sea and the Oosterschelde Estuary. Mussel seed is harvested in autumn and spring from wild beds in the Wadden Sea and transplanted to culture plots. Typically bottom culture production efficiency is on average 1.7 kg end product from 1 kg of seed. As a consequence the annual requirement of mussel seed is $65*10^6$ kg (gross weight) to achieve a production target of $100*10^6$ kg.

During a growth period of 1.5 – 3 years mussels are transplanted between culture plots within the Wadden Sea and The Oosterschelde, and from the Wadden Sea towards the Oosterschelde (vice-versa is not allowed) as a function of the culture strategy and the availability of plots of individual farmers. Market size mussels are harvested subsequently and brought to the auction at Yerseke. After sale at auction, mussels are stored on rewatering plots in the eastern part of the Oosterschelde, before processing (cleaning, sorting, packaging) takes place. All processing companies are located at Yerseke, relatively close to the main consumer market for fresh mussels in Belgium (Smaal & Lucas, 2000).

The availability of mussel seed from wild beds is presently the basis of the culture cycle and this resource is under pressure. These beds predominantly occur in the Wadden Sea. Due to the natural variability of the spatfall and stringent conservation legislation, mussel seed availability has decreased. Controversy between nature conservation NGO's, the shellfish industry (particularly mechanical cockle fishery) and the government resulted in a shellfish policy for the period 1993 – 2003, that was based on the closure of areas for fishery, food reservation for birds, co-management by the industry and a research program to evaluate the effects of these measures. As part of these measures intertidal mussel beds were closed for mussel seed fishery.

North Wales, UK,

In North Wales, the successful culture of *M. edulis* is dependent on natural variation in spatfall and also on the behaviour of predators and tidal forces in autumn (Dare *et al.*, 1983). After collection from subtidal seedbeds, mussel seed are re-laid by farmers on bottom culture plots. In the Menai Strait, North Wales (where more the half of the cultured mussels in the UK are produced), one tonne of unprotected 20-25 mm length seed mussels usually produces about one tonne of marketable >45 mm mussels (2 – 2.5 years), indicating a 85% mortality (Dare, 1976). The high rate of mortality is mainly due to shore crab (*Carcinus maenas*) predation (Davies *et al.*, 1980). The mussel seed target is not always reached (Kamermans and Smaal, 2002) due to high variability of spatfall and the small time window for collection.

The north Wales mussel industry collects seed by dredging natural seed beds. The Sea Fisheries Committees issues a licence to the farmer for the collection of seed, which are dredged once a layer of "mussel mud" has built-up under the mussel beds. This means that farmers can dredge the targeted bed and collect seed leaving the substratum relatively unaffected (Kaiser *et al.*, 1998). The mussel culture industry in the Menai Straits harvests seed from three main areas: Caernarfon Bay, Morecambe Bay and South Wales. Seed beds have also developed periodically in Conwy Bay. Seed beds in Caernarfon Bay are subtidal, on gravel or cobble substratum. In Morecambe Bay the beds are mainly intertidal, often concentrated on areas of harder substratum (e.g. glacial moraine deposits), although they can also be on sand.

In conclusion, the problems in relation to the supply of seed mussels occur throughout the European mussel industry (apart from Spain). Most countries with a shortage of seed carry out annual surveys to assess the amount of seed available and follow their own national strategy to exploit the seed available. These strategies are unique to each individual country and are dependent on the scale of the problems, stability of the beds, the stakeholders involved and relevant national legislation.

1.2.2 Historical overview of mussel seed surveys in Ireland

Finding sufficient quantities of mussel seed has proved to be a major stumbling block for the Irish bottom mussel sector in recent years. BIM have been conducting a mussel seed survey for over thirty years and have found that recruitment is extremely variable both temporally and spatially. They have conducted their survey using RoxAnn, underwater cameras and divers. RoxAnn is an analogue device, which acts as a passive receiver of acoustic signals generated by a standard single beam echo sounder. Using information from the first and second echo returns from the seabed, ground discrimination can be successfully achieved when the vessel is under way. The results of this survey can be found in Figure 1. Similarly, the South-East Shellfish Co-op have conducted surveys and fished various seedbeds in the Irish Sea since 1997 and their results to 2002 are presented in Figure 2.

The results of both surveys have shown that the most consistent seed beds have been found off Wicklow Head. In particular, two areas east of the India Bank have had consistent seed settlement for the past 8 years. In that period, 75% of mussels dredged in the Irish Sea have been taken from these sites (Crowley pers. comm.). The area has consisted of numerous small beds and some larger beds. The seabed at these sites has been described as a mix of sand, mud, shingle and stones and has ranged from "very clean to dirty" with the mussels showing no distinct substrate preference (Crowley pers. comm.).

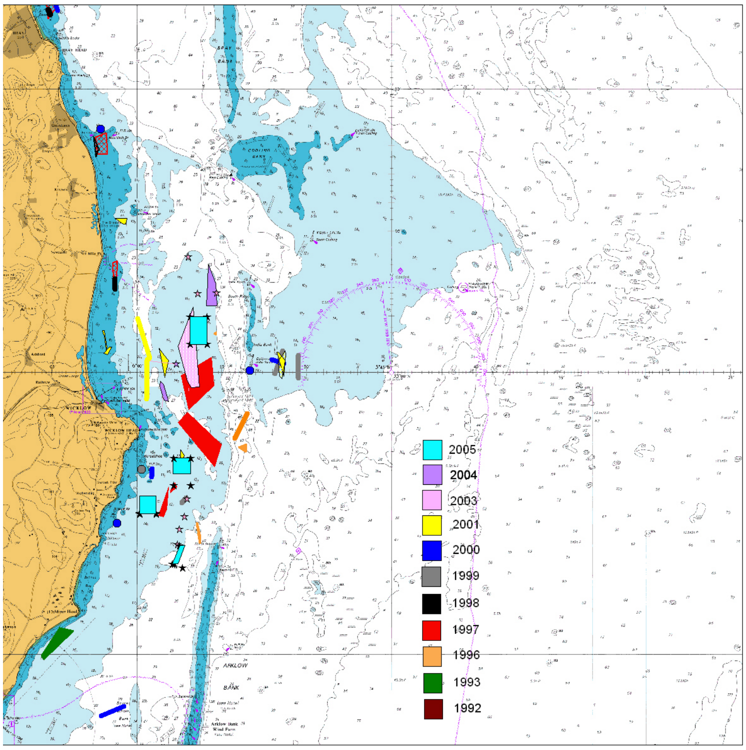


Figure 1. Location of seed beds from BIM seed bed surveys (1992-2005). Courtesy John Dennis, BIM. (Admiralty charts reproduced are © Crown Copyright and/or database rights. Reproduced by permission of the Controller of Her Majesty's Stationery Office and the UK Hydrographic Office (www.ukho.gov.uk)).

In Northern Ireland the most consistent seed bed is found in the area of the Skullmartin Rock in the inshore waters off Ballywalter on the Ards Peninsula, Co. Down. Recently, C-Mar have carried out surveys in this area (Figure 3) in order to locate and estimate the quantity and quality of seed mussel available for fishing by the bottom mussel industry. In 2004, two areas of seed of sufficient density were located and mapped (approximately 70 hectares in total). The combined tonnage of seed on the seabed in these areas was estimated at 1,500 tonnes (±400 tonnes). The seed was found at depths of between 20 and 24.5m MLWS. The mean size of seed was 19.8mm (±0.16mm) shell length. Two peaks on a size frequency distribution were found at 16-18mm and 26-28mm, indicating that the bed contained seed from two distinct settlements. The larger cohort was likely to have remained from a settlement that occurred late in 2003. The mussel seed fished from the bed averaged 1575 (±245) pieces per kg.

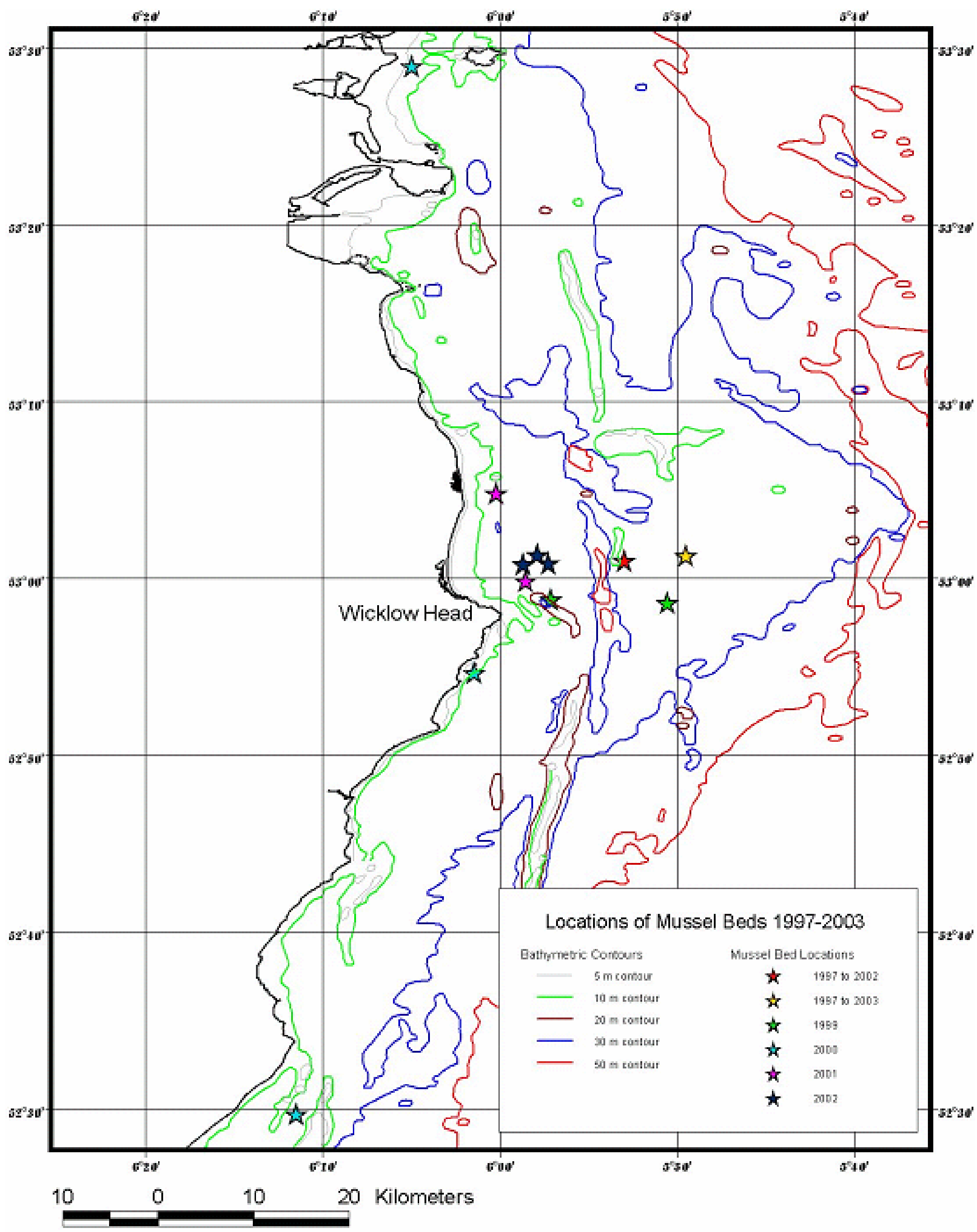


Figure 2. Results of South-East Shellfish seed bed survey (1997-2003).
Source: South-East Shellfish.

In other sites surveyed along the east coast (from Irelands Eye to Cahore Point) seed bed formation has varied temporally and spatially. In general the seed beds surveyed in the Irish Sea were found at depths between 10m to 30m. The sediment profile of the beds surveyed just north of Wicklow Head consisted of fine sand/sand at four sites and sandy/gravel at the fifth site (Crowley pers. comm.). Very good quality mussels were fished in 2000, south of Cahore Point (Wexford), between Wicklow Head and Mizen Head (Wicklow) and just south of Greystones. Only in the latter site were mussels found again the following year. The sediment in these three areas was described as fine sand, hard sand with fist sized stones and sandy muddy with big stones, respectively (Crowley pers. comm.).

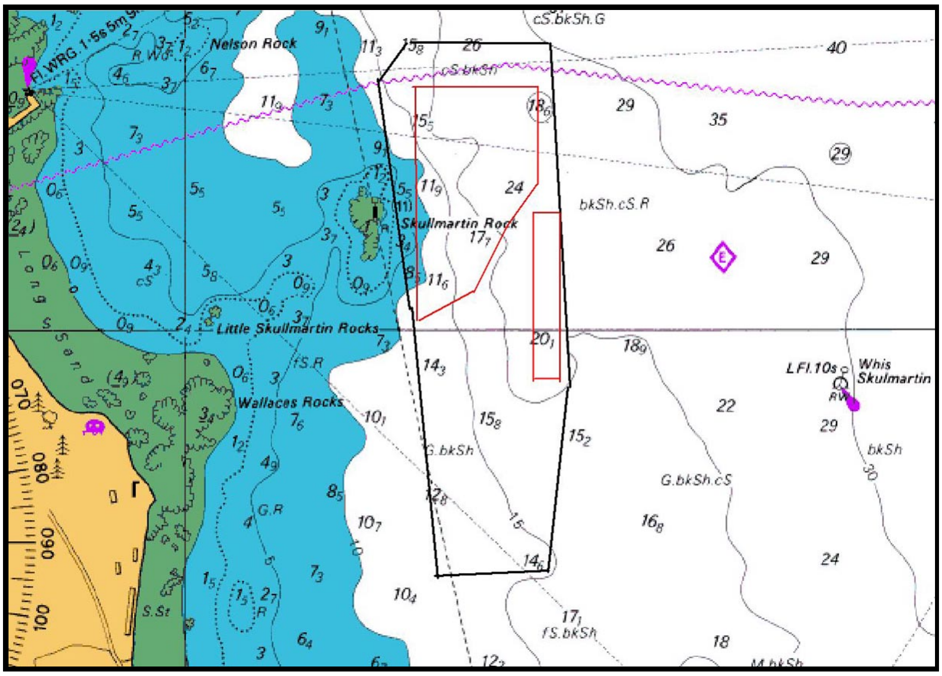


Figure 3. Map of area surveyed (black) and mussel seed beds (red) located using RoxAnn in Skullmartin in 2004. (Admiralty charts reproduced are © Crown Copyright and/or database rights. Reproduced by permission of the Controller of Her Majesty's Stationery Office and the UK Hydrographic Office (www.ukho.gov.uk).

Besides the location of the seed beds the quantity of the seed has also varied significantly from year to year. The industry was based mainly in Wexford and Kerry in the 1990s and between them, they harvested approximately 7,000-12,000 tonnes of seed annually. However, a large spatfall (30,000 tonnes) in Lough Foyle in 1997 kick-started the industry in Northern Ireland, and from then on fishing effort increased dramatically but the catch has varied inter-annually. Since then, up to 20,000 tonnes of seed has been harvested annually from the Irish Sea alone. Due to the current high demand for seed, allocation of seed has been a contentious issue for the past few years. This issue is discussed in *Section 1.2.3*. The official seed harvest figures may not be entirely accurate particularly in the earlier years as some of the seed landings may have been mis-reported. The following table (Table 3) outlines the annual seed quantities for the past three years. Data has been compiled from various sources (DCMNR, DARD, BIM and the industry).

Historical seed landings could also be extrapolated from the annual production figures for the bottom mussel culture sector. If one assumes that there was a 1:1 return from seed, then these figures will give us at least a minimum amount of seed taken. However, this return can vary according to location. Also, recently significant quantities of seed have been transported to the Netherlands after a temporary relaying period in Ireland (approximately 10,000t in 2004).

Table 3. Annual bottom mussel seed quantities from 2003-2005 (Source – DCMNR, BIM, DARD, members of the mussel industry).

Culture Bay	Source	Year		
		2003	2004	2005*
Carlingford Lough	Carlingford	340	864	
	Skullmartin			370
	Irish Sea	2750	140	462
Wexford	Irish Sea	7020	8450	140
Waterford	Irish Sea	1450	1800	250
Lough Swilly	Lough Swilly		1320	
	Irish Sea	1893	400	
	Unknown			1407
Foyle	Lough Foyle	5498	2080	
	Irish Sea	7780	5308	110
	Skullmartin			280
Cromane	Cromane	2810	950	2000
	Irish Sea		200	
Belfast Lough	Skullmartin		2325	7360
	Irish Sea	5445	60	865
Larne Lough	Irish Sea	200	250	
Dundrum Bay	Carlingford	50		
Republic of Ireland	Skullmartin			1485
No logsheets				132
Total	Irish Sea	26,538	16,608	1,959
Total	Skullmartin	340	2325	9,495
Total	Other Sources/unknown	8,358	5,214	3407
Grand Total		35,236	24,147	14,861

*Data to be updated from future submissions to the DCMNR in 2006 and from BIM questionnaires. ** Rope mussel seed transferred to Waterford and Wexford in 2005 (not included)

1.2.3 Economic and social objectives

The bottom mussel sector is the largest sector in the Irish shellfish aquaculture industry. In 2004, 66% of Irish farmed shellfish sold were bottom grown mussels. In monetary terms, 53% of the value of all Irish farmed shellfish in 2005 were from this sector (Marine Institute, Board Iascaigh Mhara and Taighde Mara Teo., 2006)). Needless to say this sector has become and important contributor to the rural coastal economy in Ireland. Figure 4 presents the annual quantity and value of this sector in Ireland.

In 2004, this sector employed 155 Full-time equivalent (FTE) personnel. This can be further broken down into 118 full-time, 67 part-time and 19 casual workers. The decrease in the number of FTEs from 235 in 2003 was mainly due to the purchasing or leasing of sites from smaller companies e.g. Carlingford Lough, Lough Foyle, which were no longer creating employment, by larger companies with enough staff to cope with the increased work (Status of Irish Aquaculture 2004). The number of registered vessels fishing for seed had risen in recent years to 28 boats, but declined in 2005 due to new requirements for vessels including the attainment of a certificate of compliance for each boat. In 2005, the official seed uptake by these licensed vessels was 17,870 tonnes (including Cromane). In 2005, the demand for seed was five times greater than the estimated amount of reported seed fished (See Table 4). Also, the overall quantity of seed allocations granted by the authorities exceeded the actual supply. Needless to say, the combination of illegal fishing, inadequate seed supply and the difficulties in allocation of seed has presented challenges for regulators, scientists and fishermen alike.

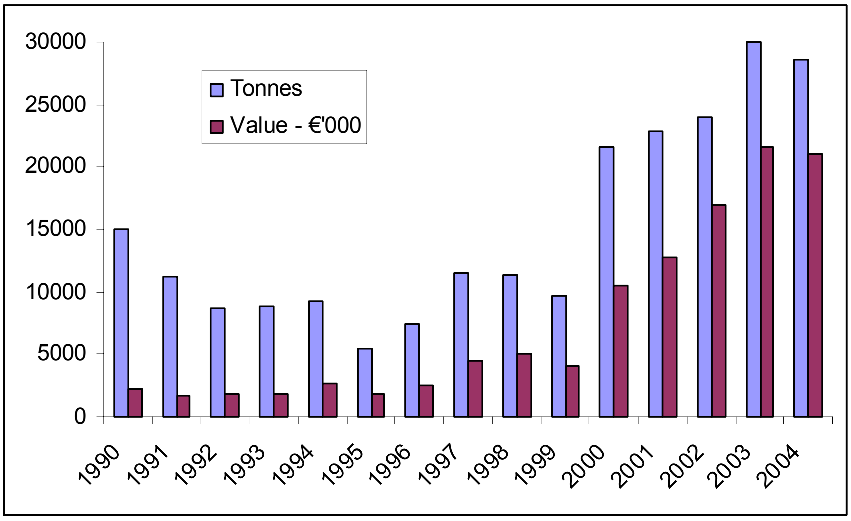


Figure 4. Production quantity and value of Irish bottom cultured mussels

Table 4. Seed demand, allocation and uptake in 2005

Bay	*Demand (T)*	*Allocation (T)*	*Uptake (T)*
Carlingford Lough	13,350	1,250	832
Wexford	6,750	4,800	140
Westport	250	250	
Waterford	4,270	1,790	250
Shannon	1,500	500	
Swilly	5,750	1,540	1,,407
Foyle	31,950	6,800	390
Cromane	7,500	1,277	2000
Belfast Lough	20,956	5,334	8,225
Larne Lough	1,000	185	
Dundrum Bay	250	250	
Source – Skullmartin, Relayed Republic of Ireland			1,485
No logsheets			132
Total	93,526	23,976	14,861

Seed allocations have been based on information provided through annual surveying for mussel seed and returns from the previous year's landings. Seed mussel survey data came from two sources:

- Industry (surveys carried out by the operators themselves)
- State Agencies

In general terms, both the industry and agency survey effort covered a geographically broad area with the aim of finding new seed in previously unsettled areas *or* new settlement in traditional seed bed areas. Once a bed was located the agency survey effort, focused more on characterising the seed beds in terms of size and limits of the bed, seed biomass and size and quality of the seed itself. Whilst survey work has been carried out for many years by BIM, more recently other organisations such as the Loughs Agency, CBAIT, DARD Aquatic Sciences and C-Mar have been involved in surveying for seed.

One of the primary difficulties faced by Seed Mussel Allocation Committee (SMAC) in making recommendations for seed allocations was the lack of reliable real-time survey data. SMAC has been required to allocate seed tonnage in the absence of real evidence that the tonnage requested was actually available. As a result, the amount of seed allocated in 2003, 2004 and 2005 exceeded significantly the amount actually fished in those years. Therefore in 2006, the legal framework for operation of the fisheries changed (*See Appendix III*). As it was imperative, that overall mussel seed survey strategies (*See Section 6)* were refined and improved.

2 REPRODUCTIVE CYCLE OF MUSSELS IN THE IRISH SEA.

2.1 Introduction

This section of the project was broken down into the following tasks:

- *Task A1. Literature review on mussel beds*

The first part of this workpackage was to review all existing literature (biological, fishery and survey data) available regarding mussel beds from the Irish Sea and other areas. The historical landings from the east coast beds were documented, this information will be very useful for predicting future stocks. Anecdotal information with respect to seedbeds, substrates and other factors observed by the industry were given due consideration.

- *Task A2. To describe the physical characteristics of adult beds*

Estimates of mussel biomass were produced for a number of selected sites using acoustic information. Grabs and underwater video footage were used to ground-truth the data and to provide density estimates of mussels per unit area of seabed. To obtain more accurate information on the densities of mussels *in situ* a diver programme was undertaken to collect samples of mussels from known areas of seabed using quadrats. Total numbers of mussels were estimated by multiplying mean densities in particular locations by the corresponding area of seabed. Biomass was estimated by applying the appropriate Length/Weight relationship to the total numbers at each length class.

- *Task A3. To relate biomass of mussel beds to their reproductive output*
- *Task A4. To assess whether mussels are iteroparous or semelparous and the age of first spawning of mussels in the Irish Sea.*

In order to investigate the reproductive cycle of mussels in the Irish Sea and their potential contribution of larvae to subtidal 'seed' stock development, an assessment of three potential sources of larvae was made. Populations of mussels on the east coast of Ireland occur in three habitats:

(1) Intertidal locations i.e. rocky shores
(2) Estuaries / grow-out regions i.e. Wexford Harbour and Boyne River
(3) Subtidal locations – 'seed' populations

The main study involved monthly monitoring of each locations at three intertidal, two estuarine and where-present subtidal populations to assess the reproductive development and time of spawning. *Anecdotal evidence suggested that 'seed' mussels were reproductively immature, not contributing to the maintenance of the subtidal resource*.

2.2 Spawning cycle

Monitoring of the reproductive development of mussel populations occurred from July 2003 - June 2005 at:

1. Clogherhead, Co. Louth
2. Dalkey Island, Dublin
3. Carnsore Point, Co. Wexford
4. Boyne River, Co. Louth
5. Slaney River / Wexford Harbour, Co. Wexford
6. Irish Sea e.g. Wicklow Head, Cahore Point, Blackwater

** Locations 1-3 are intertidal, 4 & 5 estuarine and 6 subtidal.*

Samples were collected using three methods. Core samples were collected at intertidal locations, van Veen grab samples were collected at estuarine locations and sub-samples were collected from dredge gears at subtidal locations. Most importantly, in contrast to anecdotal reports of subtidal populations being reproductively neuter (immature), all individuals collected from subtidal sources were reproductively active. This was also the case in all estuarine individuals, however neuters were present in intertidal samples, most notably among the smaller individuals (<8mm shell length).

Comparison of the reproductive development of each of the populations using gonad indices (calculated from gonad squash analysis, see Wilson & Seed 1974) found all populations reached spawning condition at similar times with spawning consistently occurring between May and June in both 2004 and 2005 (Figures 5 and 6). A secondary spawning was also observed in estuarine and subtidal populations (Figure 5) between late September and early December. This was also mirrored at the intertidal locations of Carnsore Point, but not at other intertidal location (Figure 6).

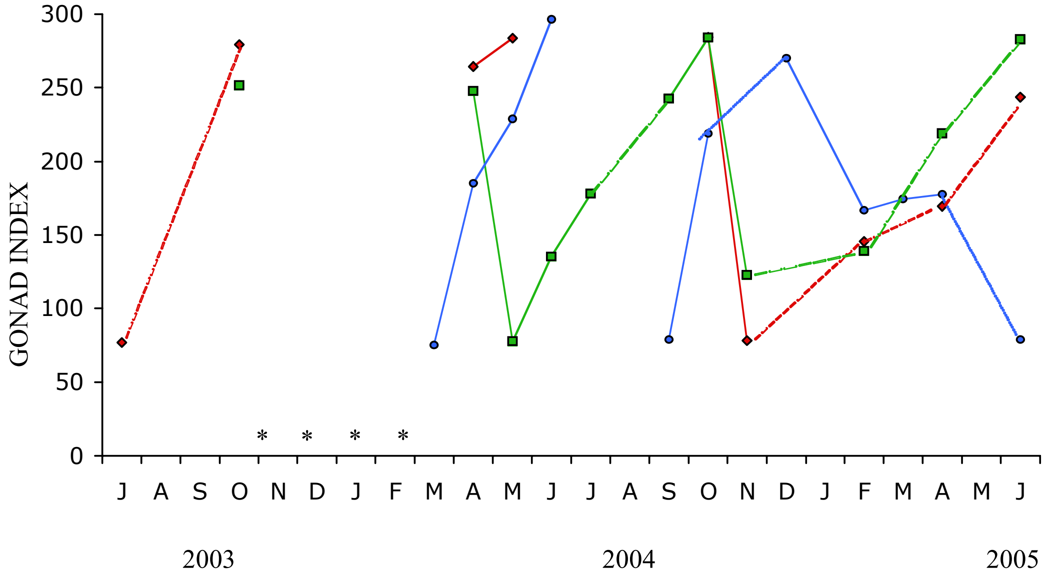


Figure 5. Reproductive cycle of estuarine and subtidal mussel populations as assessed by gonad indices in: Boyne River (blue), Irish Sea (red) and Wexford Harbour (green). Dotted lines represent hypothesised development where no samples available. The numerical ranking of a sample may vary from 0 (all animals resting) to 300 (all animals ripe or redeveloping) with ranks valued following Wilson & Seed (1974): 0 – resting; 1 – immature and / or spent; 2 – developing and / or spawning; 3 – ripe and / or redeveloping. Applies to subsequent graphs. Asterisks indicate no mussels discovered in the Irish Sea.

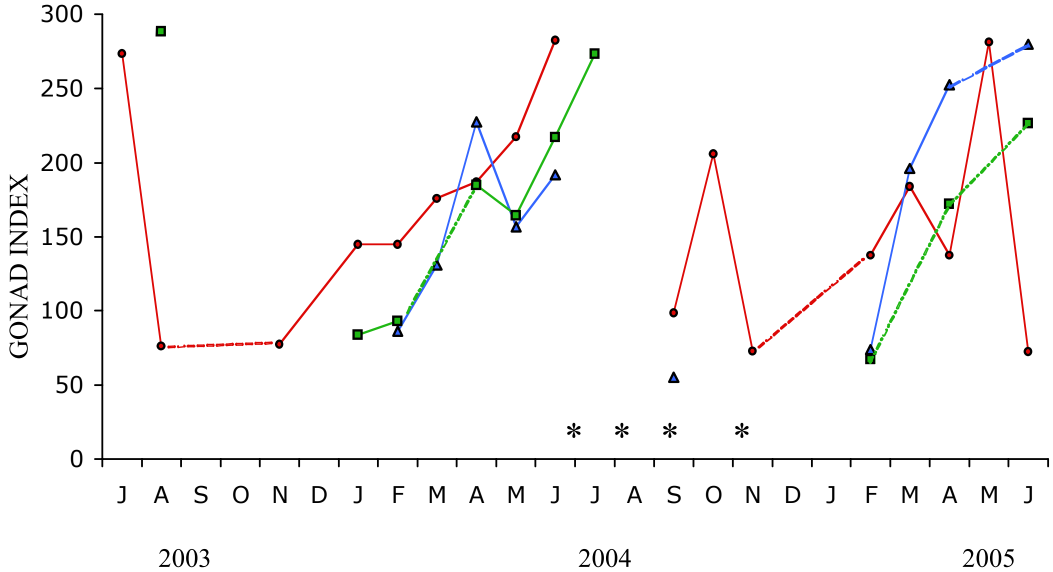


Figure 6. Reproductive cycle of intertidal mussel populations as assessed by gonad indices at: Clogherhead (blue), Carnsore Point (red) and Dalkey Island (green). Dotted lines represent hypothesised development where no samples available. Asterisks indicate no mussels present at Dalkey Island.

2.3 Broodstock biomass and reproductive output

Biomass

In order to determine the level of contribution by a population to the larval pool, its structure i.e. biomass, is an important component in its assessment as reproductive contribution is dependent on the size of the individual. The main study involved characterising the structure of populations within each habitat type by density and sex ratio. Variations in density and the ratio of male:female could dramatically effect the importance of a population to the maintenance of the regional stocks as a whole

Intertidal locations were sampled by hand core collection from the mid-intertidal zone, estuarine samples by van Veen grab and subtidal populations by a combination of commercial dredge gear, van Veen grab and diver-collected cores.

Greatest densities and smallest shell lengths were generally found at intertidal locations with densities highly variable over small spatial scales. Subtidal populations showed similar densities to those found at Carnsore Point. However shell lengths were significantly greater in the subtidal samples. In contrast, minimum densities were found in the estuarine habitats, whilst greatest shell lengths were observed in this habitat (Figure 7).

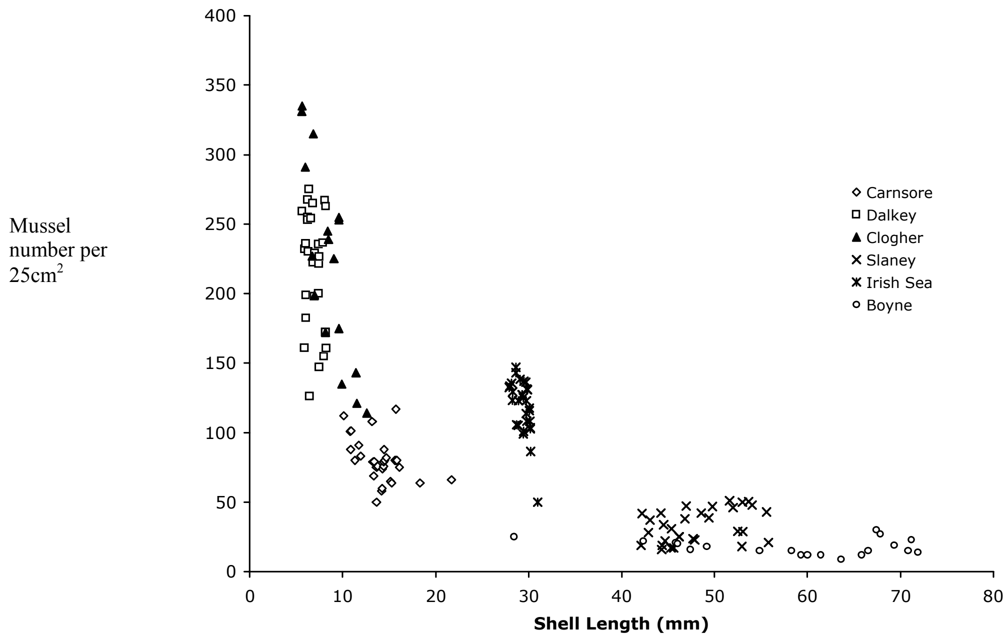


Figure 7. Shell length (mm) vs. density (25cm^2) at six locations. Shown are the mean values for each location (two sites, four replicates) between June 2003 and July 2005 (n = 20).

Fecundity

The dispersal of male and female animals within patches was highly varied. Comparisons of patches at both micro- (meters apart) and macro-scales (tens of meters apart) showed that *Mytilus* males and female dispersal was highly variable within patches at all locations. Patches were comprised of all one sex in some instances whilst males and females were equally abundant in others. Pooling of sex ratio data for populations at each location (four replicates: A1, A2, B1 and B2) found males and females to generally be randomly dispersed among patches at both intertidal and subtidal locations. This was not the case at Carnsore Point where males were, as at other locations, randomly dispersed whereas females were found to tend towards a contagious aggregation or 'clumped' dispersal pattern (Table 5).

Although male abundance exceeded female abundance at all locations, $\chi 2$ tests of frequencies of male : female abundances showed no increased association of males to five of the six locations sampled (Location sex ratio (male : female) (a) Slaney Estuary (1 : 0.94), (b) Irish Sea (1 : 0.98), (c) Boyne Estuary (1 : 0.91), (d) Clogherhead (1 : 0.90) and (e) Dalkey Island (1 : 0.85)). This was not the case at Carnsore Point where males were significantly more abundant within patches than females (1 : 0.64, χ^2_9 = 11.69, $p < 0.05$).

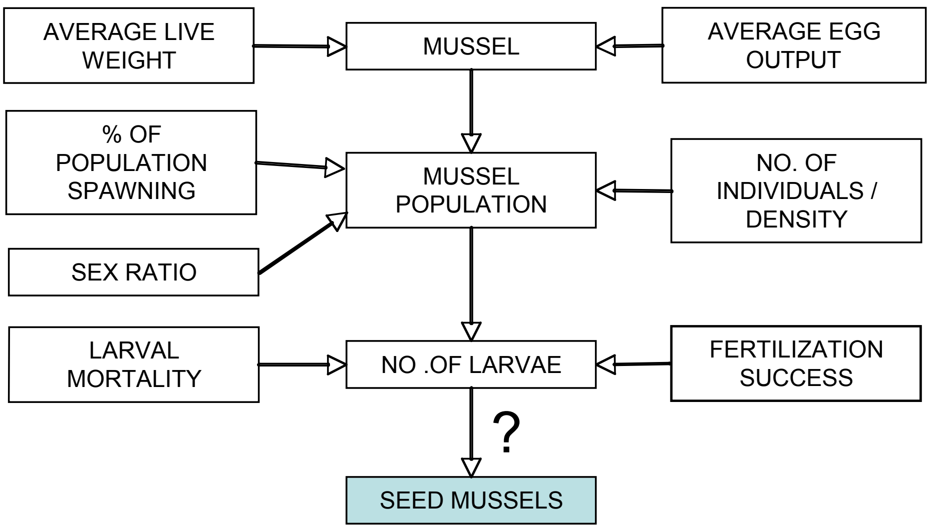
Table 5. Frequencies of male and female *Mytilus* spp. identified by gonad squash analysis (King *et al*. 1989) at six locations. Data shown are pooled samples (n = 4, 10 replicates per sample)

Location	*Slaney Estuary*	*Irish Sea (ST)*	*Boyne Estuary*	*Clogher-head (IT)*	*Dalkey Island (IT)*	*Carnsore Point (IT)*	*Total*
Male	212	205	210	195	185	235	1242
Female	188	195	190	169	146	144	1033
Total	400	400	400	364 (46)	331 (69)	379 (21)	

Values in parentheses indicate number of mussels that were neuter (no sexual tissue visible)

Reproductive output calculations

With the subtidal beds now identified as potentially highly significant sources of mussel larvae, crude values of potential output from this source are advantageous. Figures of unfinished product output from the Irish Sea from the 2005 season indicated a gross tonnage of 1437 tonnes (Source: DCMNR, BIM). The majority of this was collected from a large bed to the east of Wexford Harbour (henceforth Blackwater), that was studied during this project to classify the seed size, density and reproductive condition. Using these and a number of other criteria (Figure 8), we can estimate potential contribution of larvae from the Blackwater population to the



regional pool.

Figure 8. Schematic of inputs affecting the development of subtidal mussel populations

EXAMPLE 1.

Incorporating data collected during this research and from international literature, we can estimate the potential loss of larvae to the system by recruitment over-fishing (Peterson. 2002). Using the same framework as described above, Figure 9 demonstrates the calculation to estimate the number of larvae that would be produced from 1,435 tonnes of seed, if spawning occurs.

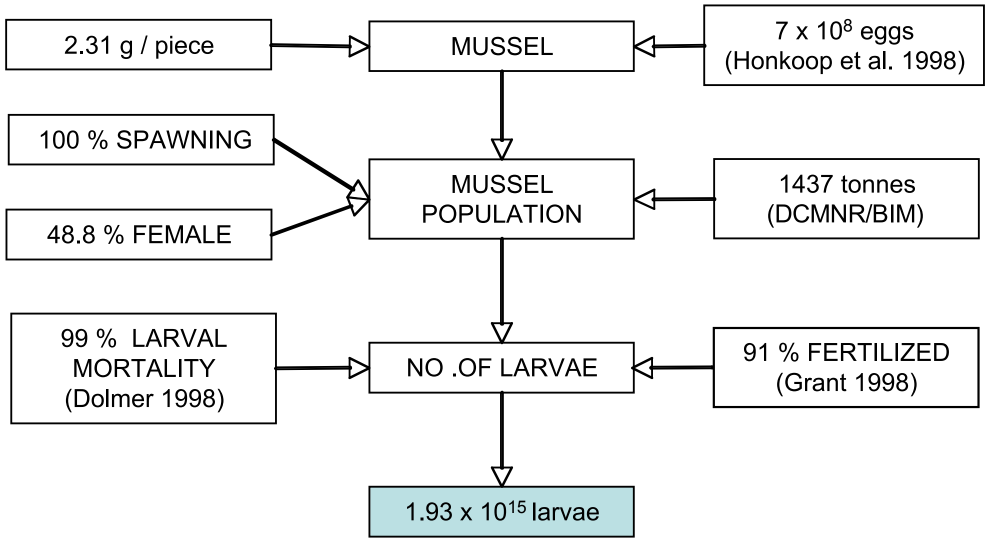


Figure 9. Incorporation of UCC data and international literature to estimate the number of larvae entering in to the Irish Sea system from a standing stock of 1437 tonnes.

The number of larvae produced by a relatively small tonnage of mussels is extremely large. The number of larvae however, is unlikely to be coupled to 'on-the-ground' biomass, with variations in abiotic and biotic factors (i.e. available substrate and predation) resulting in large losses of larvae prior to, during and post-settlement. However, the calculation suggests that subtidal populations contribute considerably to the larval pool and as a result, efforts to protect populations during spawning should be paramount. When high settlement mortality rates (~ 0.01 % survival) are considered, protection of: (1) standing stocks during spawning to maximise larval output, and (2) larvae during a critical settlement period (28 days after spawning, Bayne 1965), promotes the development of new populations and the maintenance (enlargement) of existing populations. The need for stock protection is reinforced by field-based observations and hydrodynamic models *(Section 3.3).* These suggest that larvae from many intertidal and estuarine sources are unlikely to be dispersed to subtidal regions, which would imply that the subtidal seed beds themselves are key sources for the maintenance of the seed mussel populations. This is a key issue and is by no means resolved (see suggestions for further research)

As a result, a number of key management observations and recommendations that are suggested to maximise the likelihood of 'self-seeding' of subtidal seed populations by local mussel populations are based upon the findings that the subtidal stocks are reproductively active and contributing to the larval pool. These recommendations are:

- Ensure the protection of broodstock throughout first spawning period (April-June) to allow a spawning contribution
- Allow subsequent protection of larvae during key settlement periods (up to 28 days post-dispersal) to maximise settlement success

3 LARVAL BEHAVIOUR

3.1 Introduction

This section of the project was broken down into the following tasks:

- *Task B1. Literature review on mussel larvae*

The first part of this workpackage was to review all existing literature (biological, fishery and survey data) available regarding mussel larvae from the Irish Sea and other areas. The review concentrated on appropriate techniques for larval monitoring and answered questions such as; if factors such as meat yield, temperature and primary production were suitable indicators for larval density and in turn if larval monitoring was a suitable indicator for seed recruitment and also the factors that influence successful recruitment.

- *Task B2. To assess larval distribution in the water column*

Quantitative plankton samples were collected at different beds in consultation with the hydrographic modellers in the Irish Sea area. A protocol was established that will be suitable for the long-term continuation of the sampling programme.

- *Task B3. To investigate the timing and location of larval settlement*

The focus of the review in Task B1 shaped the design of the sampling programme in this task, such that locations were chosen to provide replicate samples of different substratum, wave, climate and turbulence patterns. In order to measure spatial and temporal variation in settlement of mussel larvae, natural substrata was monitored and artificial settlement substrata – household scouring pads – were be deployed (King *et al.,* 1990, McGrath *et al.,* 1994). Because of disturbance, caused by the dredging of subtidal beds, it was not possible to deploy substrata there. Instead, settlement substrata was deployed at a range of intertidal sites close to known fishing grounds and collected at regular intervals throughout the year. Such sites were accessible and less frequently disturbed than the offshore beds. Monitoring them gave a good indication of the timing of settlement in different regions. Additional settlement substrata were deployed at sea to establish the relationship between intertidal and offshore settlement. Length frequency analysis of adult beds, both intertidal and subtidal, were also be used to detect recruitment events.

- *Task B4. To assess primary, secondary and tertiary drift of mussels*

Plankton samples were routinely collected both inshore and offshore and examined for the presence of mussel larvae and postlarvae to assess the relative roles of these processes in maintaining or establishing benthic seed mussel beds. The findings of this Task were used to help predict the extent of redistribution of mussel juveniles after settlement.

- *Task C2. Model hydrodynamic patterns of the Irish Sea in relation to mussel larval movement*

This involved the development of a model that would help to identify locations where mussel larvae would congregate due to particular oceanographic conditions. An important part of the development process was to have input from biologists at an early stage of the model development e.g. areas of interest in the Irish Sea and behavioural activity of mussel larvae. There were sufficient existing measurements of current velocity and direction in the Irish Sea to enable the establishment of good boundary conditions to the study areas. Further discussions with the biologists provided the information that was required to develop predictions as to where the larvae might either congregate, or to where they may be carried.

3.2 Larval distribution in the water column

The distribution of the larvae within the water column is likely to play a large role in dispersal of larvae throughout the Irish Sea system. In the absence of detailed knowledge of behaviour, larvae are considered in most cases to behave as passive particles and their movements are predicted by hydrodynamic models incorporating only the duration of larval life. The passive behavioural assumption limits the effectiveness of recruitment estimations, with models often only partially predicting population distribution. Behaviour of marine invertebrates during larval development (e.g. vertical migration) has seldom been investigated under field conditions for marine invertebrates, however.

The UCC project partners sampled the waters surrounding the large Blackwater / Wexford subtidal seed bed in May/June and July/August of 2005 to examine whether larvae truly behave as passive particles in this environment. The aim was to determine whether patterns of distribution of mussel larvae in the water column vary during different conditions of tidal flow. The study aimed to determine whether (1) larval densities in the water column vary at a range of temporal scales (month, tidal phase, tidal state), (2) vertical distribution of larvae through the water column varies with tidal phase and state, and (3) a greater proportion of late stage (>210 μm) larvae occur near the bottom than at other depths, and a greater proportion of early stage (<210 μm) larvae occur near the surface than at other depths.

To test for vertical distribution, an echo sounder was used to measure the depth of water which was then stratified into three zones: Top (T), Middle (M) and Bottom (B). Each zone was defined as one-third depth of the water from surface to bed. The number of mussels in each zone was recorded and calculated as a percentage of the total.

Larvae were found to be more abundant during flood tides in comparison to all other tidal states, with larvae least abundant during ebb tides. Tidal state was also highly influential on the positioning of larvae within the water column with larvae mixed throughout the water during flood and ebb tides, whereas larvae were more closely associated with bottom waters, nearest the sea bed during slack water periods (Figures 10 and 11).

Incorporation of this larval mechanism has major implications for the hydrodynamic modeling of bivalve larvae within the Irish Sea and the results indicate that larvae are likely being transported in to more favourable habitats such as estuaries for settlement and growth from subtidal sources. Larvae also become more concentrated in specific regions with less offshore dispersal of larvae that was observed in the passive behaviour models (Figure 12).

These findings have been reported in detail in the scientific literature (Knights et al (2006), Mar Ecol Progr Series 326: 167-174). Their implications for hydrodynamic modelling of larval dispersal are presented in Section 3.3. (below).

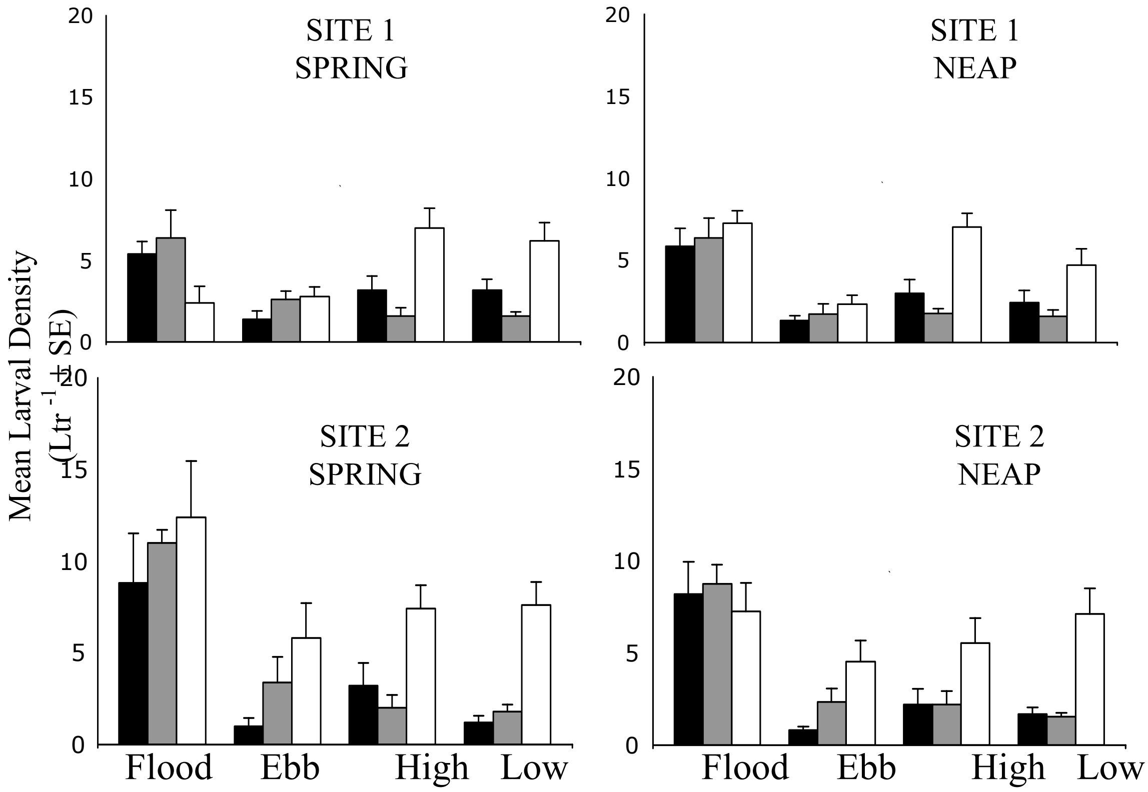


Figure 10. Mean density (± SE) of *Mytilus* spp. larvae in three depth zones: Top (black), Middle (grey) and Bottom (white). Samples collected over four tidal states and two phases at two sites during May/June 2005 (n = 5). See Knights *et al.* in press. MEPS.

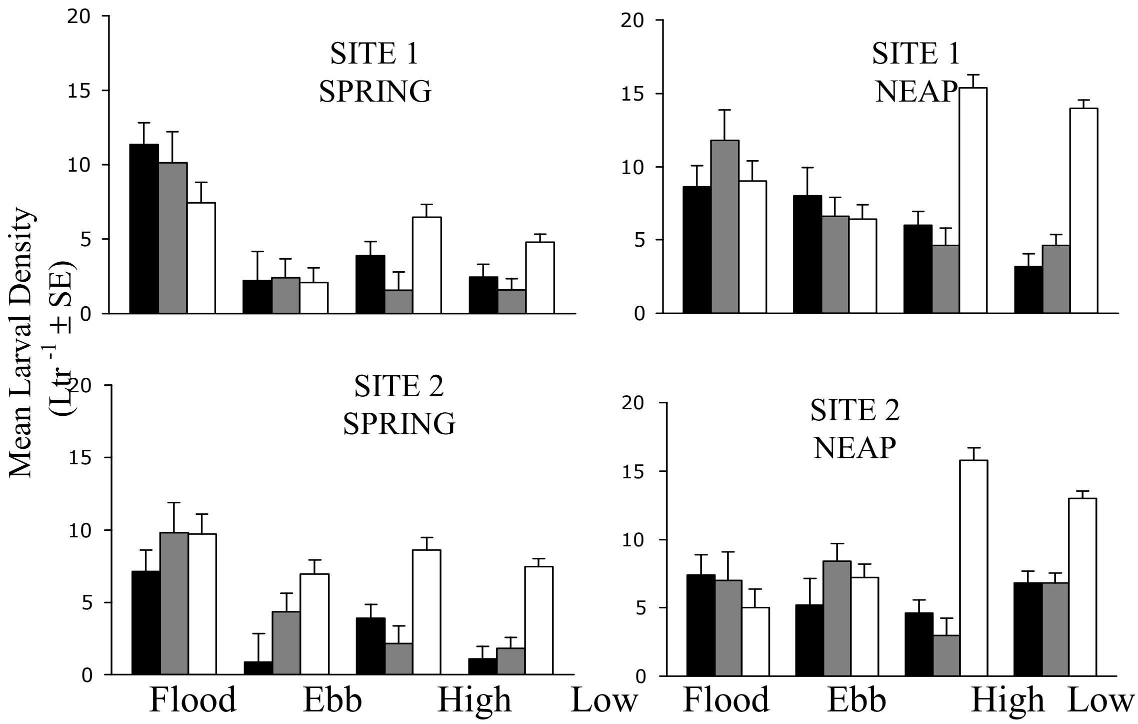


Figure 11. Mean density (± SE) of *Mytilus* spp. larvae in three depth zones: Top (black), Middle (grey) and Bottom (white). Samples collected over four tidal states and two phases at two sites during July/August 2005 (n = 5). See Knights *et al.* in press. MEPS.

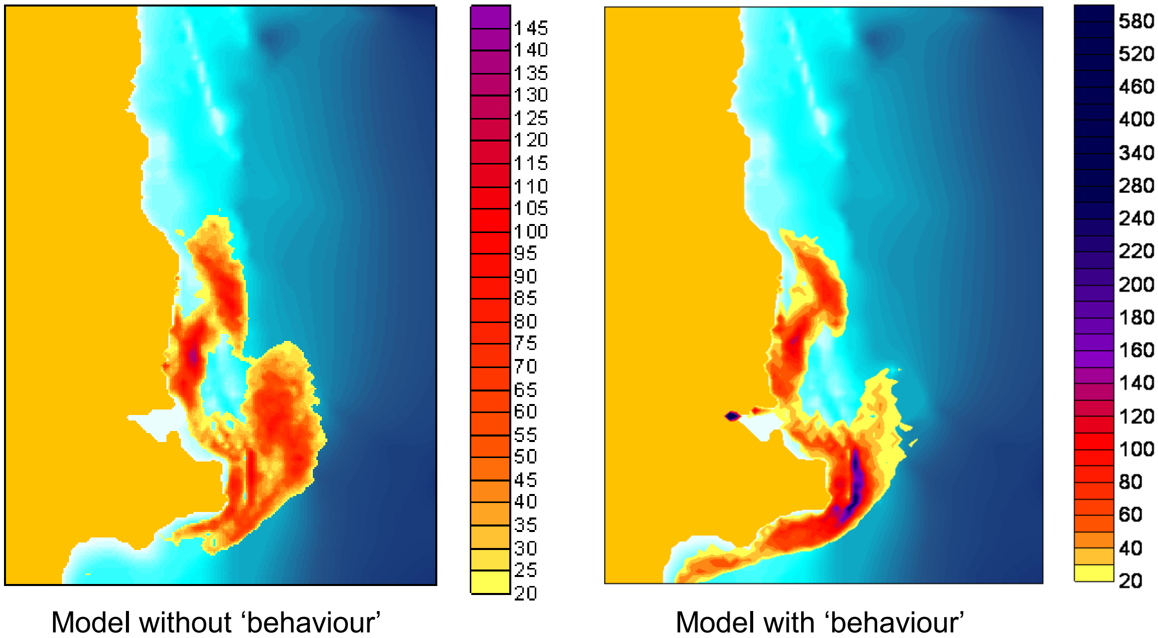


Figure 12. Lagrangian particle tracking (Coherens) hydrodynamic model showing larval dispersal (concentration per metre of water) assuming passive larval transport ('without behaviour') and with larval transport data ('with behaviour') included.

3.3 Model of the hydrodynamic patterns in relation to larval distribution and settlement

The use of hydrodynamic models to predict dispersal of commercially important species has become increasing common in recent years (Tully *et al.,* 2006). A predictive model was developed to indicate the likely distribution of seed mussel larvae in the Irish Sea taking into account the various currents generated by tides, wind and density differences. The three-dimensional hydrodynamic model COHERENS has been used for this purpose. The model development including calibration, validation, model setup, and relevant boundary conditions are presented in the end of project report. Details of model simulation and modelling of the larval behaviour including all relevant figures are described in Appendix I. In this section, the model results are outputted with a view to making recommendations regarding the implementation of a mussel management plan are discussed.

As described above (Section 3.2), the assumption that larvae behave as passive particles can limit the effectiveness of such models, leading to only partial success in predicting population distribution. The study of larval distribution in the water column (Section 3.2) indicated that mussel larvae do not behave as passive particles, but are stratified to differing degrees at different states of tides and are more abundant in the water column during flood than ebb tides. In order to test the influence of these patterns on modelling outputs, they were included in the model, with larvae distributed appropriately at the different stages of the tide. However, because data was only available for the Lucifer Bank site it was possible to include this behaviour for larvae from this site only.

Discussion of Results

River Induced Currents *(All Figures are contained in Appendix I)*

Figure A1.2 shows the currents produced by the freshwater river discharge along the eastern Irish coast. The freshwater expands seawards and then turns to the south (i.e. to the right looking seawards in the northern hemisphere) due to the Coriolis affect. The current velocities are quite small, the maximum velocity being 0.007m/s at the mouth of the River Boyne. In general streams with velocities of 0.002 – 0.005m/s are produced by the rivers, which extend from the River Boyne southwards along the entire coastline. The stream produced by the River Slaney, which appears to be the largest stream, extends all the way from Wexford Harbour around

Carnsore Point (at the south eastern tip of Co. Wexford) and westward as far as Baginbun. Although the above velocities may appear small nonetheless a particle travelling at these velocities could drift as much as 18km over a six week period (i.e. the length of a model simulation). Therefore one could expect these river induced currents to play an important role in the transportation of seed mussels from the time they hatch until maturity.

Wind Induced and Residual Currents

Particles were released from an arbitrary point in the middle of the Irish Sea to study the effect of wind direction on the particle distribution and also to examine the residual tidal flow in this area. Figure A1.3 shows the resulting particle distribution after 600hrs (i.e. 25 days) when a wind with an average speed of 10 knots is blowing from a south westerly direction. The corresponding distribution for a north easterly wind is shown in figure A1.4. The initial release point is also indicated on the figures. The contrast between the two scenarios can be seen by overlaying both distributions as in figure A1.5. From these figures it obvious that the prevailing wind conditions are important in determining the final location of the particles representing the seed mussels. There is not an enormous difference between the two distributions, but it is significant. It is also worth noting that 10 knots is an average wind speed and that much stronger currents would be induced in the event of a storm. Therefore, in using hydrodynamic models to predict settlement patterns over a particular period of time it is essential that the wind speed and directions during this period be known as accurately as possible.

Residual currents (i.e. those which are averaged over a period longer than a day) are caused by four different forces: wind, mean tide, density gradients and sea surface slopes. Figure A1.6 shows particle distributions overlaid on top of each other for output times of 25hrs, 300hrs, and 600hrs respectively. The wind velocity was set to zero and the temperature and salinity were constant so the net movement of the particles were caused by mean tidal forces only. As expected the particles diffuse in all directions and so the area they cover gets larger in time with a proportionate decrease in concentration. More significant however, is the net movement of the particles in a northerly direction which indicates the direction of the residual flow. According to the literature (Irish Sea Study Group, 1990) the flow through the Irish Sea averaged over a year or longer is northward from St. Georges Channel to the North Channel. This flow is weak averaging between 2 and 8km/day on a yearly basis. From the model simulations a flow rate of approximately 2.5km/day was observed, which is within this range. With an average south-westerly wind included in the simulations this flow rate would increase slightly. However, on a day to day basis this picture of a slow steady flow is misleading. The movement of seawater is inherently variable and even averaged over a month the overall flow can be southward if storms have occurred. Furthermore this flow northward does not extend as far as the Irish coast. Southward flowing water have been observed along the coast and are part of a general clockwise flow around Ireland. These southward flowing streams are particularly important in determining seed mussel transport since the seed beds are situated close to the coast.

Site by Site Analysis

It is important to note when analysing the output from the models that the model does not allow particles to remain lodged in the seabed but it has a bottom reflection condition which keeps the particles in the water column and therefore subject to motion throughout the simulation. The model does not allow for the fact that the larvae may stop on the seabed for a period during the course of their journey so that the distances travelled by the larvae (as predicted by the model) would represent the maximum distance away from their original position for a given time. This means that examining the overall path taken by the larvae is important in determining the most likely settling places of the larvae as well studying the predicted particle positions after a sufficient period of time has elapsed to allow the larvae to mature. The three to four week period (i.e. the outputs at 600hrs) are of particular importance since, as mentioned earlier, this is the time taken for seed mussels to reach metamorphosis. However, since the model probably over-estimates the distances travelled by the larvae, it is also important to look at the earlier output times particularly at 400hrs. The seabed and shoreline characteristics which provide favourable conditions for mussel settlement are also very important factors. The modelling study, however, only looks at the most likely locations for settlement and determining whether suitable environmental conditions exist at these sites is left to those who have a particular knowledge of the area. In the following site-by-site analysis, the figures are presented as particle concentration (i.e. number of particles/average water depth) at specific times after the initial release, which takes place at 0hrs.

Clogher Head

The results for the Clogher Head site are presented in figures A1.7 - A1.8. The initial release point is shown in figure A1.7. The most notable feature of these figures is that relatively speaking there was very little movement of the mussels throughout the entire 42 day simulation. This was not surprising due to the very low current velocities in this area. Some mussels do indeed drift southward but, they do not appear to be in sufficient numbers. Instead the majority of the mussels stay in the vicinity of Clogher Head and after 600hrs the highest concentration was located to the east of and slightly north of Dunany Pt. After this time they drift slowly northward. Therefore, based on the concentration snapshots of 400hrs and later, the predicted settlement locations are: around Clogher Head itself, from Dunany Pt across Dundalk Bay to Ballagan Pt.

The River Boyne

The results for the River Boyne site are presented in figures A1.9 - A1.10 with the initial release point shown in figure A1.9. What was immediately obvious from the diagrams was that the River Boyne was the dominant influence in determining where the seed mussels ended up. The southward flowing stream produced as the Boyne entered the Irish Sea carried the mussels southwards as far as Howth. The likely settlement locations were along the coast, particularly between Balbriggan and Skerries and around Malahide. The north side of Lambay Island was also a potential settling ground. Figure A1.10 also shows the possibility of a high concentration of mussels accumulated about 15km to the east of Howth Head towards the end of the simulation. This point corresponds to a raised sandbank where the depth is approximately 30m.

Dun Laoghaire

Figures A1.11 - A1.12 shows the snapshots of mussel concentration with time for the Dun Laoghaire site. The outputs clearly show a southward drift of the seed mussels with time due to a net southward current induced by the freshwater input from the River Liffey. The predicted settlement locations are anywhere along the coast from Dun Laoghaire as far as Wicklow Head but, in particular around Bray Head, which showed a high concentration of mussels at all of the model output times.

Wicklow Head

The results for the Wicklow Head site are presented in figures A1.13 - A1.14. The initial release point was located off Wicklow head in approximately 20m of water. Due to the greater water depth at this release point than at previous locations, the concentrations were lower and so a different colour scale was used for these figures.

The seabed off Wicklow Head is characterised by long narrow deep troughs and long shallow sandbanks. This rapidly varying bathymetry gives rises to strong tidal currents in the region of 2m/s or more on a spring tide. As a consequence the seed mussels were carried away from their source quite rapidly and even after 100hrs there was quite a spread in the seed mussel concentration plume. A significant number of these were carried in a northward direction towards the shore, while the remainder were transported to the south and into deeper water. The final settlement locations were between Wicklow Head and Bray Head and possibly along Arklow Bank to the south.

Wexford Harbour

Similar to the River Boyne seed mussel bed, the transport of seed mussels from this bed was strongly influenced by its position at the mouth of a river, in this case the Slaney (figures A1.15 – A1.16). The southward flowing currents produced by this river carried the mussels along the south eastern Wexford coast, around Carnsore Pt and along the south coast as far as Baginbun. A significant number of mussels remained in the south of the harbour. When the mussels got as far as Baginbun many of them were lost to the model domain as they crossed the southern boundary. The flooding tide carried the remainder back northwards again and a portion of these settled on the Wexford coast, north of Wexford Harbour, while the rest were carried northeast into deeper water. The concentration of the particles was very low at this stage. The most likely settlement locations according to the model were: south Wexford Harbour, Rosslare Harbour, along the coast north of Wexford Harbour and off the coast at Blackwater Bank.

Lucifer Bank

The Lucifer Bank site was the only site for which empirical data was available. Therefore the results using the behavioural data outlined in Section 3.2 could be compared and contrasted with results obtained using a uniform distribution. The results for the uniform distribution are presented in figures A1.17 - A1.18. The mussels were transported north and southward depending on the tidal direction and also towards the shore and into Wexford Harbour. The River Slaney again played a significant role and transported many of the mussels southward along the Wexford coast. Those that were transported northwards tended to settle in the Blackwater area and further north at Cahore Pt. According to the latter model outputs i.e. 800hrs and 1000hrs an elongated 'plume' of mussels was carried even further north and so another possible settling point for these mussels was on the Arklow Bank.

The mussel distribution patterns produced by the model when including the behavioural data are presented in figures A1.19 – A1.20. The difference between the patterns and those produced when using a uniform distribution illustrated the importance of including behavioural data in the model. The contrast between the two sets of data becomes more apparent as the simulation time increases. After 100hrs there was very little difference whereas at 200hrs the 'behavioural model' predicted a higher concentration of mussels in Wexford Harbour. This trend continued with the build up of mussels in the harbour being the most striking contrast between the two models. The 'behavioural model' also predicted significantly higher concentrations close to the shore which became more apparent with time (i.e. around Cahore Pt. after 1000hrs). These results were not unexpected given the preference of mussel larvae to move to the top of the water column during a flood tide. However, the concentrated build up of mussels in Wexford Harbour was not at all predicted by the uniform distribution model and thus demonstrated the value of employing 'behavioural characteristics' in a model.

Summary of Model Simulations

Hydrodynamic models are increasingly used to predict dispersal of marine species for management and research. With a lack of empirical evidence describing the 'behaviour' of many marine species with pelagic larval stages, such models have commonly modelled larvae as passive particles (i.e. no 'behaviour'). Using observations derived from a field-based study of the vertical distribution of *Mytilus* spp. larvae (see *Section 3.2.* and Knights *et al*., 2006), a comparison of models using: (1) passive dispersal of larvae, and (2) passive dispersal coupled with biological observations of larval 'behaviour' (see *Section 3.2*), was made to determine the influence of biological observations on the predictive efficacy of hydrodynamic models. Models using passive dispersal under-estimated larval dispersal during flooding tides and over-estimated dispersal during ebbing tides, in comparison to models incorporating larval 'behaviour'. The 'behavioural' model showed larvae were more highly aggregated and associated with estuarine and inshore regions than those dispersed passively. This indicates that model predictions employing simplified assumptions (i.e. only passive dispersal) must, be interpreted cautiously and indicate that the incorporation of biological data from empirical studies are vital if model predictions of population development and maintenance are to be improved.

Key Findings

- Hydrodynamic models were inappropriate without the incorporation of biological data of the target species
- Larval dispersal over-estimated during flood tides
- Larval dispersal under-estimated during ebb tides
- Larvae more highly aggregated and associated with estuarine and inshore areas in models incorporating larval behaviour than those assuming larvae behave as passive particles.

Recommendations regarding the implementation of a Seed Mussel Management Plan

1. Hydrodynamic models provide a very useful and relatively inexpensive tool for predicting the likely settlement locations of mussels (for one site only at this stage). With further development, the model could provide direct input to management decisions.
2. In applying the model predictions to a specific year and month, the relevant meteorological conditions and river flows should be included in the model for greater accuracy.
3. In the event of extreme or unusual weather conditions or river flows the final predictions for each site may be different than those presented above.
4. The importance of including mussel 'behaviour' in the model has been illustrated by the Lucifer Bank site simulations. The absence of this behaviour should be taken into account when examining the predictions for the other five sites.
5. It is recommended that a programme of sampling be conducted to verify the model predictions for each site – i.e. standard model validation
6. It is recommended that a programme of sampling be conducted to determine the seed mussel distribution in the water column at sites other than the Lucifer Bank site. These samples could then be used to determine if the 'behaviour' of the seed mussels at the other sites is similar.

3.4 Patterns of primary recruitment

In this document, the term 'recruit' is used to refer to an individual that has recently settled (not one which has recently become large enough to harvest); 'recruitment' is the number of such individuals sampled at a given place and time. To investigate patterns of primary recruitment (i.e. recruitment direct from the larval stage), several approaches were used. The main study involved monthly monitoring of intertidal beds at three locations to assess variation in magnitude and timing of primary recruitment. Intertidal beds are much more accessible than subtidal beds and may serve to indicate patterns of recruitment to subtidal beds.

Although the data set is patchy due to availability of samples, recruits were present in samples collected in every month of the year (Figure 13). However, recruits were not found in large numbers between late autumn and early summer (October – June).

Patterns of recruitment varied markedly from location to location and from year to year (Figure 13). At Clogherhead in 2003, there was a significant peak (approximately 1000 recruits per 9 cm^2 of scouring pad) that was confined to July (Figure 13). In 2004, the peak of recruitment at Clogherhead was maintained in June, July and September and reached a maximal mean value of 2,175 per 9 cm^2 of scouring pad at one site in September 2004. At Dalkey Island, no peak of recruitment was observed in 2003 or 2004, with low numbers of recruits (<20 per 9 cm^2 of scouring pad) being recorded in all months sampled.

At both sites, but particularly Dalkey Island, there were marked differences in magnitude (but not timing) of recruitment at two sites separated by only 10s of m (Figure 13). At Dalkey Island, Site A almost always received larger numbers of recruits than Site B. Combined with the consistently higher peak recruitment at Clogherhead than at Dalkey Island, this suggests that there may be sites of inherently greater or lesser recruitment potential at a number of scales in the Irish Sea. This implies that monitoring to assess timing and magnitude of recruitment in a given year would need to be conducted at multiple sites. It would also be of value to identify sites of inherently greater recruitment potential and to test whether there are any overriding regional patterns.

The key management recommendation that had been derived from this section was that the fishery commence in late July rather than early June. This recommendation is fully justified by the findings relating to the timing of spawning (*Section 2*).

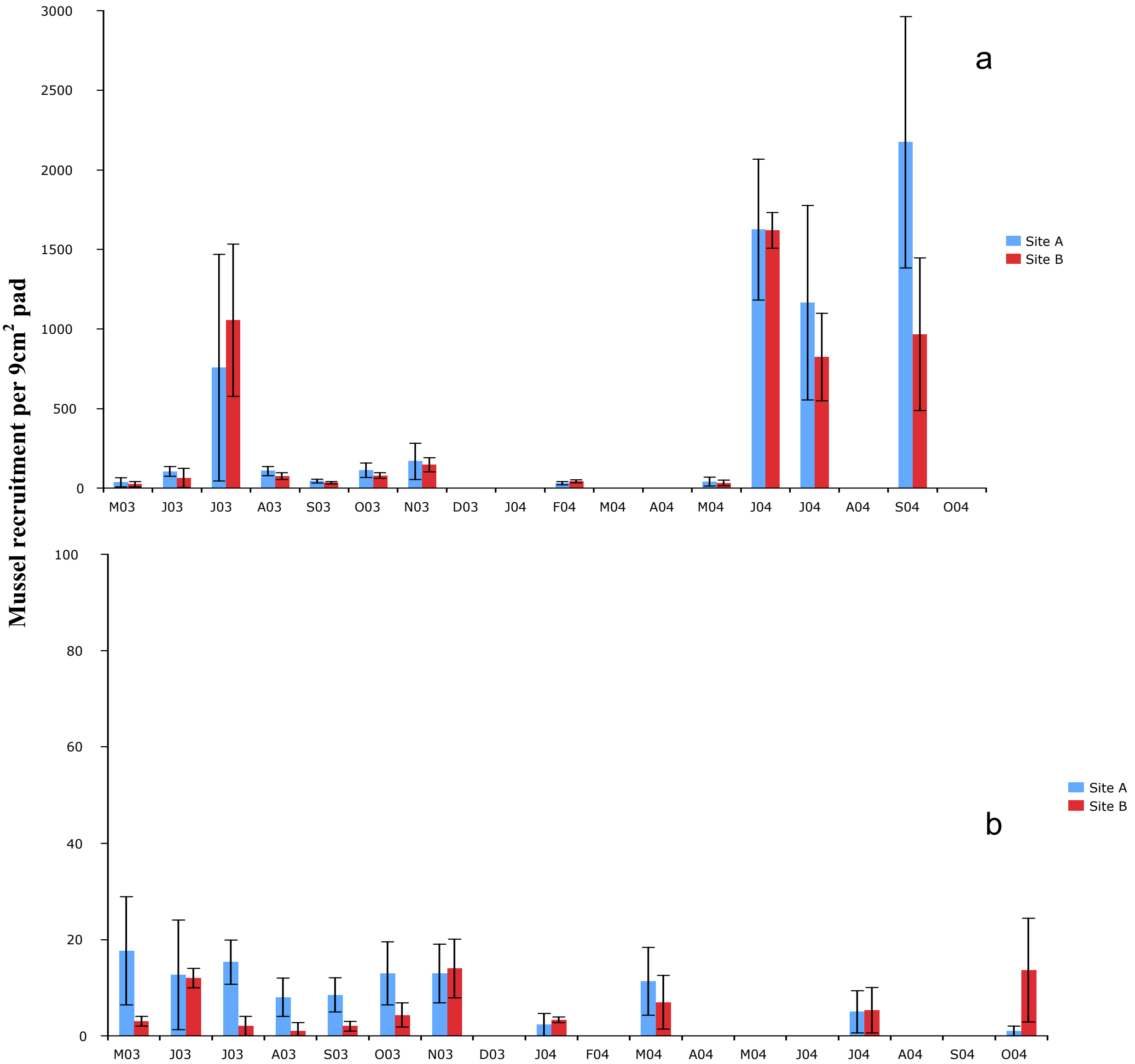


Figure 13. Recruitment of mussels into scouring pads deployed at two sites (A and B – indicated by blue and red bars) separated by 10s of m at each of (a) Clogherhead and (b) Dalkey Island in 2003-4. Each bar represents the mean (+sd) number of recruits found in 3 x 3 cm pieces of pad cut from each of 3 replicate pads deployed for 1 month. Gaps indicate months in which no data are available. Note difference in scales on Y axes.

4 PHYSICAL CHARACTERISTICS OF BEDS

4.1 Seed bed survival over winter

It is important to emphasize that mussel seed beds can be *stable* or *unstable*. As the seed beds mature, they initially stabilise the sediment matrix by increasing the sedimentation rate from the water column. However, mussel faeces and pseudofaeces production combined with accumulated shells and silt eventually result in a build up of "mussel mud" beneath seed mussel beds. This "mussel mud" layer can create an elevation of 30-40 cm above the surrounding bed, and may cause the whole bed to detach from the underlying substratum and become unstable. The most likely hypothesis to explain the ephemeral nature of seed mussel beds is that they are dispersed each winter with the onset of autumn storms, although density dependent secondary migration or predation may also be important (Nehls and Thiel, 1993; Reusch and Chapman, 1995; Hilgerloh *et al.*, 1997). It is important to bear in mind that many of the seed beds studied are also those which are fished and dredging is likely to destabilise seed beds. Studies in the Wadden Sea show that most of the seed mussel beds which were partially fished disappeared after fishing activity occurred, whereas the non-fished beds and bed areas remained. On the other hand, mussel farmers who dredge in Caernarfon Bay suggest that dredging may prolong the life of a bed such that it lasts through the winter. This is possible if a reduction in density due to dredging means that the mussels do not loosen their byssus as happens in more dense beds (Saurel *et al.,* 2004).

In this project, two approaches were used to determine whether Irish Sea mussel seed beds survived over-winter. In September 2004, a large bed was found at Blackwater towards the end of the harvesting season. It was therefore partially harvested and we were able to monitor its persistence through the winter. A dredging survey in February 2005 revealed that a significant proportion had persisted.

Our second approach had been developed in spring 2004, when no beds had been identified that could be protected over winter. We undertook sampling based on the proposition that if large mussel beds are destroyed during the winter months due to storms or predators, no mussels will be present in the sea the following spring. If large mussels are present in early spring they must have survived the winter, even if they are present in only small patches. This approach involved extensive structured surveys of the sea-bed in May 2004 and May-June 2005.

In May 2004, two areas, India Bank and Cahore Point, which had been fished in the 2003 season, were sampled using a Van Veen hand-grab. Each area was divided into 1 km^2 boxes (Figure 14). Within each 1 km^2 box a regular sampling grid of 25 points was established. At each point in 4 of the boxes in each area, a sample was collected using a hand grab. No mussels were found at any sampling point in either of the two areas. A few weeks later, however, dredgers harvested seed mussel from the areas surveyed. There are two possible explanations for this: either (a) the dredgers found seed mussels that had been present a few weeks earlier (i.e. had over wintered), but were missed by the EchoPlus / hand grab survey (e.g. because mussels were buried by sediment or because of the limited coverage of the hand grab) or (b) the seed mussels settled and grew to 20mm+ during the interval between the survey and the commencement of the dredging season. Given the fact that growth rates are generally <2mm per month, the latter explanation seems extremely unlikely.

A similar survey was again conducted at India Bank and Cahore Point in late May - early June 2005. This time the sampling was done using dredges (both commercial and hand dredges), along ten 100m tracks scattered randomly within each of 4 boxes in each area. Once again, no mussels were found in either area. In the subsequent 2005 season, very few mussels have been harvested from these areas by commercial fishers. This combination of findings (a double negative) does not make it possible to deduce the explanation for 2004's results. It suggests, however, that no mussels over wintered that year in the areas sampled.

Survey work on the Skullmartin seed bed in Northern Ireland in 2004 was undertaken by C-Mar using a combination of a RoxAnn Groundmaster seabed type discrimination system and side-scan sonar. Ground truthing was carried out with a small hand dredge (60cm wide) and a custom built Van-Veen Grab. Two peaks on a size frequency distribution were found at 16-18mm and 26-28mm, indicating that the bed contained seed from two distinct settlements. The larger cohort was likely to have remained from a settlement that occurred late in 2003. The mussel seed fished from the bed averaged 1575 (±245) pieces per kg (McDonough pers. comm.).

Overall, there is clear evidence that, at least in the Blackwater and Skullmartin, mussels can over winter in the Irish Sea. The extent of over-wintering (even in small patches) in other areas of the Irish Sea (e.g. Cahore Point, India Bank) is not yet fully clear. Beds have been found by commercial fishermen in May. BIM surveys have also revealed large mussels (26 mm, and in some cases 40 mm) in May (e.g. survey reports from Lough Foyle 17-19 May 2004 and off Wicklow Head 25-28 May 2004). As described above, it is extremely unlikely that these could have settled and grown that spring. It is therefore very likely that mussels do survive over winter at a number of locations. Given the doubt surrounding findings from surveys on uniform grids using small-scale hand grabs, it is clearly better to use carefully structured sampling programmes using commercial dredges to test hypotheses about the extent of over wintering and to survey for seed in the late spring.

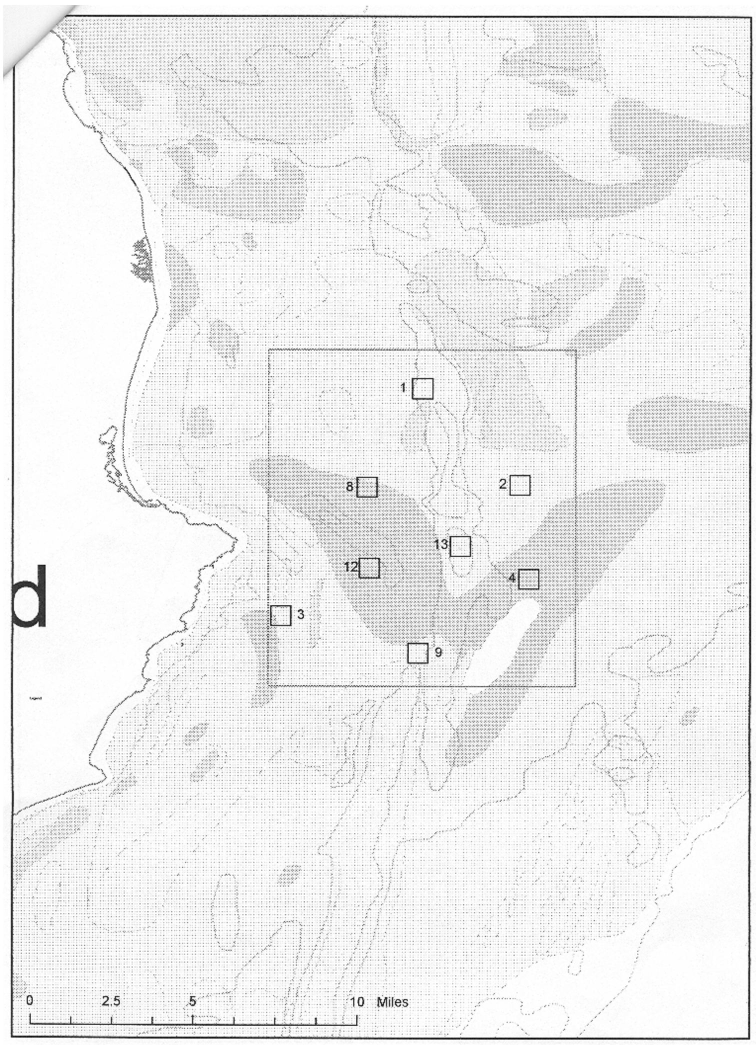


Figure 14. Arrangement of 1 km^2 boxes sampled within a defined area off Wicklow Head (India Bank), boxes numbered in order of priority for sampling. A similar arrangement of boxes were sampled off Cahore Point. A new set of boxes was randomly selected within the area on each sampling occasion. Within each box, 10-25 samples were taken (see text for details).

4.2 Dredging in the Irish Sea

The effects of dredging on the seabed has been described by Maguire *et al.* (2002). On soft / sandy grounds, the most noticeable environmental impact of dredging is the burial of organic material (Mayer *et al*., 1991) thus, making it unavailable for consumption by animals further up the food chain such as meio- and macro-faunal species and instead favouring anaerobic microbial respiration. This leads to increased proportions of remineralisation products such as CO_2. Anoxic conditions can occur within a few millimeters of the sediment-water interface. The impact of dredge fishing gear on grounds where severe disturbances are naturally rare or absent depends on substrate type. Soft bottoms comprise sediments with very small mineral grains bound loosely with organic material and associated microorganisms, in which live epifauna and infaunal macroorganisms. After a disturbance these grains can be carried away by the current thus leaving a harder substrate in their place. Also on pebble, sandy and muddy ground, homogenisation of the bottom eliminates habitat features important to recruits.

A study by Davies (2003), examined by-catch taken by a commercial mussel seed dredger and overall a total of 33 taxa from 29 families were identified as mentioned earlier. The combination of being towed in the dredge with rocks and stored in the hold (up to 12 hours during dredging and transport to the pier or relaying site) stresses both the mussels and non-target species. Finally the method of pumping the mussels from the hold, using water to fluidise the seed, can also impact the target species due to the presence of rocks (up to 50% by weight). Generally the biodiversity associated with Irish mussel seed beds appears to be low when compared with other commercial fisheries and would lie outside the top twenty fisheries with respect to discard ratios by weight (Alverson *et al.,* 1994). A detailed description of seed bed biodiversity is outlined in Appendix II.

Further scientific studies on by-catch need to be carried out especially with regards to the possible negative impacts that they might have on the relayed seed. For example if whelks and starfish are not killed during transport, then they will continue to prey on the mussels in their new site. On top of this, any dead and moribund by-catch will attract indigenous predators to the newly laid seed.

5. ALTERNATIVE TO DREDGE FISHERY FOR SEED

5.1 Artificial Collection and Hatcheries

The recent expansion of bottom mussel cultivation in Ireland has generated a need to explore alternative sources of mussel seed to supplement or even replace the current reliance on an unpredictable wild seed resource. Two options currently under consideration are:

- Collection of wild-settled seed on artificial materials
- Hatchery production

The purpose of this desk-based investigation was to review previous work and available information on a global scale on both of the above seed supply methods. By examining the success, cost and commercial application of mussel seed collection and hatchery production globally, it is hoped to provide a technical and economic appraisal of the potential of each method to supply the Irish industry.

Mussel farming is carried out on a commercial scale in a number of countries in Europe, North America, South America, Asia and Australia. Depending upon the species and the ongrowing method, seed supply falls into one of four categories: inter-tidal seed collection, sub-tidal fishing, artificial collection and hatchery production. Table 6, illustrates what methods are practiced and where.

Table 6. Global seed supply sources extracted from the literature (references cited).

Country	*Method of seed collection*				*Reference*
	Inter-tidal shore seed	Sub-tidal Seed beds	Suspended collectors	Hatchery	
Australia			✔	✔	Anonymous, 2003
Canada			✔		McDonald *et al.*,2002
Chile			✔	✔	Illanes, 2002
China	✔		✔	✔	Qisheng *et al.*, 2002
Denmark		✔			FAO
England		✔			Saurel *et a.l*, 2004
France			✔		Prou and Goulletquer, 2002
Germany		✔			Walter and Liebezeit, 2003.
Iceland			✔		Gunnarsson and Theodórsson,2001
Ireland	✔	✔	✔		O'Carroll, 2002
N. Ireland		✔	✔		
Korea			✔	✔	http://www.lib.noaa.gov /korea/main_species/mussel.htm
Netherlands	✔			✔	Bol, 2002
New Zealand	✔		✔	✔	Hearn, 2002
Spain	✔		✔		Fuentes *et al.*, 1998
Norway			✔		Lekang *et al.*, 2003
Scotland			✔		Karayücel and Brown, 1997
Sweden			✔		Hammer, 1994
USA		✔	✔	✔	King and Cortes-Monroy, 2002
Wales		✔			Saurel *et al*, 2004

5.2 Artificial Spat Collection

Mussels can and do settle in very high densities on collector materials placed in the water column in a suitable location and at a time of year when larvae are in abundance and ready to settle. A number of key factors influence the success of artificial seed collection: a good broodstock resource, close proximity to spawning grounds, good water exchange, an abundant supply of food (phytoplankton) a sheltered site and a low incidence of fouling organisms (Qisheng *et al.,* 2002). Ireland's rope mussel sector is currently entirely reliant on artificial seed collection as a source of seed for ongrowing. However, artificial seed collection may also have potential as an alternative source of seed for the bottom mussel sector.

Numerous studies have investigated factors which can affect mussel spat settlement, settlement patterns by season and geographical location and performance of different collector materials. An artificial collector trial conducted as part of the current study found maximum mussel seed settlements of 7,000 per metre of collector material (Ceann Mara mesh) at a depth of 2-3m in Strangford Lough, Co. Down. Maximum settlement occurred on a collector deployed on 17 April 2003 and the size of mussel seed when the collector was retrieved four months later ranged from <1mm to 18mm, indicating that settlement was occurring throughout the entire period that the collector was in the water column. Other studies such as Walter (2004), Kamermans and Brummelhuis (2003)and Lekang (2003) have found similar levels of settlement in Germany, Netherlands and Norway respectively.

Some studies have investigated the success of collector seed when transplanted to the seabed. Kamermans (2003) found that survival of artificially collected seed transplanted on the seabed was lower than that of wild seed but that growth rate was higher. Walter (2004) transplanted collector seed in the Lower Saxonian Wadden Sea with poor results. Transplanted seed was washed away by strong tidal movements and suffered heavy predation. Both studies found no difference in shell thickness between collector seed and wild seed.

Owing to the limited supply of wild mussel seed available for fishing each year in Ireland, there is increasing use of artificially collected seed for bottom cultivation. During 2005, 3,246 tonnes of collector seed were transferred to licensed seabed aquaculture plots for ongrowing (DCMNR documented movements). Undocumented movements of collector seed to seabed plots may also have occurred. The vast majority (97%) of the documented movements of rope mussel transferred for relaying originated in Bantry Bay. This was largely driven by biotoxin closures in the Bay as growers needed to achieve a financial return on mussels that they could not send for processing or to market. Other source areas included Ardgroom, Castlemaine, Beara, Berehaven, and Killary Harbour. Notable features of this practice included:

- Prices paid for rope collected seed by bottom growers varied between €250 and €400 per tonne
- The size of mussels supplied varied from 20mm to market size (50-60mm)
- Seed was mostly transported loose (i.e. had been removed from the dropper) in one tonne bags and was generally perceived to be of good quality

Only a limited amount of monitoring has taken place to assess the performance (growth and survival) of collector seed relayed on the seabed. Bantry Bay rope mussels relaid in Lough Swilly in 2004 and 2005 have showed mixed results. Transport mortalities were estimated as 10-15% and a large proportion of the mussels laid on the seabed in 2004 were lost to starfish predation. However, growth of the surviving stock was found to be equivalent to that of relayed wild seed. Significantly better results were achieved with seed that had been artificially collected in Lough Swilly itself, indicating that prolonged transportation could reduce success of ongrowing or that seed which has settled in the same area might exhibit better growth and survival in the ongrowing phase (O'Sullivan, pers. Comm.).

A number of factors will dictate whether the use of artificially collected seed for bottom culture will continue or increase:

1. Supply of wild seed mussel available to the industry in any given year
2. Final destination of fished wild seed
3. Spatfall of mussel seed in major rope mussel areas (variable annually)
4. Continued or prolonged closures of rope mussel bays resulting from biotoxin contamination
5. Performance (growth, survival, meat yield etc) of rope-collected seed when transferred to the seabed

Further research on the performance of rope mussel seed in bottom culture would establish if it has continued potential as an alternative supply of seed for the bottom mussel sector.

5.3 Mussel hatchery production

While most mussel producers rely on natural collection of seed where it is readily available in the wild, the variable nature of its settlement can lead to problems in meeting a consistent and rising market demand (Brake *et al.,* 2000). Hatchery production is usually employed when the cost of production is sufficiently low and/or the market price of the final product is sufficiently high to make hatchery production a feasible option. Hatchery production can also develop as a result of an unreliable supply of wild spat (fished or collected) or when other problems such as disease prevent continued production of a local species.

There are a number of advantages to a mussel hatchery programme, not least the potential for year round production of seed at a predictable price. Hatchery techniques used in bivalve culture can also select for faster growing mussels through progressive grading and facilitate selective breeding to optimise growth rates, yields and disease resistance (King and Cortés-Monroy, 2002). The production of triploid seed is also possible. That triploid progeny are essentially sterile provides a commercial benefit, as metabolic energy normally targeted towards gonadal development may instead be diverted to somatic growth, leading to increased growth rates (Gosling, 1992). Also, as they do not spawn, triploids can be harvested and shipped year-round.

The primary drawback of hatchery production is the potential cost of production when compared with that of seed supplied through more traditional sources (in Ireland seed is currently wild fished for the bottom culture industry and artificially collected for suspended cultivation). The development of a dedicated mussel hatchery to supply the mussel aquaculture industry in Ireland would require a significant capital investment. If such funds were not forthcoming, hatchery production would need to utilize existing bivalve hatcheries.

The study reviews mussel hatchery production globally and uses the information to assess:

- Is hatchery production a feasible alternative for the mussel industry in Ireland?
- Is there potential for hatchery-produced seed to be used for seabed cultivation?
- What are the key factors or problems that must be addressed to make hatchery production a reality?

Hatchery production techniques

On a global scale, commercial production of mussel seed using hatchery methods is currently undertaken in seven countries and for a range of species:

Australia (Tasmania, Victoria)	- *Mytilus edulis planulatus*
Chile	- *Mytilus chilensis* / *Choromytilus choros*
China (Liaoning, Shandong)	-*Mytilus edulis* / *Perna viridis* / hybrid
Korea	- *Mytilus edulis / Mytilus coruscus*
Netherlands (Yerseke)	-*Mytilus edulis*
New Zealand	- *Perna viridis*
USA (Washington, Hawaii)	- *Mytilus galloproviancialis;*

Hatchery production of mussel seed was first practised on a commercial scale in China. Experimental work on *Mytilus edulis* began there in 1958. Since then, the technology has improved significantly and allows several batches of seed to be produced each year. With the success of cross fertilization of *Mytilus edulis* and *Perna viridis* in the Guangdong province, China's mussel industry, strongly underpinned by hatchery seed production, is in a healthy state (Menzel, 1989; Qisheng *et al.,*2002).

Hatchery production of mussel seed in Washington State on the Pacific coast of the US began in the early 1990's owing to poor survival at maturity of the native species, *Mytilus trossulus*. Two commercial hatcheries, Taylor United and Coast Oyster, began production of *Mytilus galloprovincialis* seed for sale. These hatcheries now supply all of the mussel growers on the western coasts of the US and Canada with the exception of Penn Cove, which still produces about 75% *Mytilus trossulus* (J. Davies, pers. comm.).

Techniques for hatchery production of *M. galloprovincialis* in the US are similar to those for other bivalves such as clams and oysters. Once sufficiently ripe to spawn (August-March in Washington State), the mature mussels are cleaned and hung in tanks to spawn naturally. Alternatively, for specific crosses and triploid production, mature adults are separated by gender and spawned in trays and individual containers with the resulting eggs and sperm subsequently mixed together. For triploid production, fertilised eggs are chemically treated (cytochalasin or 6-dimethylaminopurine) or subjected to heat shock. Once spawning is completed, it takes approximately fourteen days before larvae are ready to settle. The pediveliger larvae are settled onto 160μm downwelling screens or directly onto substrate in a well aerated tank. The settled spat reach approximately 1mm by 6 weeks and the seed are then transferred to fibreglass window screen frames and placed in a netted cage. The seed are transferred to the final grow out substrate at a size of 6-10mm (King and Cortés-Monroy, 2002).

In Tasmania, Shellfish Culture Ltd. use similar technique is to produce *Mytilus edulis planulatus*. However, seed are settled onto ropes in large settlement tanks and remain there until they reach 1mm in size. At this stage mussel seed can be supplied to the grower as newly settled spat supplied on 4 metre dropper ropes or the ropes are transferred to the sea nursery where they are grown to the size required by the customer (to a maximum of 20mm in shell length).

Notably, given the terms of reference of the current work, practically all commercial hatchery-produced mussels are ongrown to market size in suspended cultivation. However, the only commercial mussel hatchery currently operating in Europe is an exception to this rule. The newly developed hatchery at Yerseke in the Netherlands is producing mussel spat with the ultimate goal of ongrowing on the seabed. The hatchery was set up in 2004 by Roem Van Yerseke B.V., a Yerseke-based shellfish company, with the sole aim of providing an alternative source of seed for the company's mussel farming operations. The hatchery does not (and has no plans to) supply other mussel production companies.

The Roem Van Yerseke hatchery employs 3-4 people on a full-time basis and plans to produce 200 million spat during 2006. The hatchery is located in a former mussel factory on Zoelenstraat, where broodstock conditioning and larval rearing takes place (a spawning is undertaken every 3-4 weeks). When the settled spat reach 1.5mm they are transferred to nearby ponds (20m x 10m) for nursery cultivation. Once they have reached between 4mm and 6mm, the spat are ready to be transferred to the Oosterschelde for ongrowing. The spat produced to date have been ongrown both in suspended cultivation and on the seabed. While the suspended mussels have grown well and are proving successful, the bottom-grown mussels have fared poorly. As expected, crab predation has been the primary problem. The company has set a realistic objective of 10-15 years to develop a cost-effective hatchery-produced spat product that can be grown on the seabed as with the vast majority of current mussel aquaculture in the Netherlands (Geijsen, pers. comm.).

Although there is no commercial source of hatchery-produced mussels in Ireland, mussels have been produced at the Redbank Shellfish hatchery in Co. Clare (Connellan, pers. comm.). It is anticipated that there may be a demand for hatchery-produced seed to supply the rope mussel industry in the future (I. Connellan, Redbank Shellfish, pers. comm.). This is based on the unreliability of artificial collection of mussel seed and also the potential for "out of season" mussel crops which can be permitted through hatchery production. Redbank successfully produced 140 million settled spat in 2004 and settled them on a wide range of substrates. Nursery production was carried out in ponds and a number of conclusions were drawn from this work:

- Recent studies have shown that spawning can be induced with chemicals
- Once spawning is achieved, larval rearing is relatively straightforward
- Mussels settled very evenly on all substrates tested
- Attachment is strong and settled spat are easy to handle
- Spatting ponds may not be the best option for nursery cultivation – may be best put straight out to sea
- Work is needed to determine optimum methods of conditioning broodstock for year-round spawning (Connellan, Pers. Comm.).

Figure 15. Adult broodstock *M. edulis* spawning following thermal cycling (*courtesy Iarflaith Connellan*)

Figure 16. *M. edulis* pediveligers surface rafting (*courtesy Iarflaith Connellan*).

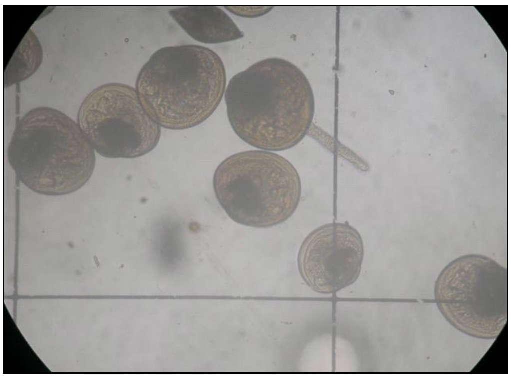


Figure 17. *M.edulis* pediveligers ready to settle (*courtesy Iarflaith Connellan*)

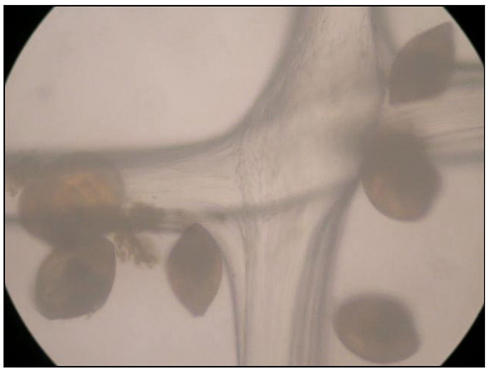


Figure 18. *M. edulis* spat settled on mesh (*courtesy Iarflaith Connellan*)

5.4 Biological feasibility of hatchery production

Given that the current study is targeted toward seed supply solutions for the bottom mussel sector, a critical concern is whether hatchery produced seed can survive on the seabed or is suitable, in general, for bottom cultivation. Leaving aside any economic arguments against "planting" hatchery seed on the seabed, the practical viability is largely untested (save for the current work by Roem Van Yerseke, which is at a very early stage). It is too early to determine if hatchery-produced seed can survive and grow on the seabed with similar levels of success as are achieved for wild-caught seed. Concerns naturally exist that seed produced in a hatchery will not be sufficiently robust to withstand transfer to the seabed when compared with wild-caught seed which has naturally settled and grown in that more testing environment.

Assuming a reliable source of good quality hatchery-produced mussel spat (not readily available in Ireland), a research programme would need to be undertaken to compare the performance of hatchery produced seed with that of wild fished seed and artificially collected seed. Initial laboratory investigation should compare shell thickness, shell strength, strength of adductor mussel, ability to withstand a range of stress tests including prolonged emersion, extreme conditions during emersion, salinity and temperature tolerance.

Replicated growth trials could focus on standard performance indicating factors including growth, survival (and causes of mortality), meat yield etc. As results from ongrowing trials will relate strongly to local conditions at the site where ongrowing experiments are conducted, it will be necessary to monitor water quality parameters that can influence growth and survival (temperature, salinity, food availability etc.).

Should initial trials with hatchery-produced seed prove that it may be viable as an alternative to wild caught or artificially collected seed, then research should focus on producing an optimum quality seed in the hatchery. If suitable facilities and capacity were available, a selective breeding programme could be undertaken in order to produce family lines selecting for characteristics that are optimal for aquaculture production. Finally, a functional genomic investigation on *Mytilus edulis* could complement the proposed selective breeding programme, whereby genes that code for key traits are identified and characterised.

5.5 Economic feasibility of hatchery production

The other key issue relates to the economic viability of planting hatchery-produced seed on the seabed. Given the much lower expected survival rates of mussels in bottom cultivation compared with rope-grown culture, employing hatchery production to supply seed for the bottom mussel industry may be simply uneconomical. Because the factors that determine cost of production are so broad and varied it is difficult to make any estimations on how much it would cost to produce hatchery seed and, in turn, the potential per-unit cost that the industry would have to pay for this seed. A number of inter-related factors will determine the cost of production and purchase price including *inter alia*:

- Scale of reliable demand (would depend on status of other seed sources)
- Timing of peak demand (may clash with established production of other species)
- Scale of production required to meet demand
- Other activities of hatchery
- Capacity of hatchery (size, equipment, staffing levels)
- Location of hatchery (availability of sufficient pond space for nursery production / proximity to ongrowing areas)
- Success rate of mussel production

In the U.S., 2005 prices (to the grower) for seed produced at the Taylor Shellfish hatchery in Washington State were as follows (J. Davies, Pers. Comm.):

(Seed size: 500-1000μm on droppers)
1-5 million seed: US$2,500 (€1,950) per million
5-10 million seed: US$1,950 (€1,520) per million
>10 million seed: US$1,900 (€1,480) per million

Prices for seed (*M. edulis planulatus*) from Shellfish Culture Ltd, Tasmania, Australia in 2005 were as follows(R. Pugh. Pers. Comm..):

AU$2,100 (€1,230) per million seed @ size range 500μm+
Or AU$3,000 (€1,750) per million seed @ size 4mm on hatchery droppers (4m long 12mm braided rope)

This illustrates the high cost of hatchery-produced seed. The cost of production is considerably lower than the sale price but the hatchery must take into account the risks involved and miscellaneous and unforeseen costs in hatchery production. Simple economics dictates that a higher demand for hatchery produced seed will result in lower per-unit prices to the grower.

A basic economic analysis (using figures for general hatchery running costs supplied by Iarfhlaith Connellan of Redbank Shellfish) allows an estimation of what hatchery produced mussel seed might cost to produce in Ireland. With running costs for the hatchery of approximately €4,500 per month (does not include capital costs, maintenance or depreciation), and costs for necessary labour input at €7,000 per month, Redbank could realistically produce approximately 20 million settled mussel pediveligers in one month. A further month will allow this spat to be grown in nursery conditions (ponds) or on longlines at sea at an estimated cost of €4,500 (€3,000 in labour and €1,500 in running costs). It follows, therefore, that a hatchery on the scale of Redbank Shellfish could feasibly produce 20 million mussel spat ($\geq$1mm) settled on onto trays for approximately €11,500, which equates to €575 per million or 57.5c per 1000. If sold at equivalent prices to Taylor Shellfish (approx €1,600 per million), this would represent a healthy return for the hatchery.

Unlike the Puget Sound mussel farmers, however, rope mussel growers in Ireland currently prefer to start with settled spat of at least 5mm in shell length. More importantly, given the scope of the study, it would appear to make little economic sense to incur such a high cost in seed production to then relay the seed on the seabed with all of the uncertainties that this would involve. Seed for seabed cultivation would need to be ongrown in suspended culture to a minimum of 15mm or even 20mm in shell length before it would be sufficiently large and robust to risk planting on the seabed. This further ongrowing in suspended culture would add to the per-unit costs already described. Having incurred such a major expense and invested so much time and effort to bring the mussels through to this stage, it would make more sense to bring the mussels to market size in suspended culture and achieve maximum returns in terms of yield and survival.

A combination of two or more of the following factors may make hatchery production for seabed cultivation a viable option:

- A major increase in market price of finished product
- A collapse of the wild seed fishery
- A collapse in settlement on artificial collectors

Currently, there are three hatcheries operating in Ireland that would have the capacity to produce mussel seed at commercial levels: Redbank Shellfish, Co. Clare (Iarfhlaith Connellan), Lissadell Shellfish, Co. Sligo (Kevin O'Kelly) and Boet Mor Seafoods, Co. Galway (Jean leDoervan). These hatcheries produce other shellfish seed including pacific oysters, native oysters, clams, scallops and abalone. It is likely that there would need to be a clear demand for hatchery produced mussel seed before any of these hatcheries invested in mussel hatchery production.

6. RECOMMENDATIONS

There are a number of recommendations that have resulted from the findings of this study. These take the form of direct recommendations towards the management of the industry that can implemented immediately and others take the form of additional research or investigations that will validate some preliminary observations resulting from this project.

Recommendation 1 Science-based management systems
To develop a science-based management system for the sustainable exploitation of seed mussels in the Irish Sea. This should result in the implementation of fishery plans based upon scientific evidence and survey effort involving close collaboration between state agencies and industry. The case study of the Netherlands mussel industry (Appendix IV) is a good working model upon which to base such a management system.

Recommendation 2 Optimum time of year for dredging to take place
The results indicate that subtidal populations having originated from over-wintering beds or have settled early in the season can become reproductively active and contribute to the current year settlement. As a consequence, it is recommended that in order to facilitate a complete spawning season and subsequent larval development and recruitment that the southern Irish Sea fishery commences at least two months after the last spawning has been observed. Therefore based upon the information to-date the season should commence in late-July rather than early-June. The exact timing should be informed by weekly surveys of gonadal development and settlement patterns in the Irish Sea. The delay in the season will allow the harvest of larger sized mussels, which will increase the mussel biomass and ensure greater potential survival when relayed.

Recommendation 3 Closed areas
There is evidence that at least some subtidal mussels over-winter in the Irish Sea. If areas containing resistant beds can be identified and those beds are considered to make a significant contribution to larval production, then there would be a strong case for protecting some of them from harvesting. This would correspond to the system that has been developed in the Netherlands, in which beds are determined to be either ‘stable’ or ‘unstable’ and ‘unstable’ beds are harvested first. To implement such a system in the Irish Sea, it would be important to determine which beds are stable and which are not (*See Section 4.1*). To date, the only beds for which we have direct evidence of survival overwinter are the Blackwater and Skullmartin beds. Some beds may be inherently protected, e.g. by the presence of windfarms (e.g. Arklow bank) or rocky reefs (eg part of Schullmartin bed) and these may also contribute to larval production.

We have yet to confirm the locations of the main sources of mussel larvae (intertidal, subtidal or estuarine beds). When these have been identified (part of the output of workpackage A), strong measures should be taken to protect them and to promote maximal output of larvae. It should be noted, however, that it will not be possible to be sure which sources of larvae actually supply the dredged beds themselves because it is not yet possible to identify the source of any given settling larva. This capability could potentially be developed through genetic analyses coupled with hydrodynamic modelling.

This study has deduced that subtidal mussel beds can survive over-winter and may contribute to early season recruitment in subsequent years. As a consequence, it is recommended that the location of stable seedbeds (those that survive for more that one winter) is confirmed and a management plan for each of these beds is established, which might include information such as the minimum viable stock to remain on the seedbed following harvest.

Recommendation 4 Long-term monitoring of spawning patterns

In a non-published study carried out by Stephenson and Davenport in 1993 to investigate the reproduction and settlement patterns of the blue mussel in the Firth of Clyde Scotland, they concluded that "monitoring adult reproductive state and of the population structures of mussels on their primary settlement sites allows the onset of significant settlement to be predicted with some confidence" (Davenport pers. comm.). Thus pre-season assessments of the reproductive state of mussels can give some indication of recruitment quantity. However, mass spawning is not a guarantee of mass settlement. Belzile *et al*. (1984) reported that mussel plankton represented up to 66% of the total zooplankton in a Canadian bay. However, mortality in larvae is very high and is estimated to be 99%. The main causes are predation, starvation and adverse environmental conditions (Jorgensen, 1981). In the same study, he followed a cohort of *M. edulis* larvae in the plankton of Isefjord, Denmark and found a daily mortality rate of 13%. Because mortality is so high, it would be impossible to use any combination of these factors to predict larval settlement accurately.

De Vooys (1999) concluded that larvae had a higher survival rate at low larval concentrations in the field. He also suggested that inter-annual differences in plantigrade abundance could not predict mussel recruitment success on tidal flats in the Dutch Wadden Sea, which can vary by a factor of 1,000 (Honkoop and Van der Meer 1998). Similarly, Chicharo and Chicharo (2000) measured *Mytilus galloprovincialis* larval abundance and environmental parameters (temperature, salinity, chlorophyll a, wind velocity and tidal amplitude) in the Ria Formosa, Portugal. They concluded that the availability of settlement substrates and not larval numbers or environmental conditions was the key factor in the recruitment of mussels.

Even though annual monitoring of the spawning cycle of mussels in the Irish Sea may not accurately indicate final settlement numbers. It can indicate the timing of settlement. In general, the larval life of a mussel can is four to six weeks (if a suitable settlement site can be found). The timing of spawning and settlement is invaluable information for long term monitoring of recruitment and for the overall management of the fishery.

Generally, in Ireland the activation of the gonad commences during October and November and gametogenesis takes place over winter. Spawning can occur in spring followed by rapid gametogenesis so that by early summer the gonads are again fully ripe. This second period of gametogenesis is associated with mussels living in optimal conditions where there is plenty of food e.g. the lower intertidal or subtidal zone. Less intensive spawnings may occur throughout the summer and by September the gonad index reaches its lowest value and the resting phase begins again. From August to October energy reserves are built up in the mantle, which will fuel gametogenesis during the winter (Seed and Suchanek, 1992).

However, *M. edulis* show a remarkable ability to adapt their reproductive strategy according to prevailing environmental conditions. Studies have shown that gamete release can occur throughout the year with peaks occurring in spring and summer (Fell and Balsamo 1985). The specific timing of spawning in the Irish Sea for the past three years has been described in this study. The timing of peak spawning has been narrowed to a period of 1-2 months. Decisions about exactly when to open the dredging season to enable such spawning to take place require finer scale resolution. It is recommended that timing of spawning is measured on a weekly basis during the months of May–August for 2-3 years.

Recommendation 5 Early recruitment and stock assessment – annual seed survey

Seed mussels are a natural resource that requires proper management and exploitation in order to maximise the potential return. Due to increased pressures on this resource in recent years a formal set of guidelines are required. The policy document outlined in *Appendix IV* is the result of consultation with the bottom grown mussel industry and government bodies both North and South and is subject to review from time to time.

Since 2003, DCMNR and DARD Fisheries Division (Northern Ireland) have implemented a joint management strategy for the exploitation of mussel seed in the Irish Sea, Carlingford Lough and Lough Foyle. The Seed Mussel Allocation Committee (SMAC) is the body that allocated tonnage to operators annually. SMAC is comprised of representatives from a number of State agencies and government departments both north and south of the border.

In order to make seed allocations realistic, SMAC relied on information provided through annual surveying for mussel seed carried out in the Irish Sea, Lough Foyle and Carlingford Lough. Seed mussel survey data came from two sources:

- Industry (surveys carried out by the operators themselves)
- State Agencies

The main difficulties in making seed allocations has been the shortfall in good survey data (*See Section 1.2.2*). Therefore, that overall mussel seed survey strategies need to be refined and improved in terms of:

- Extent of survey effort
- Location of survey effort
- Timing of survey effort
- Protocol and equipment used to survey

Recent discussions between the agencies involved in surveying and research work on mussel seed have highlighted the need for a more co-ordinated approach to surveying for mussel seed. It is proposed that two standard mussel seed survey protocol documents be developed; one for industry and one for state agencies. The protocols will ensure consistency of survey effort and the most effective use of time and resources invested in surveying. The protocols will, in turn, be used to develop an overall strategy for seed surveying in future years.

The development of this public/private partnership will have three primary benefits:

- Improve the return from survey effort in terms of locating new and traditional seed settlements, bed demarcation, biomass estimation and seed quality assessment
- Establish the amount of seed available quickly for the determination of harvesting quotas.
- Enable consistency in survey methodology which will allow survey data and results from different teams/operators to be directly compared. This will facilitate the development of a long-term dataset for mussel seed settlement in the Irish Sea and the two Loughs

For over the last ten years the demand for seed mussel has far outstripped supply. At present the only large scale source of seed is from natural settlement, which has to be located on an annual basis. Generally, if co-ordinated, the more vessels involved, the more ground is covered and the greater the likelihood of a bed being found. So to this end the SMAC has always tried to encourage the industry to survey in a fair and equitable manner.

Annual surveys should be conducted throughout the traditionally fished seedbed areas in order to identify viable mussel seedbeds. These surveys should be carried out in the spring/early-summer (April/May) of each year and consist of an extensive, concerted and coordinated survey effort that should be conducted to agreed standards, involving a commitment from both industry and state agencies. The findings of these surveys would introduce considerable confidence in subsequent management decisions

Specific recommendations where to survey are difficult due to the transient nature of subtidal mussel beds. Figure 20 indicates areas of historic beds, and the associated substrate for those locations. A 30m contour has also been applied to indicate the operational depth range of traditional vessels. Using this map, we would recommend that survey effort be focused in the sediments and within the 30m contour highlighted in Figure 20. Furthermore, we recommend that initial effort be restricted to areas where no historic beds have been located prior to exploration of historic areas to maximise seed discovery.

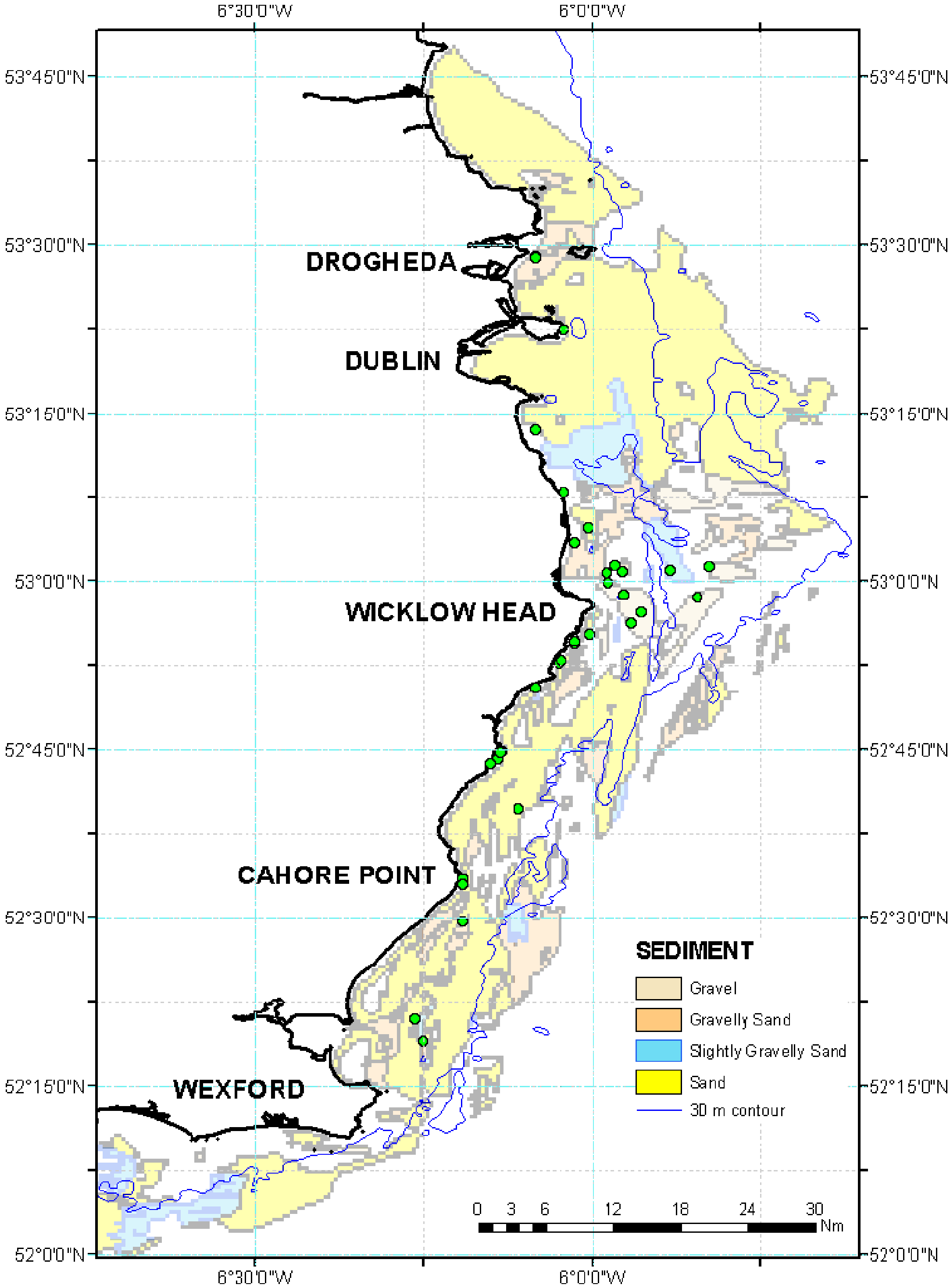


Figure 20. The southern Irish Sea showing historic beds (green circles), sediment type and 30 m depth contour. Boxes indicate reductions of ICES boxes. Blue lines indicate ¼ ICES and grey lines ⅛ ICES boxes.

Industry survey methods

The *industry mussel seed survey protocol* outlined in *Appendix VI* was circulated to all companies with bottom mussel licences for feedback and consultation. This feedback was not available to include in this publication.

State Agency Survey

While the industry survey effort will cover a geographically broad area with the aim of finding new seed in previously unsettled areas or new settlement in traditional seed bed areas, the agency survey effort, would focus upon characterisation of located seed beds by determining the limits of the bed, quantifying seed biomass and shell height and determining the quality of the seed itself. They will ensure that the information is made available to the rest of the industry and the government departments so that important management decisions can be made as to when to open the bed for transplanting and to give an overall picture of the seed mussel resource available during the season. These surveys will primarily take place in the spring and summer just prior to the seed mussel transplanting season. Whilst survey work has been carried out for many years by BIM it is important that this survey work be intensified. As ultimately the results of this detailed survey will establish the amount of seed available for the determination of harvesting quotas. A consistent survey by trained staff may increase available seed resources by 20% or more (Carter Newell, Great Eastern Mussels pers. comm.).

A dedicated survey vessel has been in operation for the Dutch Mussel industry for many years (See Appendix IV for details of Dutch Survey). The vessel is a cockle dredger that has a container mounted on board for processing samples. The dredge samples quantitatively, and in shallow water it can be used on a pipe, or in deeper water it can use a longer hose and is lowered using a winch and cable. By doing transects across sites, it eliminates the problem of patchiness of mussel clumps where grab samples are relatively ineffective. The vessel can also use RoxAnn or similar to help identify areas to sample, and should have a drop video and standard dredge for delineating areas for quantitative sampling. A similar vessel is needed for the Irish Industry and to this aim it is understood that BIM are currently procuring a 32ft research survey boat.

Reporting

After the seed survey the scientific team will provide a stock assessment for each mussel bed found. This will include the seed biomass, seed size and quality and a description of the habitat. All data will be assessed and an estimate of the allowable catch will be made. The provision of this impartial advice is critical to achieving the sustainable exploitation of this resource. A report containing the stock assessment and advice for management will be produced using a similar format to that used in “The Stock Book” (Marine Institute annual publication).

Research Survey

In addition to the general stock assessment provided by the industry and State agency surveys a third type of survey is recommended that has a more scientific basis. Further information is required as to when the seed beds develop in which areas and why. So these surveys should be carried out throughout the year in areas likely to produce seed so that the dynamics of the bed can be studied over a period of time.

7. FURTHER RESEARCH RECOMMENDATIONS

Many of the results of this project have been extremely valuable and have led to sound scientifically based recommendations highlighted above. However, not all results can lead to definitive recommendations regarding the management of the seed mussel resource in Irish waters. A number of new insights have been provided. But in several cases, these need to be refined or have led to a number of new research oriented recommendations that would require a combination of applied and basic research to address. For example, in order to accurately predict the recruitment of mussels, a three year dataset is not long enough. Inter-annual variation is so great that many years of data are needed before predictions can be made with any authority. A number of future research recommendations are listed below.

Sources of larval recruits to the seed beds

We have shown that mussels in at least three habitat types are potentially capable of contributing recruits to the fishery (Section 2). The habitat types are, intertidal beds, estuarine beds and the subtidal seed beds. A key question remains unanswered i.e. which of these sources is the most significant contributor of recruits? The answer to this question would guide the focus of management measures to conserve larval sources. At this stage, we are capable of estimating larval output per m^2 of each habitat (Section 2). The question cannot be answered, however, by simply measuring reproductive output because there is not sufficient understanding of the fate of larvae spawned from a given habitat or location. Given the importance of this question, attempts should be made to ascertain which sources of larvae are most significant for given beds. It may be possible, for example, to develop genetic markers to characterise the relationships between mussels in the seed beds and mussels in a range of potential source habitats and locations.

Given the tonnage of seed mussel in the Irish Sea, the discovery that the seed mussel spawn (*Section 2*), suggests that they may contribute significantly to the recruitment of the fishery. This would have important implications for management as it provides motivation to protect the beds until spawning is complete in the spring and to allow some beds to overwinter. However, there is some evidence to suggest that the viability of larvae spawned by young bivalves may be poor, such that their contribution to recruitment may, in fact, be negligible. It is therefore essential to establish the relative viability of larvae spawned by seed mussels and those spawned by mussels in intertidal and estuarine populations. This question could be addressed using laboratory spawning and rearing trials in combination with field based research using genetic tools to trace larval origins. Therefore further research could determine whether viable larvae may be transported to suitable settlement sites.

Seed bed longevity / stability

The other key feature of seed beds that we have demonstrated is that some are definitely capable of over-wintering in the Irish Sea. Prior to this work, the prevailing opinion was that any beds not harvested by the end of the season would not survive the winter. Now, it is clear that there may be some value in management which recognises that some beds are stable and could potentially be left to overwinter so that they improve in quality and contribute to spawning the following year. This philosophy is employed in the Netherlands (Appendix IV). A key question is, therefore, ‘which beds are stable and which are not?’, or, more generally, ‘which intrinsic factors (mussel density, size, shell thickness) and environmental factors (such as currents, bottom type, predator abundance, etc.) affect stability of beds?’ Research to address these questions would be necessary to underpin informed decisions about selective bed closures or restrictions.

Vertical distribution and behaviour of larvae

In a ground-breaking field study, we have shown that larval abundance in the water column is greater on flood than on ebb tides and that vertical position of larvae varies with tidal state (*Section 3.2*). These insights significantly alter the patterns of larval dispersal predicted by models based on hydrodynamics (*Section 3.3*). If we are to further refine such predictions, a more detailed understanding of variation in larval distribution in the water column is essential. We established a pattern, but cannot be certain whether it is caused by active larval behaviour or some physical process. The temporal and spatial scope of the study was also limited. Further field and laboratory studies would enable us to establish whether the observed pattern is general to other sites in the Irish Sea and to understand its mechanism, so that the predictive model can be further improved.

Sensitivity and ground truthing of the predictive model

The project has delivered a model capable of making potentially valuable predictions of sites of recruitment of seed mussel based on hydrodynamics and mussel behaviour (*Section 3.3*). The accuracy of the model has yet to be determined. We recommend a ground-truthing study focussing in a particular region with a limited set of potential sources of larvae. The model could be used to predict larval dispersal from the known potential sources and larval settlement could then be sampled at a range of locations within and outside the predicted settlement area.

A sensitivity analysis should also be undertaken to determine how the predictions of the model are influenced by differences in parameters such as climate, river flows and mussel behaviour.

Using retrospective reconstructions (hindcasting), the model may also be a valuable tool for research into the origins of recruits. In a given year in which the locations of major beds are already known, it may be possible to parameterise the model with the specific weather conditions and spawning patterns for that year and trace the sources of larvae likely to be mainly responsible for the establishment of the bed. This may help to resolve the continuing debate about the most important sources of larvae for recruitment to the fishery.

Optimum seed size for fishing and relaying

Selecting wild seed for relaying to ongrowing areas is a complex issue involving many variables. It is a critical component in the management of the Irish seed resource to understand the dynamics and performance of the different size seed particularly when demand far exceeds supply. While every attempt should be made to protect small seed if it is too immature for relaying nevertheless the losses of such seed to predation must also be addressed and balanced. This topic raises more questions than answers and it is very apparent that further research is necessary before recommendations can be made. The following factors should be considered by management prior to fishing small seed:

- Determine the minimum size seed to relay – this can be done by analysing the scientific data already available for handling different size seed in the different ongrowing areas in conjunction with local knowledge. It is readily acknowledged that some ongrowing sites can handle small size seed while other sites fail.
- Predation both on the seed bed and on the ongrowing sites. Should seed be left to grow to a larger size before fishing commences versus the risk of losses to predation, should it exist? Some farms have the facility to relay into shallower water depths before transferring to deeper depths in an attempt to avoid predation. Will the risk of predation be higher on the seed bed as opposed to the relaying ground?
- Depth of seed fishing and depth of relaying area. Will seed survive after being relayed from deep waters into shallower depths?
- Transport of seed, mode and time. Smaller seed, by its nature, is more fragile therefore less handling and reduced transport should reduce stress and mortality.
- Relaying densities. It is recommended that small seed should be relayed at lower densities.
- Temperature, salinity and local relaying conditions. What level of stress is caused by fishing, transporting and relaying in summer temperatures? Should mussels be shipped in dry or wet conditions?

- It is imperative that producers keep records of different seed size and quality and follow the different shipments throughout its life cycle in an attempt to understand the optimum seed size most suited to the different relaying sites.
- Impact of towing on small size seed.
- Producer's knowledge. It has been noted, in more recent times, that the same seed (Cahore) while fished as the same time and relayed into a number of different relaying sites in Ireland resulted in very large mortalities in some instances while other sites had good returns.

Investigate why the ratio of return is low and carrying capacity of re-laid areas

Carrying capacity

In general bivalve populations are capable of removing substantial amounts of organic material, they assimilate some as biomass and excrete the rest as waste, thus they play an important role in controlling levels of eutrophication and nutrient recycling (Prins and Smaal 1990; Hickman *et al.*, 1991). However, the reduced production in the major shellfish areas (particularly for mussels) is attributable primarily to carrying capacity issues (Couturier, 2000) and the depletion of natural resources necessary for growth by overstocked mussel farms. The study of carrying capacity in bays will prevent seed mortality by inappropriate seeding densities on mussel plots. If for example the carrying capacity of a mussel plot indicates a seeding density of 400 mussels / m^2, seeding the plots at over a 1000 mussels / m^2 will result in density dependent mortality, slower growth and poor seed to harvest yields. Appropriate seeding densities may increase seed to harvest yields by 50% or more (Newell pers. comm.). The Irish Shellfish Association has raised the issue of the low ratio of return in some mussel bays and plans are already in place to carry out a carrying capacity study in Killary, Wexford and Dungarvan Harbours by BIM.

Investigate why condition of seed varies in different beds

The factors affecting mussel growth and how to optimise seeding densities on a site-by-site basis have been outlined earlier. Great Eastern Mussel Farms Ltd. found that the seed to harvest yields were considerably less on soft bottom sites due to low currents and burial of mussels during harvest and determined these sites as unsuitable (Newell pers. comm.). They considered *bottom hardness* as a key criterion in site selection for mussel plots. This should be carried out in conjunction with the carrying capacity study.

Further research: Investigate the correlation between bottom sediment/hardness and mussel productivity

Mussel farming in The Netherlands is based on the culture of mussels on bottom plots in the Wadden Sea and the Oosterschelde estuary. Mussel seed is harvested in autumn and spring from wild beds in the Wadden Sea and transplanted to culture plots. The bottom culture production efficiency is on average 1.7 kg end product from 1 kg of seed. During a growth period of 1.5 – 3 years mussels are *transplanted between culture plots* within the Wadden Sea and The Oosterschelde, and from the Wadden Sea towards the Oosterschelde, as a function of the culture strategy and the availability of plots of individual farmers. Similarly in Ireland some sites are used as nursery sites and seed is transplanted at a later stage.

Further research: Should holding sites be used as nurseries (holding seed for shipment at a later date)? How do temporary nursery areas affect overall productivity of a bay?

Impact of dredging and handling

Dredging

The impact of dredging in the Irish Sea has been discussed in Section 4.2. Dredge fisheries face stock and environmental management pressures particularly as many dredge fisheries take place in coastal waters which are increasingly managed in terms of multiple resource use. The practice of mussel seed catch and re-laying using dredges will require that shellfish undergo minimum stress when fished. Thus understanding the cause of such stress requires not only knowledge of the physical interaction between the dredge and the target species, but also an understanding of the ecological and physiological effects of dredging.

Also, scientific studies on by-catch need to be carried out especially with regards to the possible negative impacts that they might have on the relayed seed. For example if whelks and starfish are not killed during transport, then they will continue to prey on the mussels in their new site. In addition, any dead and moribund by-catch will attract indigenous predators to the newly laid seed.

Future research needs to address the issues surrounding technical measures and non catch mortality by systematically examining the dredging process and its physiological and ecological consequences. Innovations in terms of technical measures and dredge design should be examined for their consequences in terms of environmental effects and their effect on the target species.

Further research: To examine the mode of action of dredging on affected species and the seabed and to develop means to reduce any negative impacts.

Handling and Transport

Standards need to be established for transport and handling of seed. The stress effects of various husbandry practices such as transportation on the physiology of mussels is largely unknown, but is believed to be significant. It is expected that by improving handling (refrigerated transport, more careful handling, wet storage of seed during transport etc.), seed survival would be significantly improved, by 30% or more (Newell pers. comm.). This recommendation could be accompanied by studies on seed mortality suggested in Section 6.

Potential transport study

A desk study to select the most promising transport systems (both dry and wet) and techniques (including the use of buffers in wet transport systems) should be undertaken. This should encompass best-available and emerging transport technologies. Information should come from fish farmers, published literature and exploiting established networks. Acceptable performance criteria for transport including the cost should be established.

The most promising techniques should be tested, throughout these transport trials environmental parameters such as temperature, pH, dissolved oxygen and ammonia should be recorded at each sampling period. The stress levels of the animals should also be regularly measured during the trials in order to pin point exactly when acute stress takes place. A previous study by Maguire and Burnell (1999) assessed the usefulness of various techniques for stress assessment on *Pecten maximus* and found that Adenylic Energetic Charge (AEC) could be used effectively to measure short-term acute stress. Therefore the AEC levels should be measured regularly throughout the trials. For each transport system tested the effect of length of journey and stocking density should be investigated and any other bottlenecks should also be highlighted and potential solutions identified. The knowledge gained from transport solutions identified should be disseminated widely to the industry.

Further research: To examine methods to improve handling and transport of stock

Husbandry

To investigate why condition of seed varies in different beds husbandry practices are also very important. It is important that all changes to the farm stock should be noted; initial stocking density, batch size, and batch arrival schedule, which have to be operationally matched with harvest frequency and weight at market time. It is important also that all mortalities are reported particularly after seeding. This information should help in addressing issues such as seed size, quality and productivity of sites. Clearly, such research must be carried out in close cooperation with farmers and draw on their experience. However, difficulties in this type of research may arise regarding farm co-operation. As some farmers may perceive this research as a comparison of different farmers ability to on-grow mussels rather than variation in productivity due to site differences. It is recommended that results are confidential. Best practice guidelines should be produced for sites where productivity is highest due to husbandry practices.

Further research: Best practice guidelines to be produced for husbandry of stock

It is further recommended that industry partners, state agencies and academia (research performers) avail themselves of the funding opportunities provided by both Sea Change[3] and the Cawley Report[4] to develop research programs relating to seed mussel supply and management.

[3] A Marine Knowledge, Research & Innovation Strategy for Ireland 2007-2013. Marine Institute 2006

[4] Steering a New Course - Strategy for a Restructured, Sustainable and Profitable Irish Seafood Industry 2007-2013. Report of the Seafood Industry Strategy Review Group December 2006

Appendix I. Hydrodynamics of the Irish Sea

Brendan O'Connor, AquaFact Ltd. Galway

Details of Model Simulations

Average tidal amplitudes and phases were obtained from Admiralty tide tables and were interpolated along the boundary grid points. The number of tidal constituents used in the model was confined to four (i.e. M_2, S_2, O_1, and K_1). The following rivers along the east coast of Ireland were considered in the study: the Slaney, the Avoca, the Liffey, and the Boyne. The rivers were considered to be freshwater rivers having zero salinity (i.e. 0 PSU), whereas an average salinity value of 34 PSU was taken throughout the Irish Sea. In the absence of detailed measurements of sea temperatures and wind conditions, 30 year average values were obtained from the meteorological office. The 30 year average sea temperatures for May and June were 9.9^{o}C and 12^{o}C while the average air temperatures were 10.5^{o}C and 13.4^{o}C respectively. The average wind speeds were 11.4 and 10.1 knots and the prevailing direction was south-westerly.

The currents were initialised by first running the program for a spin-up period of two days with zero initial currents and open boundary forcing for the 2-D mode, but without stratification, particles and river discharges. Six different seed mussel beds were examined as sources for the model simulation. These locations are shown in figure A1.1. At each of the six release stations a series of 50,000 particles (distributed uniformly over the vertical) were released. The program calculates the trajectories of all 50,000 particles during the simulation. The total number of particles at the end of the simulation can be smaller than the initial number since particles which traverse one of the open boundaries of the computational domain, are considered as lost to the system. Each simulation was run for approximately 42 days. Velocity, surface elevation, and particle concentration data were written to output files at specified times during the model simulation. In addition to these simulations, further models runs were conducted to try to isolate the effects which rivers and varying wind conditions would have on the particle transport. To examine the effect of varying wind conditions a generic release station was used in the middle of the Irish Sea. When studying the currents induced by river flow, tidal amplitudes and wind velocities were set to zero.

Modelling of Larval Behaviour

One of the greatest challenges in trying to predict the spread and distribution of mussel larvae from the seed beds was the question of how to incorporate seed mussel 'behaviour' in the hydrodynamic model. The transport of the larvae due to the tides, wind induced currents, diffusion, and river inputs could all be calculated directly by the model, but this resulted in treating the mussels as 'passive' particles, which of course they are not.

According to the data provided by other participants in this study, bivalve larvae show alternate vertical migration and sinking at speeds of 0.15 - 10mm per sec with some diurnal behaviour (near surface at night). At this sinking speed the larvae would migrate through a depth of approximately 36m in one hour. Obviously this sinking speed could not be applied to the particles throughout the simulation as it is simply not a realistic scenario. It was also noted that as the larvae mature and approach settlement, they would tend to move closer to the sea bed. This would expose them to differences in current speed between the surface and sea bed. In the hatchery mussel larvae take about 25 days to reach metamorphosis. Therefore, one approach was to treat them as inert particles that slowly sink over their planktonic life of 3 - 4 weeks. The sinking rate applied was equivalent to the larvae swimming through 20m in this period of time.

This approach however proved to be unsuccessful since larvae, which initially were quite close to the seabed, hardly moved at all and the resulting settling patterns were adversely affected by this artificial 'behaviour'. Furthermore, changing the code in the COHERENS model to incorporate this 'behaviour' resulted in complications when the model was implementing boundary conditions on the seabed. Lastly, it also seemed to be too arbitrary a value – why not use a sinking rate whereby larvae would swim through a depth of 10m, or 30m? For these reasons it was decided to abandon the 'constant sinking rate' approach.

An alternative way of including the mussel larvae behaviour was then suggested to us T. Knights (UCC) who conducted the sampling work to examine larval distribution in the water column at different stages of the tide. The output of this exercise is presented in Section 3.3 of this report.

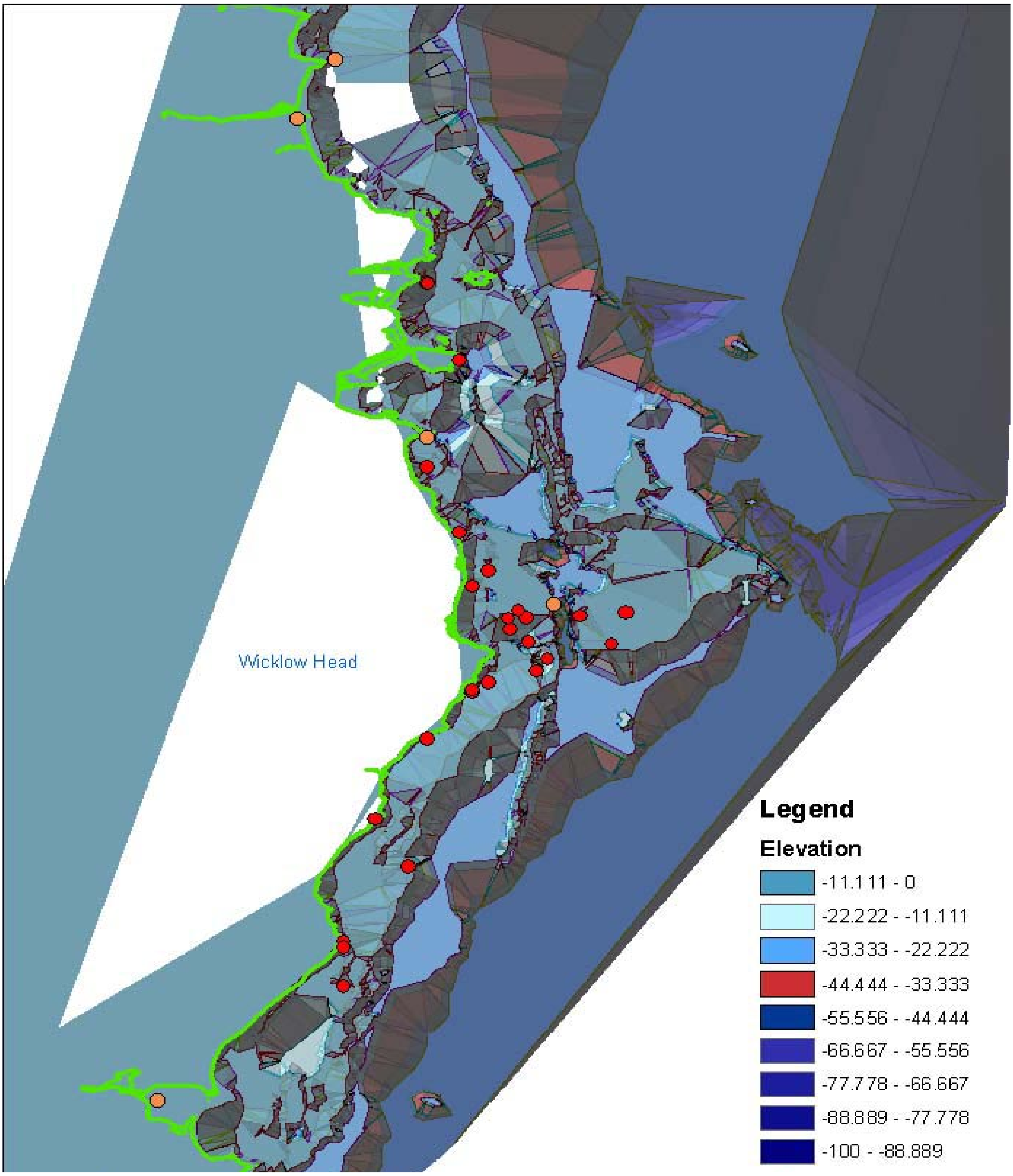


Figure A1.1 : Locations of the seed mussel beds used as sources in the model (orange circles)

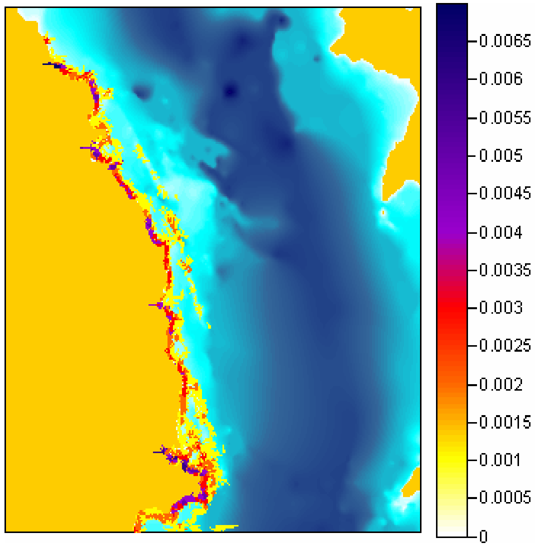


Figure A1.2: Current velocities (m/s) produced by river discharge along the east coast of Ireland

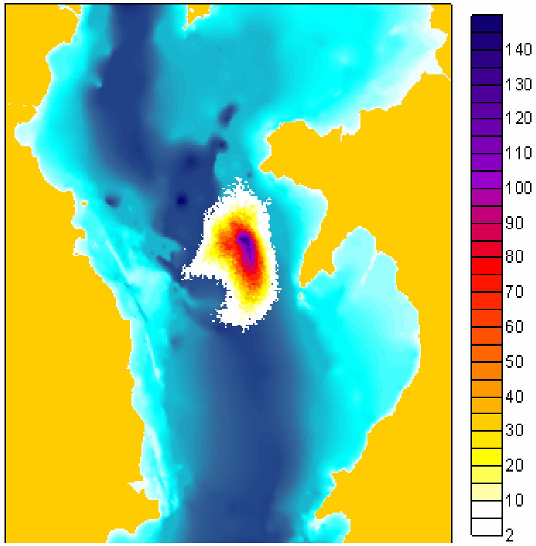


Figure A1.3: Particle distribution after 600hrs (wind blowing from south west)

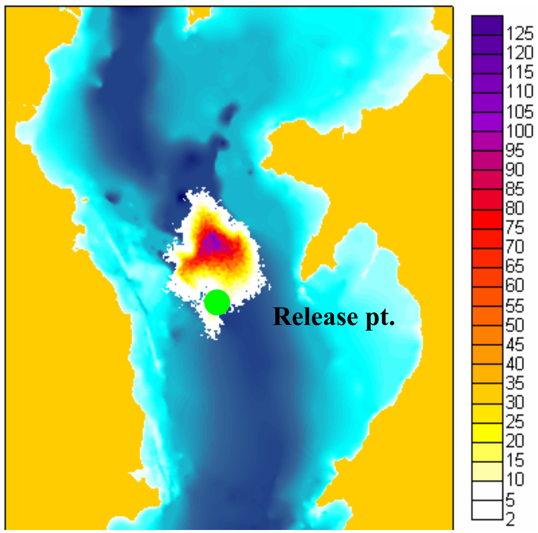


Figure A1.4: Particle distribution after 600hrs (wind blowing from north east)

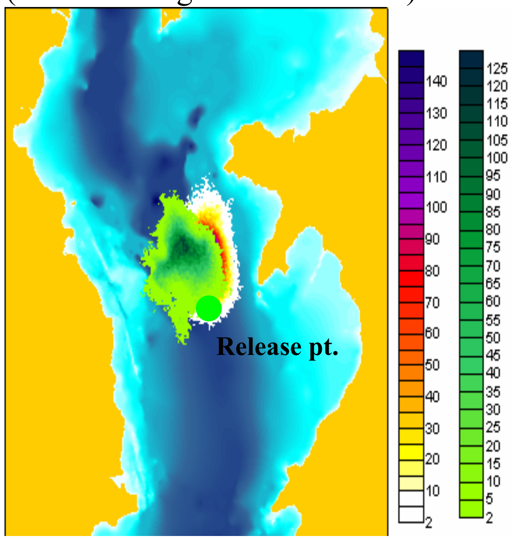


Figure A1.5 : Contrast between particle distributions after 600hrs for two different wind conditions

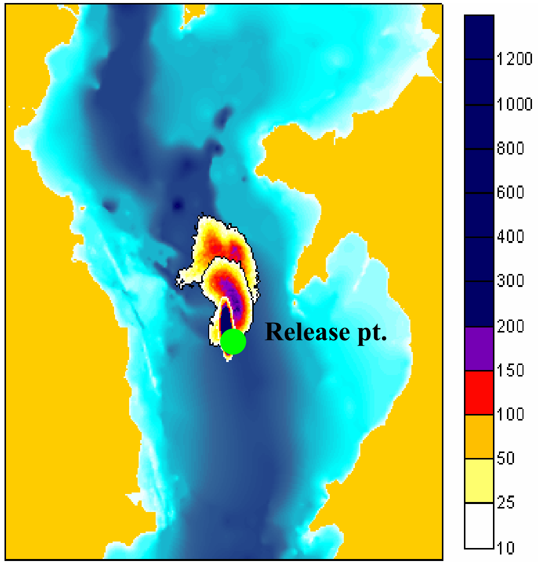


Figure A1.6: Particle distributions after 25, 300, and 600hrs for a zero wind condition

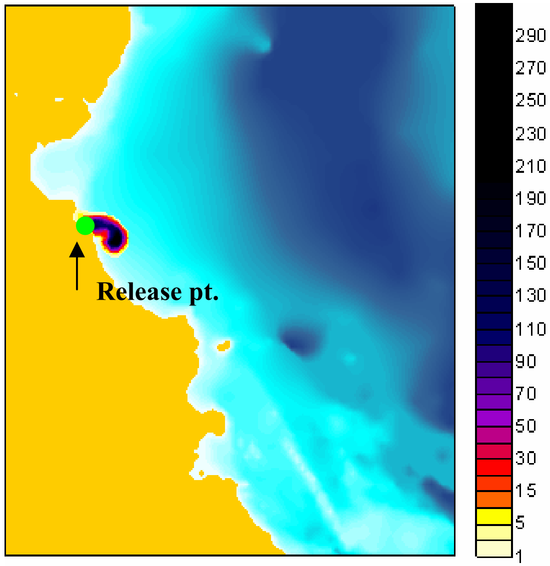


Figure A1.7: Particle concentration after 100hrs (Clogher)

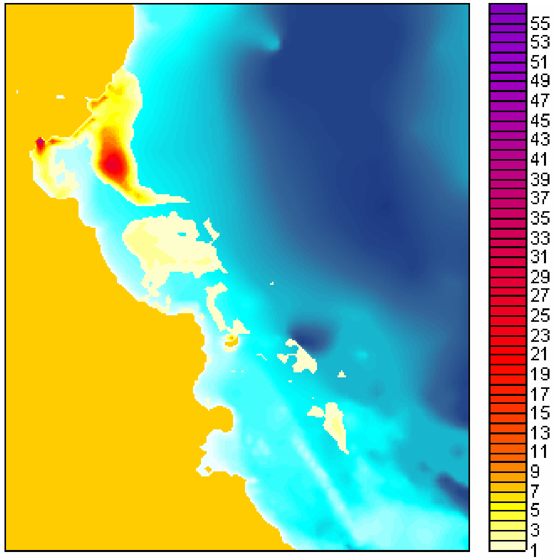


Figure A1.8: Particle concentration after 1000hrs (Clogher)

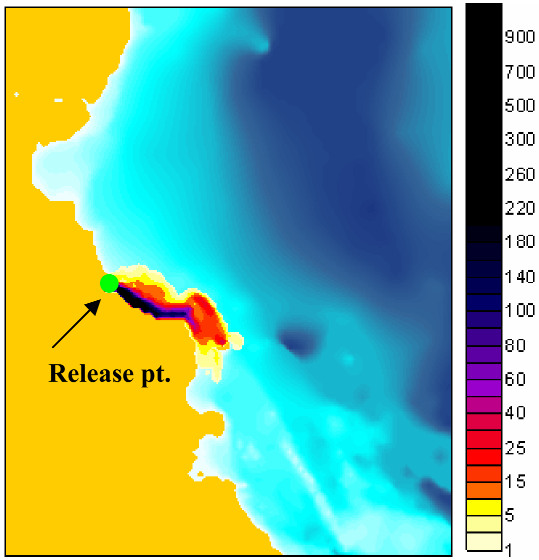


Figure A1.9: Particle concentration after 100hrs (Boyne)

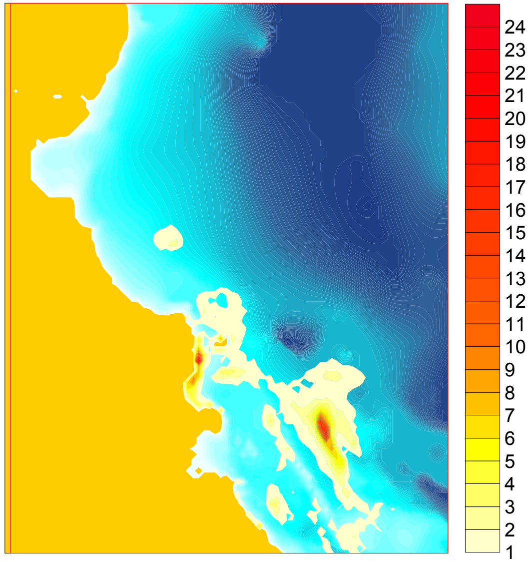


Figure A1.10: Particle concentration after 1000hrs (Boyne)

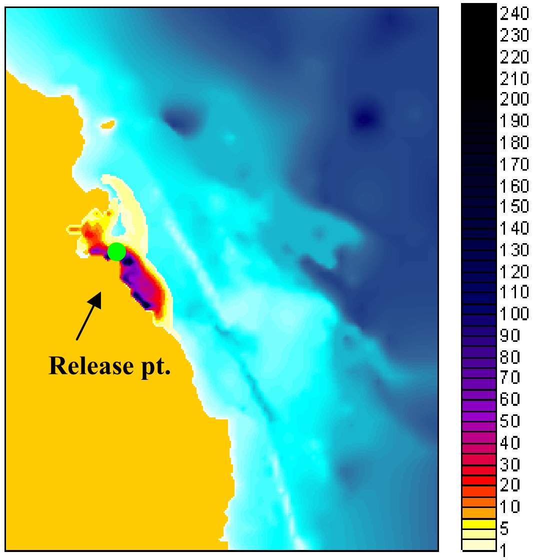


Figure A1.11: Particle concentration after 100hrs (Dun Laoghaire)

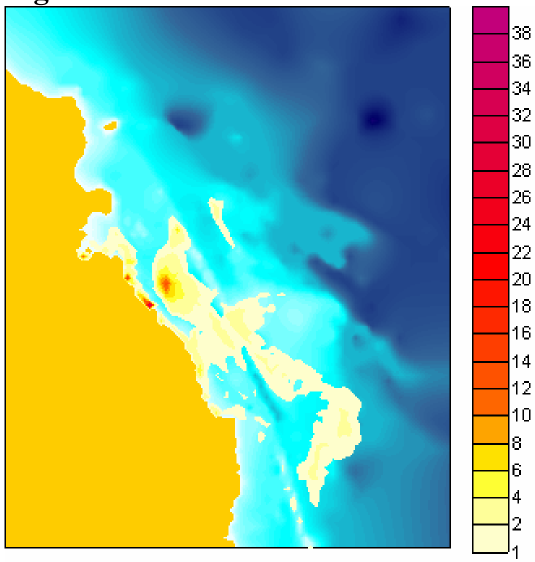


Figure A1.12: Particle concentration after 1000hrs) (Dun Laoghaire

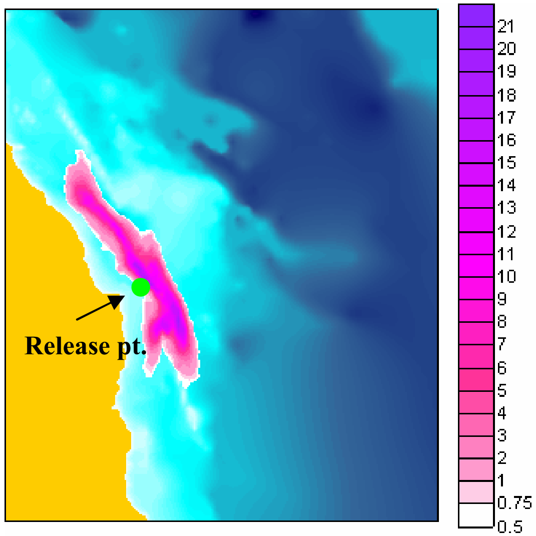


Figure A1.13: Particle concentration after 100hrs (Wicklow)

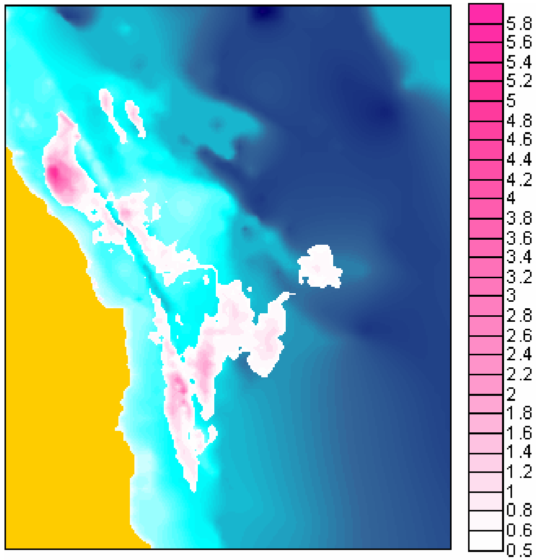


Figure A1.14: Particle concentration after 1000hr (Wicklow)

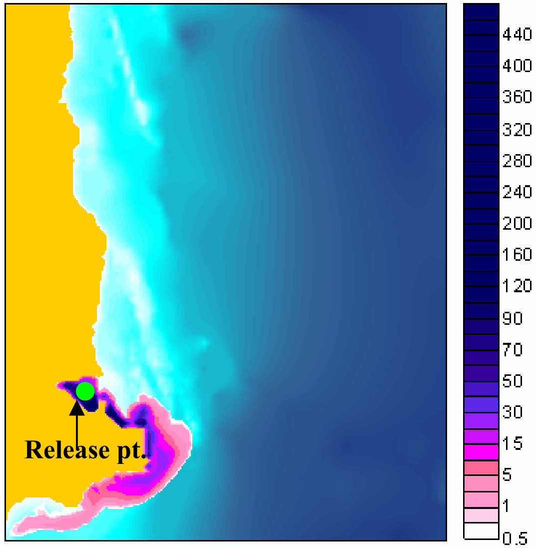


Figure A1.15: Particle concentration after 100hrs (Wexford)

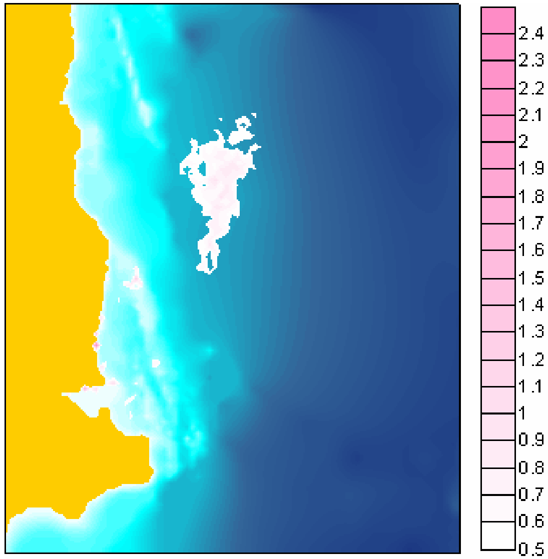


Figure A1.16: Particle concentration after 1000hr (Wexford)

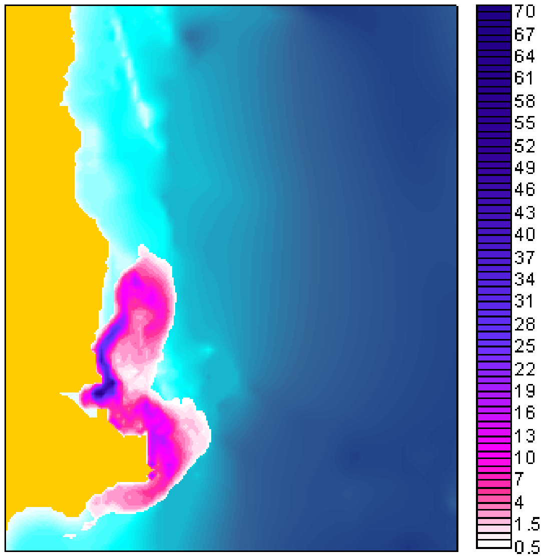


Figure A1.17: Particle concentration after 100hrs (Lucifer Bank)

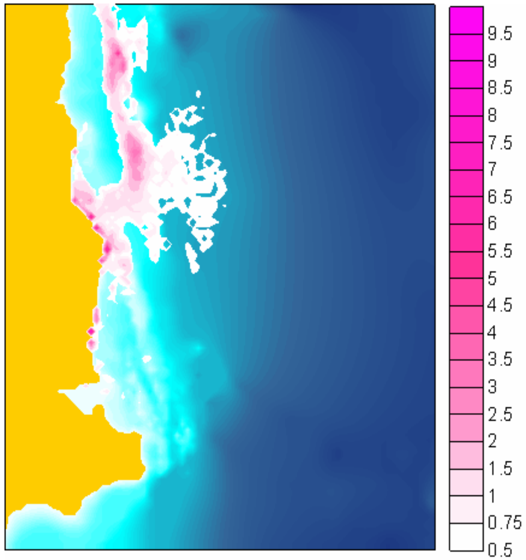


Figure A1.18: Particle concentration after 1000hrs (Lucifer Bank)

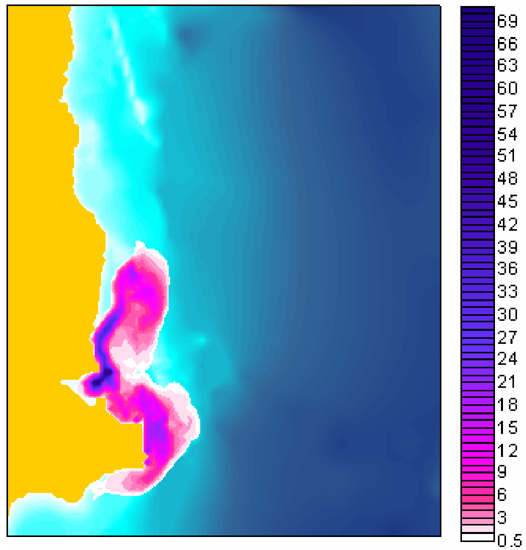


Figure A1.19: Particle concentration after 100hrs (Lucifer Bank) – behaviour included

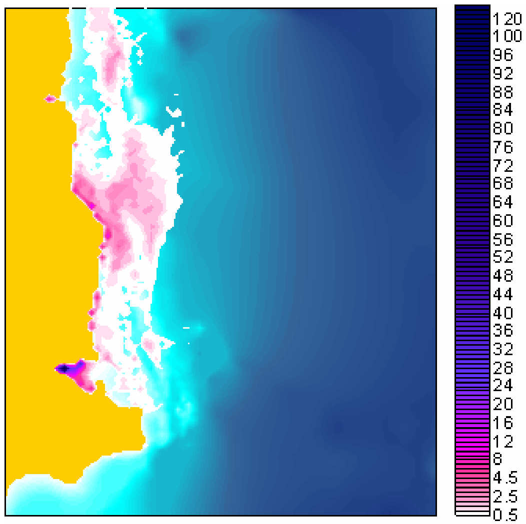


Figure A1.20: Particle concentration after 1000hrs (Lucifer Bank) – behaviour included

Appendix II. Seed bed biodiversity

Mussel bed structure

Mussel beds are composed of;

- Physical matrix of living and dead mussel shells, can form a single layer or a multi-layer with five or six mussel layers
- A bottom layer attached to the substratum, which accumulates; sediment, faeces, detritus and broken shell.
- A diverse array of associated flora and fauna (Seed and Suchanek, 1992).

In general, subtidal mussel beds thickness increases with mussel bed age. On Irish coasts most intertidal beds consist of only one layer of mussels. Nixon *et al.*, (1971) reported a thickness of 10cm in intertidal beds on the US east coast whereby Simpson (1977) reported a thickness of 120cm in subtidal beds off shore. The density of the mussels and the topography of the mussel bed interact with the dynamics of the mussel population. Mussels living near the edge of beds are observed to be larger than those living in the centre (Svane and Ompi 1993). Sediment accumulation increases proportionally with increasing bed thickness (Widdows *et al.,* 1998) and sediments may eventually become anoxic particularly in beds built on soft substrata (Newcombe, 1935).

Mussel beds often form in highly energetic areas with high flow rates and turbulent near bed mixing. Mussels play an important role in "benthic-pelagic coupling" in these areas, by transferring material from the water column to the sea bed. A multivariate analysis of physical factors in seed mussel beds in the Wadden Sea predicted the distribution of spatfall in two years (1994 and 1996) quite successfully, suggesting that physical factors play an important role in determining the formation of seed mussel beds, although it is not clear whether physics impacts most upon the settlement process or survival after settlement (or both). Seed mussel beds in this area formed preferentially in the low intertidal zone, in areas of low wave orbital velocity and medium overall flow (not very high or very low) and not in areas of coarse sand or silt (Saurel *et al.,* 2004).

Mussels are active filter feeders, capable of processing large volumes of water through their gills. This results in a continuous flux of particulate matter from the water column to the bivalve beds. The rate of particle sedimentation in cultivated mussel beds can be 2 to 3 times higher than comparable locations without mussels. Mussels thus have a large impact on the seston flux in the water column. Filtered inorganic material is either ingested, resulting ultimately in faeces production, or rejected prior to ingestion as pseudofaeces. The deposited material is enriched in organic content (Saurel *et al.,* 2004).

Only a fraction of the suspended particulate matter (SPM) filtered by the mussel population is stored as deposits in the sediments. The majority of filtered and biodeposited material is resuspended immediately. Mussel faecal material is easily resuspended relative to non-biogenic sediment due to its low density and high water content, particularly in the energetic environments in which mussels are found. Furthermore, resuspended mussel biodeposits have been found to settle extremely slowly compared to inorganic sedimentary material. Hence mussel beds increase sediment flux both from water column to bed and from the bed back to water column, and mussel biodeposits may contribute significantly to the total suspended load in estuarine and coastal environments (Saurel *et al.,* 2004).

A wide range of flora and fauna are associated with mussel beds (Briggs, 1982; Tsuchiya and Nishihira 1986; Morgan 1992; Suchanek 1979; 1980; 1992; Hatcher *et al.,* 1994; Riese *et al.,* 1994; Albrecht 1998; Ragnarsson and Raffaelli 1999). A recent study by Davies (2003), examined by-catch taken by a commercial mussel seed dredger from the India and Rusk banks in the Irish Sea. Overall a total of 33 taxa from 29 families were identified. These included 11 species of commercial value such as the plaice, *Pleuronectes platessa* and the whelk *Buccinum undatum* and several fragile echinoderms (e.g. the feather star *Antedon bifida* and the sea urchin *Psammechinus miliaris*). However, it is important to remember that mussel seed beds by definition are relatively young and hence may not have the diversity of species that are associated with adult beds. They do however; have a large assemblage of predators (Table 1) that can significantly determine their local distribution (Seed, 1969).

Table 1. Predators associated with mussel seed beds.

Group	*Species*	*Reference*
Starfish	*Asterias rubens*	Seed (1976)
Crabs	*Cancer pagurus*	Seed (1976)
	Carcinus maenas	McGrorty *et al.* (1990)
Gastropods	*Buccinum undatum*	Davies (2003)
	Nucella lapillus	
Lobsters	*Panulirus interruptus*	Seed and Suchanek (1992)
	Homarus americanus	
Flatfish	*Platichthys flesus* (flounder)	Seed (1969)
	Pleuronectes platessa (plaice)	Dare (1976)
	Limanda limanda (dab)	Seed and Suchanek (1992)
Birds	*Haematopus ostralegus* (oystercatcher)	Craeymeersch *et al.* (1986)

Production

Production represents “the net gain in body energy and occurs when the energy content of the absorbed ration exceeds metabolic requirements” (Seed and Suchanek, 1992). Production in mussel beds is extremely high. Dare (1976) estimated the production of mussels for two year classes in Morecambe Bay in England which amounted to 62.89 x 10^3 and 86.40 x 10^3 kJ m^{-2} yr^{-1} respectively. This equated to a standing crop of 1.5kg m^{-2} Ash Free Dry Weight (Dare, 1976). These figures rival other highly productive systems, such as tropical rain forests (Leigh *et al.,* 1987). In this population in Morecambe Bay, most of the production occurred in the first year and ceased after 16 months.

Mussel populations are capable of removing substantial amounts of organic material from the water column. They assimilate some as biomass and excrete the rest as waste, thus playing an important role in controlling levels of eutrophication and nutrient recycling in certain bays and estuaries (Prins and Smaal, 1990; Hickman *et al.,* 1991).

Widdows *et al.* (2002) measured the scope for growth (SFG) in mussels collected from 38 sites around the Irish Sea. SFG is a measure of the energy balance of an animal (i.e., the difference between energy intake and metabolic output). The SFG was correlated with water quality. On the British coast there was a significant decline in the water quality in the Liverpool and Morecambe Bay region. High water quality and SFG was observed along the west coast of Wales, south west England and northwest Scotland (outside the Irish Sea). On the Irish coast a similar trend was found with SFG reduced within the Irish Sea. The SFG was poor north of Duncannon in Wexford and only improved north of Belfast.

APPENDIX III

The fishing and movement of seed mussels stocks in Ireland is subject to the following controls:

S.I. No. 311 of 2006 - Mussel Seed (Fishing) Regulations 2006

The master of an authorised boat shall -

(a) ensure that a fully functioning black box system is installed and operational at all times on the boat, and

(b) inform a sea-fisheries protection officer at least 4 hours in advance of his or her intention to fish for mussel seed and give the officer the name of the holder of the authorisation on whose behalf he or she intends to fish.

The master of an authorised boat shall not fish on behalf of more than one holder of an authorisation at any one time and shall retain on board a copy of the relevant authorisation.

The master of an authorised boat shall keep a record of the transplantation on to a place or waters specified in an aquaculture licence of mussel seed fished under an authorisation, which shall include the following information:

(a) the reference number of the aquaculture licence of the place or waters to which the mussel seed is transplanted,

(b) the amount of mussel seed so transplanted, and

(c) the date of its transplantation.

S.I. No. 344 of 2006 Mussel Seed (Conservation) (No.2) Regulations 2006

The Mussel Seed (Conservation) Regulations 2006 (S.I. 310 of 2006) are revoked.

S.I No. 345 of 2006 Molluscan Shellfish (Conservation of Stocks) Regulations 2006

1. These Regulations may be cited as the Molluscan Shellfish (Conservation of Stocks) Regulations 2006.

2. In these Regulations –
   "a specified vessel" means a sea fishing boat or boat of any other class of description.

   "Molluscan Shellfish" means molluscan shellfish of any kind whether alive or dead and includes any part of a molluscan shellfish and any (or any part of any) brood, ware, half-ware or spat of molluscan shellfish, and any spawn of molluscan shellfish, and the shell, or any part of the shell, of a molluscan shellfish.

3. These Regulations shall not apply to molluscan shellfish which are intended for direct human consumption, which molluscan shellfish have not been relayed from one part of the exclusive fishery limits of the State to another, either directly or overland, by any means.

4. A specified vessel or a person on board a specified vessel shall not, except under and in accordance with a license under these Regulations engage in dredging for, fishing for or taking molluscan shellfish within the exclusive fishery limits of the State and the master of a specified vessel shall not cause or permit the vessel or any person on board to engage in such dredging, fishing or taking within the exclusive fishery limits of the State.

5. (*a*) A specified vessel shall not, except under and in accordance with a licence under these Regulations, have molluscan shellfish on board within the exclusive fishery limits of the State,

(*b*) The master of a specified vessel shall not, except under and in accordance with a licence under these Regulations, cause or permit the boat or any person on board to have molluscan shellfish on board within the exclusive fishery limits of the State.

6. The master of a specified vessel shall not, except under and in accordance with a licence under these Regulations, cause or permit the boat to be used within the exclusive fishery limits of the State for the transhipment of molluscan shellfish from a specified vessel.

7. (1) In a prosecution for an offence under Article 6 of these Regulations, the following shall be *prima facie* evidence that the specified vessel concerned was, at the time of the alleged offence, used for the transhipment of molluscan shellfish in contravention of that Article:

(a) evidence that such specified vessels had on board any books, papers or other documents from which it appears to the court that on the day on which the offence is alleged to have been committed molluscan shellfish were received on board the boat otherwise than in the course of fishing.

(b) any admission by any person who is for the time being the master or other person in charge, or another member of the crew, of such specified vessel that at such time she was so used.

(2) In a prosecution for an offence under Article 5 of these Regulations it shall be a defence for the defendant to prove that the molluscan shellfish to which the prosecution relates were taken outside the exclusive fishery limits of the State.

(3) In a prosecution for an offence under these Regulations, it shall be a defence for the defendant to prove that the molluscan shellfish to which the prosecution relates were intended for direct human consumption and had not been relayed from one part of the exclusive fishery limits of the State to another, either directly or overland, by any means.

8. A person shall not, except under and in accordance with a licence under these Regulations, within the State, have in possession molluscan shellfish in any package, vehicle, premises, pier, wharf, jetty, dock or dock premises, ship, boat, railway wagon, lorry, cart or other vessel or vehicle used for the conveyance of goods.

9. A person shall not, except under and in accordance with a licence under these Regulations, within the State, sell, or have for sale molluscan shellfish in any package, vehicle, premises, pier, wharf, jetty, dock or dock premises, ship, boat, railway wagon, lorry, cart or other vessel or vehicle used for the conveyance of goods.

10. (1) Subject to paragraph (3) of this Article, the Minister may, upon the application of any person and upon being furnished by the person with any information which the Minister may reasonably require in relation to the application, grant to the person a licence authorising—

(a) the dredging for, fishing for or taking mulluscan shellfish within the exclusive limits of the State,

(b) the relaying of molluscan shellfish from one part of the exclusive fishery limits of the State to another, either directly or overland, by any means.

(2) A licence under these Regulations may be granted for such period and subject to such conditions, if any, as the Minister thinks fit and specifies in the licence.

(3) The Minister may, at his discretion, refuse to grant a licence under these Regulations or may at any time amend or revoke a licence granted under these Regulations.

11. These Regulations shall not apply to mussel seed harvested in connection with relaying for the purposes of ongrowing.

S.I No. 367 of 2006 - Mussel Seed (Conservation) (No. 3) Regulations 2006 and S.I No. 368 of 2006 - Mussel Seed (Conservation) (No. 4) Regulations 2006

It is prohibited to engage in fishing for mussel seed in the area of the Irish Sea bounded by the following coordinates until further notice

Point 1 52 32.0 N 06 09.6 W (North East Point)
Point 2 Landfall west of point 1.
Point 3 52 30.0 N 06 09.6 W (South East point)
Point 4 Landfall west of point 3.
and:

NE 52 59.5 5 56.4
SE 52 58.9 5 56.4
SW 52 58.9 5 57.2
NW 52 59.5 5 57.2

The effect of these Regulations is to prohibit fishing for mussel seed in an area of the Irish Sea off Cahore Point South/Rusk Bank and Wicklow Head North East until further notice, for the purposes of mussel seed management and conservation.

Vessel licensing/registration

All vessels involved in fishing and re seeding of mussels must satisfy the licensing and registration requirements of DCMNR or DARD as appropriate. The UK register includes Northern Ireland vessels. Only UK registered dredgers with a proven Northern Ireland economic link may fish in Irish waters. Reciprocal arrangements will apply to Irish vessels.

Aquaculture operations

Assessment of applications to dredge seed mussels for the purposes of reseeding will take account of a number of factors including licence status of aquaculture operations and agreed prioritisation criteria.

Fish Health Legislation

All movements of mussel stocks for on-growing/reseeding must comply with any national and EU fish health legislation currently in force and must be accompanied by the appropriate health certification.

Legislation governing movement of shellfish

Dredging of mussel seed by Irish registered vessels and reseeding of the seed for the purposes of on-growing within the exclusive fishery limits of Ireland may take place only on issue of a licence under the Mussel Seed (Conservation of Stocks) Order 1987, (S.I. No. 118 of 1987) as amended by the Mussel Seed (Conservation and Rational Exploitation) Order 2003 (S.I. No. 241 of 2003). Such licences are issued by DCMNR.

In Northern Ireland, dredging and movement of seed mussels is controlled by means of a licence granted by DARD under the Sea Fish Conservation Act 1967. In Northern Ireland under the Molluscan Shellfish (Control of Deposit) Order (Northern Ireland) (SR 1972 No 9) mussel seed imported from outside Northern Ireland waters can only be reseeded under the authority of a permit granted by DARD.

Environmental protection

Also having significant implications for mussel operations is the selection of areas of aquatic environments which merit legal protection under various EU Directives and national statutes.

Responsible for the selection and the monitoring of the conservation status of protected areas and species is National Parks and Wildlife Service (NPWS). The most important conservation legislation concerning aquaculture are the Wildlife Act (1967) as amended by the Wildlife (Amendment) Act 2000, the European Communities (Conservation of Wild Birds) Regulations (1985) and the European Communities (Natural Habitats) Regulations (1997), as amended by the EC (Natural Habitats) (Ammendment) Regulations (1998). These pieces of legislation provide for the designation of Natural Heritage Areas (NHAs), Special Areas of Conservation (SACs) and Special Protected Areas (SPAs). All these areas include significant amounts of foreshore and freshwater bodies and are of direct interest to mussel operations.

Natural Heritage Areas are areas that are important to the conservation of wildlife and nature. Some NHAs are in areas where aquaculture operations already exist or in areas suitable for future development of aquaculture. Their importance is widely recognised and many are listed for protection in local development plans. Special Areas of Conservation are a selection of those parts of NHAs that meet the criteria listed in the Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitats Directive). Special Areas of Conservation are protected sites for certain natural habitats and listed species of flora and fauna. Special Protected Areas are another group of sites which are protected in order to comply with Council Directive 79/409/EEC on the conservation of wild birds (Wild Birds Directive), which provides for the protection of listed rare/vulnerable species and regularly occurring migratory birds.

The management plans that have been or are being developed for designated SPAs with existing aquaculture or potential for future aquaculture development contain specific Aquaculture Zone Management Plans (AZMPs). These AZMPs, which may also be applied to SACs, are subject to public consultation and divide the relevant areas into four sub-zones. Highly Sensitive Zones (Zone W) are the most sensitive areas within SPAs relevant to the species for which the area was designated. Aquaculture will not be allowed to develop in these areas. Sensitive Zones (Zone X) are areas where aquaculture and wildlife may co-exist subject to conditions. Expansion of existing operations or new aquaculture applications will be considered on a case by case basis. Less Sensitive Zones (Zone Y) are areas that are included inside an SPA/SAC and which have low usage by the species for which it was designated. In such areas the regulation of aquaculture will be in line with the licensing legislation of DCMNR. Finally, External Influence Zones (Zone Z) relate to areas that are on the edge of designated SACs/SPAs but where aquaculture activity may still have an effect on the designated area through noise levels or access routes etc. Some regulations may apply to these areas. They will be considered on a case by case basis.

<u>Water and wastewater</u>

The principal legal framework for the prevention and control of water pollution are the Local Government (Water Pollution) Act (1977) and the Local Government (Water Pollution) (Amendment) Act 1990). The acts include, *inter alia*, a general prohibition against water pollution as well as provisions on licensing of discharge of wastewater.

Council Directive 79/923/EEC on the quality required of shellfish waters requires member states to designate certain areas as needing protection or improvement in order to contribute to a high quality of shellfish products. Member states must establish programmes for reducing pollution to ensure that designated waters comply with defined standards. The Directive has been implemented by the Quality of Shellfish Waters Regulations (1994), which prescribe quality standards for shellfish waters and designate the waters to which they apply, together with sampling and analysis procedures to be used to determine compliance with the standards. The Regulations have been amended by the Quality of Shellfish Waters (Amendment) Regulations (2001), which require the preparation and implementation of action programmes in respect of all designated shellfish waters.

Ireland is in the process of implementing Council Directive 2000/60/EC establishing a framework for Community action in the field of water policy (Water Framework Directive). The purpose of this Directive is, *inter alia*, to establish a framework for the protection of inland surface waters, transitional (estuarial) waters, coastal waters and groundwater in order to prevent further deterioration and to protect and enhance the status of aquatic ecosystems. The Water Framework Directive will also replace several existing Directives. Among others, in 2013 Directives 79/923/EEC and 76/464/EEC will be repealed (http://www.fao.org/figis/servlet/static?dom=legalframework&xml=nalo_ireland.xml).

Shellfish Water Classification

Up until recently the EU Directive 91/492/EEC laid down the health conditions for the production and the placing on the market of live bivalve molluscs. However, this legislation has recently been surpassed by a new set of regulations EC Nos. 852/2004, 853/2004 and 854/2004. These new regulations came into force on the 1st January 2006. The regulations make provisions for ensuring that where the relevant authority decides, in principle, to classify a production area or relay area, it must undertake a sanitary survey and the results of which must be used when establishing an on-going sampling programme. The sanitary survey requirement legally only applies where new harvesting areas are identified after January 1st 2006.

Within the new legislation the requirements for category B classification areas has been changed. Previously in EU Directive 91/492, 10% of samples from a harvest area were allowed to be above the upper limit of 4,600 *E. coli* $100g^{-1}$ and the area would still qualify for category B status. In the new legislation no samples are allowed to be above this upper limit, in other words the requirement is for continuous compliance with 100% of sample results less than 4,600 *E. coli* $100g^{-1}$.

Appendix IV. Management of Mussel seed – strategy of the Dutch mussel industry and recent experiences

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1 – Introduction

Mussel farming in The Netherlands is based on the culture of mussels on bottom plots in the Wadden Sea and the Oosterschelde estuary. Mussel seed is harvested in autumn and spring from wild beds in the Wadden Sea and transplanted to culture plots. As usual for bottom culture production efficiency is on average 1.7 kg end product from 1 kg of seed. As a consequence the annual requirement of mussel seed is $65*10^6$ kg (gross weight) to achieve the production target of $100*10^6$ kg.

During a growth period of 1.5 – 3 years mussels are transplanted between culture plots within the Wadden Sea and The Oosterschelde, and from the Wadden Sea towards the Oosterschelde (vice-versa is not allowed) as a function of the culture strategy and the availability of plots of individual farmers. Consumption mussels are harvested subsequently and brought to the auction at Yerseke. After sale at the auction mussels are stored on rewatering plots in the eastern part of the Oosterschelde before processing (cleaning, sorting, packaging) takes place. All processing companies are located at Yerseke, relatively close to the main consumer market for fresh mussels in Belgium (Smaal & Lucas, 2000).

The availability of mussel seed from wild beds is presently the basis of the culture cycle and this resource is under pressure. These beds predominantly occur in the Wadden Sea. Due to natural factors like limited spatfall possibly related to climate change, but also due to management measures that have resulted in protection of beds for nature conservation purposes, mussel seed availability has decreased. This might be a general phenomenon: mussel culture is often carried out in relatively pristine and clean environments and these areas nowadays also have functions for recreational use and as nature reserves (Smaal, 2002). Controversies between nature conservation NGO's, the shellfish industry (particularly mechanical cockle fishery) and the government have resulted in a shellfish policy for the period 1993 – 2003, that was based on closure of areas for fishery, food reservation for birds, co-management by the industry and a research program to evaluate the effects of these measures. As part of these measures intertidal mussel beds were closed for mussel seed fishery.

In the framework of co-management fishing plans were drawn up and vessels were equipped with a *black box* that registers sailing and fishing activities and locations. It is the task of the producers organisations to prepare the fishing plans, to ask for the fishing permits and to manage the black box administration and control. This practice has developed in the nineties.

2 – Strategy of the shellfish industry: Triple P approach

Under the influence of ongoing controversies the shellfish industry developed a strategy for sustainable exploitation that was published in 2001 (www.schelpdieren.nl). The strategy was based on the triple P approach for sustainable enterprising. The basis is to consider not only Profit as a basis for the industry but to give equal priority to Planet, addressing environmental issues and People, that regards the general public and the politicians as well as the workers in the industry. An important part of the strategy is to develop plans for continuous improvements (learning by doing), to communicate with external stakeholders (tell what you do and do what you tell), and to implement a planning cycle including research and evaluation.

As part of this strategy the Dutch mussel industry has developed a mussel seed management plan. The concept is to concentrate mussel seed fishery in autumn on unstable beds that have the tendency to flush away during winter storms. Harvesting should be done in such a way that no seed is being spoiled by excessive dredging, and future spatfall potential of the sites would be maintained. In spring the major part of the subtidal mussel seed beds are harvested and transplanted to the culture plots. Existing data show that new seed beds are formed naturally in the same areas and the idea is that spring fishery makes space available for new beds.

Mussel seed fishery on intertidal beds is at present only allowed on unstable seed beds if the total area of relatively stable beds exceeds a threshold of 2000 ha. Other possibilities for intertidal seed fishery are under study. After a large spatfal in 2001 experimental fishery of intertidal beds has been carried out on 10 * 10 ha, to test the hypothesis that fishery would improve the survival of dense beds because of thinning out and prevention of instability due to silt accumulation. The results show that fishery had neither a negative nor a positive effect (Ens *et al.,* 2004). The experiment will be repeated after a good spatfall.

The exploitation of mussel seed is now a collective action. For each fishery campaign a fishing plan is drawn up with detailed protocols for participating fishing vessels. The plan is based on a field survey by RIVO under contract of the PO and Ministry. Each spring an extensive quantitative survey of shellfish stocks is carried out by RIVO, and in autumn an expert judgment of the new seed stock is done by RIVO in cooperation with the fishermen (see annex). Immediately after the survey data are worked up and used for the fishing plan and the permits from the government in the framework of nature conservation and fishery laws. This strategy is in operation since the nineties and meanwhile a lot of field data have been collected and stored in the RIVO database.

3 – Governmental shellfish policy

In 2003, the ten year period of the fishery policy was evaluated on the basis of an extensive evaluation study (Ens *et al.,* 2004). A new policy has been developed since (Min, 2004). The new policy includes a stop and buy-out of mechanical cockle fishery in the Wadden Sea. The ban on cockle fishery was a result of pressure from nature conservation NGO's rather than an outcome of the evaluation studies. This process was complicated by new initiatives for the exploration of gas from the Wadden Sea that eventually prevailed.

For the mussel industry the new policy creates perspectives under the condition that the industry would invest in innovation and research and in a reduction of the use of wild mussel beds as seed resources. Initiatives for the development of artificial mussel seed collectors in Wadden Sea and North Sea, the production of hatchery/nursery seed and improvement of production efficiency will be supported. Also a new policy with respect to the importation of seed/half grown mussels from abroad will be developed. The policy is formulated for a period of 15 year with various evaluation milestones.

4 – Bird and Habitat Directives

The Wadden Sea and the Oosterschelde including the culture areas and the wild mussel seed beds are selected as nature conservation areas that are under the rules of the European Bird and Habitat (BHR) Directives. The actual governmental policy implies limited possibilities for harvesting mussel seed from intertidal beds. Subtidal beds are the main source for mussel seed. For each fishery campaign a permit has to be issued by the government that allows fishery in a nature conservation area. These permits are subject to a procedure that allows third parties to make objections to the permit, within a given period of time (6 weeks).

Since 2004, this procedure is in a new phase due to a decision of the European court in a case of cockle fishery in the Wadden Sea. As a consequence each permit has to be treated with more care. In this procedure no difference is made between a permit for building new infrastructure with an irreversible impact and a permit for fishing mussel seed that is in itself a recurrent activity. The procedure requires a careful judgment of possible impacts and it should be made clear whether significant effects can be expected and if so what measures are being taken to compensate or mitigate these effects. If effects are expected not to be significant, the basis of this expectation should be made clear and also what research is done to fill in knowledge gaps and reduce uncertainties. As management objectives have not been formulated as yet by governmental institutions as is foreseen in the BHR implementation, it appears that governmental policy is overruled by new interpretations of the BHR by the judges as far as these are subject to cases in court. The latter is often the case as shellfisheries are still criticized by nature conservation NGO's and the criticism seems to be in line with the BHR interpretation by the judges. As a consequence, in the present situation shellfish policy is a matter of juridical interpretation of EU directives rather than the result of political decisions.

5 – R&D program

The mussel industry has formulated a program for innovation for the coming 15 years. A major focus is at (1) the production of mussel seed through alternative techniques such as large scale artificial spat collectors, hatchery/nursery production and the use of wind parks for mussel seed production, (2) improvement of production efficiency by adjustment of culture plots to changing environmental conditions and by developing improved culture techniques, and (3) the use of inshore areas that are being developed in the framework of new coastal zone management. This program is now being discussed with nature conservation groups, as a start for a common marine resources strategy.

A research program was started in spring 2005 by a consortium co-ordinated by RIVO, under contract of the government and the mussel industry. This project "Produs" aims to address research questions of the new governmental shellfish policy and includes a number of questions of the mussel innovation agenda. The main topics are, the improvement of production efficiency, the artificial collection of mussel seed, further development of mussel seed management, carrying capacity analysis and the evaluation of the biodiversity potential of sublitoral mussel beds.

These programs are in addition to the shellfish surveys that are carried out each year in spring and at a smaller scale in autumn (see annex)

6 – Conclusions

i. The most important mussel seed beds that are the major resource for Dutch mussel culture occur predominantly in the western Wadden Sea, the largest Dutch nature conservation area.

ii. The Dutch mussel industry has adopted the triple P approach as a strategy for sustainable fishery. As part of the strategy a mussel seed management plan has been developed, focusing on exploitation of unstable seed beds, co-ordinated fishery and use of seed survey information.

iii. New governmental policy provides opportunities for further development of the mussel industry if a program of innovation is carried out, aiming at a reduction of environmental pressure.

iv. Fisheries in nature conservation areas require permits that are nowadays evaluated under the European Bird and Habitat Directives. This implies a new procedure including extensive documentation of potential impacts. The Dutch mussel industry has decided to closely co-operate with nature conservation NGO's, aiming at a common strategy for the exploitation of the resources. This is considered as a first step towards a European Marine Strategy.

v. Uncertainties about possible effects should be dealt with by research. This is considered as an application of the pre-cautionary principle for activities that have reversible impacts, like fisheries.

Annex Dutch mussel seed survey

Quantitative spring survey

Since 1990, surveys have been carried out for spatial distribution mapping and stock assessments of mussels and cockles.

In the Wadden Sea, about 1800 littoral and 600 sublittoral stations are sampled annually in spring. In the first years, a fixed design was followed, with stations being located on north-directed transects. The sublittoral survey was restricted to areas where it was known that there were mussels. In later years, a systematic sampling design is used. The survey area is divided into a number of strata according to the known or expected distribution and density of mussels (since 1995) and cockles (since 1998). The division is based on former surveys, on information provided by fishermen and colleagues, and for intertidal mussel and oyster bed, aerial surveys. Samples are organised within each stratum by cells in a grid. In the littoral, the cell size of the grid is dependant on the stratum. In strata with high clam densities, a smaller cell size is used than in areas with low densities. Sampling points are placed at the grid nodes. In the sublittoral a single sampling grid is used. Depending on the stratum, sampling points are placed on each node, every second node, etc., in a way that the total number of stations is about the same every year.

In the Oosterschelde area, the survey is mainly restricted to the littoral. About 450 stations situated on the grid nodes of a single grid are sampled annually in spring.

Sampling is done using either a modified hydraulic dredge (sampling width 20cm; sampling distance 100m, an adapted dredge with a fixed sampling area (0.42 m2; sampling width 21cm), a trawled dredge (width 10cm; length of haul: 100m), a small, handheld dredge (surface area 0.0333m2), or cores (diameter 10-25cm). Sampling depth is 7cm, the mesh size used is 0.5cm.

Qualitative autumn survey

In the first 2 weeks of September an expert judgement is made on the new mussel seed stock by sampling a grid in the western Wadden Sea with a commercial mussel fishery vessel. Based on information from the spring survey and expertise from fishery inspectors areas that are known for mussel seed, beds are surveyed. As this survey is done to inform the fishermen about amount and position of new seed beds, no time is available for a quantitative survey. The seed fishery begins directly after the survey in the second half of September.

Countours

In the Wadden Sea, the spatial contours of littoral mussel beds has been measured for the last 10 years, by walking around each mussel bed with a GPS device during low tide (Steenbergen et al, submitted). Because the Japanese oyster is increasing rapidly, the same procedure is followed for oyster beds since 2004.

In the Oosterschelde, Japanese oysters were introduced in 1964 and showed an enormous expansion. Since 1998 contours of intertidal oyster beds are measured either, at low tide, directly by GPS or, at high tide, from pricking the seabed surface. The latter is done on a small vessel following north-directed parallel transects located 0.1-0.2’ apart. Pricking is done every 0.01’. In general, pricking surveys result in smaller surface areas for the same oyster beds than GPS-surveys. In the sublittoral, the distribution has occasionally been followed using dredges or side-scan-sonar records (Dutch Geological Survey).

At selected locations, part of an oyster bed (0.25 – 4m^2) has been excavated and the tarra, number and weight (DW and ADW) of living oysters has been measured or calculated.

Appendix V. Joint arrangements for management of seed mussel stocks in relation to Irish and Northern Ireland vessels

Policy Document 2004

Source: SMAC Committee

Seed mussels are a natural resource that requires proper management and exploitation in order to maximise the potential return. Due to increased pressure on this resource in recent years and the all Island dimension, a formal set of guidelines are required. This document is the result of consultation with the bottom grown mussel industry and government bodies both in Northern Ireland and in Ireland and is subject to review from time to time.

These guidelines set out the management arrangements to apply to seed mussel stocks within the jurisdictions of Ireland and Northern Ireland. The Guidelines do not apply to seed mussel stocks within licensed aquaculture areas.

In recent years, Ireland's seed mussel resource both North and South has not met industry demand. The Department of Agriculture and Rural Development (DARD) introduced a moratorium in Northern Ireland on the processing of further Aquaculture Licence applications for bottom culture of mussels on 23rd September 2002.

Both DARD and the Department of Communications, Marine and Natural Resources (DCMNR) are keen to encourage the undertaking of surveys by the sector to identify new sources of seed.

It is envisaged that surveys by An Bord Iascaigh Mhara (BIM), the studies being undertaken by the Marine Institute and the Centre for Marine Resources and Mariculture (CMAR) on areas of spat settlement together with surveys by industry will identify new sources of mussel seed and decrease over-reliance on existing known resources. Applicants with a proven record of active participation in, or in support of, mussel seed surveys may receive priority

As mussels are a non-quota species, mussels located outside licensed aquaculture sites may be fished for consumption by any licensed and registered fishing vessel with the appropriate shellfish gatherer's documentation granted by either the DCMNR or the Food Standards Agency (FSA) - in Northern Ireland. However, if mussels are to be re-seeded or on-grown then any movements of stock must be in compliance with relevant National and EU fish health legislation.

Management regime to apply in regard to dredging and movement of mussel seed:

- The exploitation of the seed mussel resource around the coastline of the Island of Ireland will be on the basis of Statistical Sub Rectangles as defined by the International Council for the Exploration of the Sea (ICES).
- The number of vessels that may operate at any one time in a rectangle will depend on a number of criteria including *inter alia* the orderly exploitation and monitoring of the resource, available berthing and landing facilities.
- Applicants wishing to dredge mussel seed must complete an application form (parts A and B). Fully completed applications should be returned to either DARD or DCMNR.
- An application will be ineligible for consideration for any of the following reasons:
    - Failure to fully complete the application forms and /or to submit all relevant support documentation.
    - Failure to submit the fully completed applications and all supporting documentation so as to ensure receipt by DCMMNR or DARD within the required deadline
- Applications will be assessed and prioritised on the basis of resource availability, agreed criteria and compliance with business plans / aquaculture plans.

- Licences to fish will be issued in respect of vessels following assessment of information available.
- Licences will be subject to appropriate conditions and will specify the operator on whose behalf the vessel will be fishing, the quantity of mussel seed that may be fished and the period during which fishing may take place.
- The licensing/certification process will also apply to movements within a seed zone.
- The relevant Authority may restrict the number of vessels permitted to be used by an applicant in any one zone at any given time. The applicant must specify the vessel to be used and the reseeding site.
- Vessels may only land seed at designated ports, as confirmed in their application and so approved by the relevant Authority.
- The relevant Authority may restrict the number of landings permitted per vessel per day.
- If a vessel is to fish on behalf of another operator or operators, it is the responsibility of each operator to indicate on the application form which vessel is to be used and to also indicate the prioritisation of the fishing effort. Written confirmation of the intended arrangement from either the skipper or the owner of the vessel to be used should support this information.
- Fishing in any zone may be restricted at the direction of a fisheries inspector.
- All vessels must maintain daily logbooks in respect of their seed mussel fishing activities and submit copies to the local sea fisheries inspector on landing or on request.
- With regard to the requirement to provide historical data, the person/s who commissions the vessel to undertake the mussel fishing activity will be credited where appropriate. Paid crew members will not qualify for credits under certain headings of prioritisation.

Application procedures.
Application forms A and B must be *fully completed (all sections)* and forwarded to the relevant Authority (Department) in advance of any proposed fishing activity.

The application form is in two parts.

Form A must be submitted to the relevant Department. Applicants must fully complete all sections of form A and provide all relevant support documentation and submit to the relevant Department so as to ensure receipt in that Department by the date specified for such receipt. Details of history of participation by the applicant in a particular seed mussel fishery are required. The applicant is requested to provide, *inter alia*, accurate details of overall seed requirements for each site to be operated. Each site must be assigned a priority by the applicant. Where it is proposed that a vessel will be used for transplanting seed on behalf of a number of applicants, the order of priority of fishing activity to be undertaken must be clearly stated. The onus is on the aquaculture operator to secure and provide details in writing from the skipper or owner of his intended dredging priorities. All associated business/family interests in other aquaculture operations must be stated clearly in the application.

Form B must be fully completed (all sections) and submitted so as to ensure receipt in the relevant Department by the date specified for such receipt. The form requests information on proposed area/s to be fished, tonnage required, history of applicant's participation in zone, vessel details etc.. The information provided will enable decisions to be made on the issue of the licence/health certification and quota allocations. Subsequent renewals will be made on the basis of a review of all initial applications, estimated uptake to date by licensed vessels (logbook returns), estimated quantities of seed remaining in the fishery and quality of seed. Renewals will also take account of other factors such as tides and weather. Applicants will not be permitted to carry forward any unfished quota from one round of allocations to any subsequent rounds or to transfer any unfished quota from one zone to another.

Assessment procedure

Assessment of all initial applications will be undertaken by means of the Seed Mussel Assessment Committee (SMAC). Renewals may be decided outside the framework of SMAC if both the Departments are in agreement that an application should be renewed. In the event of agreement not being reached, applications for renewal will be referred for decision to the Committee. The SMAC will be comprised of representatives from DCMNR, DARD, Loughs Agency (LA), BIM and Aquaculture Initiative (EEIG). Applications will be scored by applying the prioritisation criteria and weighting factors to criteria outlined below.

The applications will be scored on the following prioritisation criteria:

- Historical mussel fishing activity
- Percentage fished of requirement
- Percentage of allocation on grown in sites within the Island of Ireland
- Average ratio return
- Average selling price per tonne
- Distance from zone to reseeding area
- Verified survey history
- Efficiency of seed operation
- Associated employment local coastal communities
- Percentage seed fished sourced from zone over last 10 years, and
- Means of transport to be employed.

Each Department will examine applications received and assess those, which are fully completed (all sections) and supported by relevant documentation. In certain cases, additional information may be sought which should be provided within specified timescales to ensure the assessment and prioritisation of applications is not delayed. Departments will consult with each other each and with other agencies on applications as appropriate. The provision of false or purposely misleading information will render the application ineligible.

Each Department will submit to the Committee a prioritised list of projects in a format that includes score sheets and a summary sheet of all applications received.

The SMAC will make decisions on

- Opening dates of fisheries and duration of fishing;
- Seed beds that may be fished;
- Maximum quantities to be fished;
- Duration of licences;
- Vessels to be licensed to operate in any particular zone at any one time;
- Maximum quantities that may be fished by each vessel; and
- Designated landing ports.

Taking account of:

- Size and condition of seed;
- Suitability of bed;
- Infestation by predators; and
- Windows of opportunity for dredging.

It will be a matter for DARD/DCMNR as appropriate, to issue the relevant licences/health certification and to formally notify applicants of decisions. Any queries regarding decisions taken on applications should be addressed in writing to the relevant Department.

If a situation arises that requires an immediate response from the Committee following consultation between the DARD and DCMNR representatives, the Committee may make a decision that will be recorded and detailed at the next meeting of the SMAC.

Designated Ports/Vessel Access
Ports for landing will be designated. The relevant authority may restrict the number of vessels operating in a zone at any one time. An applicant may apply to use more than one vessel provided that each vessel used will be transplanting into a separate fishery/reseeding area. A substitute vessel may be nominated by an applicant in the event that an application to use that vessel in another area has been unsuccessful, that an application is not now proceeding or in the event of vessel breakdown. In the event of any of the above situations arising, the permission of DARD/DCMNR to operate the substitute vessel in the zone will be required.

Control of Fishing activity
Notification of intention to fish must be given to the relevant Department at least 24 hours in advance of commencement of fishing activity. Notification must include the name of the vessel, name of skipper/owner, contact telephone number, intended zone of operation and intended duration of operation. Compliance with inspection procedures and provision of logbook information will be included as licence conditions.

Surveys.
Surveys may only be undertaken with the prior written approval of the relevant Department.

Appendix VI. Industry Survey Protocol

Source: *McDonough, N., **T. O'Carroll, **J. Dennis & ***K. Parker
*C-MAR, Queens University Belfast,
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***Dept. of Agriculture and Rural Development, N. Ireland

If duly registered and licensed mussel dredgers wish to survey in an individual and private capacity then the following procedures should be complied with:

- Permission to survey in a specified location should be obtained from the local fishery officer. The operator should discuss with the fishery officer the areas into which they plan to survey. This is important as the local fishery office will know of other fishery activities in the area such as pot fishing and salmon netting etc. which the survey vessel will need to take into consideration. Ideally the operator should inform the fishery officer of the intent to survey verbally and in writing (fax) giving dates and locations.
- The responsibility is with the survey vessel not to interfere with any other type of fishing gear that may be deployed. If the vessel wants to survey any area in which gear is deployed then arrangements should be made with the owners of the gear to remove it temporarily etc.
- It should be noted that any vessel can be boarded and inspected by fishery protection vessels and in the case of a mussel dredger which is not fishing for direct human consumption (i.e. under a EU Directive 91/492) then they are not permitted to retain on board any shellfish unless they have the appropriate movement/disease certification etc. This means that while surveying apart from small samples of seed (1 to 5 Kg) no other shellfish should be retained on board. If problems arise once boarded by a fisheries protection vessel the operator should refer them back to the local fisheries officer (this is why it is advisable to have copies of faxed application to survey etc. on board).
- Full details of the vessel (name and registration identification number), call signs and mobile phone contact details should be provided to the fishery officer by the operator of the survey vessel.
- Prior daily notification of landing/return to port to the local fishery office is required. The fishery office may make an inspection to ensure that no quantities of seed have been retained on board or transplanted onto aquaculture sites.
- Though not a requirement, it is advisable that the operator notifies the local fishery officer the details of any seed bed located. This can be done on a confidential basis. The benefit of this is that if a second operator is surveying in the same area then if they also report a find then the fishery officer can ascertain if it is the same bed that has been found. This will ultimately make the job of SMAC easier as there will be a better estimate of the seed resource available on which decisions will be made for the coming season. It should be noted that unless the operator finding the seed wishes the details circulated then it will not be done and the person finding the seed will have first chance at the bed once the season opens.
- The guidelines for carrying out and recording information detailed below should be followed.

Coordinated Industry Survey

As was carried out last year, it will be a requirement for each vessel operating in the seed mussel fishery to participate in a coordinated industry survey prior to and possibly during the seed mussel fishing season (once all known seed sources have been exploited).

It is proposed that the survey will co-ordinated by the chairman to the scientific sub committee of the SMAC. Areas of the coast will be surveyed according to the ICES statistical sub rectangles. In consultation with the available mussel fishing fleet groups of boats will be assigned various areas to survey. Ideally one vessel in every group should have ground discrimination equipment and a 'black box'. Either a fisheries officer or an agency staff member will be appointed to act as a liaison officer with each group. Before the appointed survey periods the liaison officer will discuss the survey strategy for his/her area and consult with vessel operators about dividing up effort to maximise geographical coverage. Planning will take into account tides, weather, capabilities of the different vessels, previous survey effort etc. A survey plan will minimise the potential for overlap in survey effort (several vessels covering the same ground and finding the same seed) and maximise the potential for finding new seed.

SURVEY DESIGN

According to the survey plan each vessel involved will be asked to cover a particular area of ground in a particular day. Of crucial importance will be the vessel track when surveying. Because some beds (particularly in the south Irish Sea) are long and narrow and run in a north-south orientation, it may be useful to adopt a zig-zag survey track with vessels travelling in an overall north to south or south to north direction whilst steaming towards and away from the shore (see diagram). This would ensure maximum coverage whilst minimising the possibility of missing a long narrow seed bed.

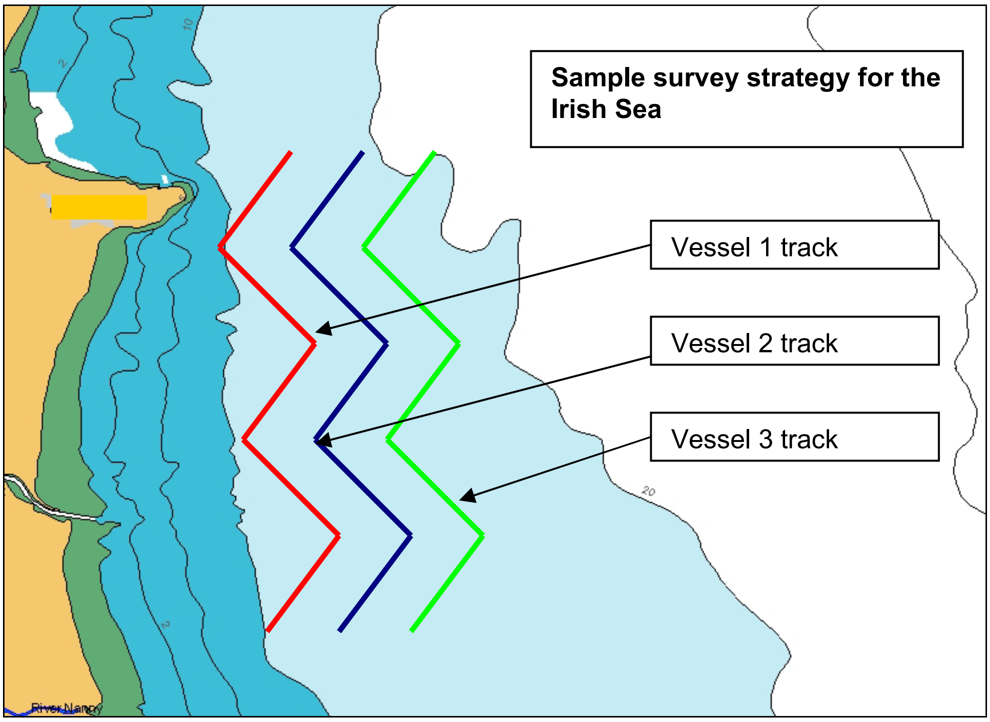

Figure A2.1 Sampling strategy for the Irish Sea.

Survey Strategy

As normal, dredgers can use periodic deployment and retrieval of dredges to search for seed. Acoustic Ground Discrimination System (ADGS) (e.g. RoxAnn/Echo Plus etc.) should be used where available to assist the process. Marks should be recorded on plotter of all deployments / dredge tracks.

Survey Equipment

Vessel operators should ensure they have all the necessary equipment on board to enable them to make some basic observations on seed quality if they find seed.

GPS / Plotter:

- Equipment must be checked at a fixed point of known co-ordinates each time a vessel leaves harbour. This is to ensure the accuracy of lat/long co-ordinates.
- Equipment must be set to WGS84
- Equipment must provide readings in decimal degrees.

Acoustic Ground Discrimination System (e.g. RoxAnn/Echo Plus etc) – if available:
- Equipment must be ground-truthed regularly each day the vessel surveys.

Echo-sounder:
- Check depth at known depth (tide gauge mark on pier or use weighted line with depth marked in increments).

Other equipment on board:
- Small scales / spring balance
- Callipers
- Sample bags
- 1 litre beaker

WHAT TO DO WHEN SEED IS FOUND

Basic observations on seed size and quality can be made using:
- 1-litre container
- Spring balance
- Callipers

These should be noted on the standard recording sheet (to be supplied, this sheet will also give details on how various measurements etc. should be made) which will include the following information:
- Time and date.
- Co-ordinates (decimal degrees) of location where seed was initially found (e.g. start and finish of tow).
- Extent of the bed. An attempt should be made to establish the co-ordinates of the north/south and east /west extent of the bed.
- Depth.
- State of tide (e.g. hours after high/low water).
- No. pieces per kilo.
- Mean size of seed.
- % seed in sample (i.e. the percentage by weight of seed versus "other material" in three samples.
- Strength of seed shell.
- Observation on byssal attachment or clumping of seed.
- Presence of predators in haul (starfish, crabs etc.).
- Presence of dead shell.
- Any other comments worth noting.

A representative sample of seed (1 to 5 Kg.) should be retained by the vessel in case a sample is required for health check analysis or in cases where the seed is small and fragile and there is a question as to its suitability for fishing. In the latter case by having a sample on board then other skippers and the liaison officer can examine the seed in port and make a decision on whether or not the bed should be opened for fishing (N.B. the final procedure for this aspect of deferring opening of a bed needs to be agreed with industry).

All of this information should be recorded on a supplied data sheet (See Appendix VI) and returned by fax to the co-ordinating officer as soon as possible who in turn will forward the information to the overall co-ordinator. It is important that data sheets showing the ground covered should be returned by all operators for all survey days at sea. It is just as important to build a database of areas of where seed has NOT been found as this will contribute to the long-term dataset.

Appendix VII. Sample record sheet

Source: Nuala McQuaid, C-MAR, Queens University Belfast

General Information

Name of Vessel	
Skipper	
Date	
Time (seed located)	

Co-Ordinates (decimal degree's) where seed initially found

Start Tow		End Tow	
Latitude	Longitude	Latitude	Longitude

Co-Ordinates marking extent of bed where possible (At least 4 corners of bed)

Latitude	Longitude	Metres Depth	(Hrs after high/low water) Stage of Tide

Quality of Mussels

What is your average time per tow?
Approx Wt of dredged sample (Kg/Tonnes)?
Are predators present in sample?
What kind of predators?
% dead shell in the dredged sample (<10%;10-50%; 50-90%; >90%) ?
Is seed shell strong/weak/in between?
Is the seed mainly loose/clumped?
How many pieces per Kg are in the sample?
What is the average mussel size? *
What is the average % seed in the sample? **

*Measure (at longest point) 30 mussels randomly selected from each of the 3 samples and record overleaf.

**take 3 samples (between 250-500g) from the catch recording the weight for each on the sheet overleaf. Separate the mussel component then count,weigh and record this also overleaf.
% Seed in sample = Wt of mussel/Total sample wt *100. Get an average for 3 samples

Mussel Quality Continued

Sample No.	1	2	3
Total Wt:			
Mussel Wt:			
No of Mussels			
	Mussel length (mm)	Mussel length (mm)	Mussel length (mm)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
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29			
30			
Comments:			

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ACKNOWLEDGEMENTS

We wish to thank all the participants and sub-contractors of this study; UCC, UCD, South-East Shellfish Co-op, QUB, AquaFact International Services Ltd., Seabed Surveys Ltd. and LYIT. A special thanks goes out to the external advisors who attended the steering group meetings; Ray Seed (University of Bangor), Carter Newell (Great Eastern Mussel Farms Ltd.), Aad Small (RIVO) and Terence O'Carroll (BIM).

Thanks also to the various State Agencies (BIM, Marine Institute, Dept. of the Marine and DARD) and individual fishermen (particularly Michael Crowley from SE Shellfish Co-op) who provided valuable historical data and statistics for the fishery.

Finally special thanks to the Marine Institute for funding this project and to Francis O'Beirn and Micheal O'Cinneide in particular for all their support and advice throughout the study.