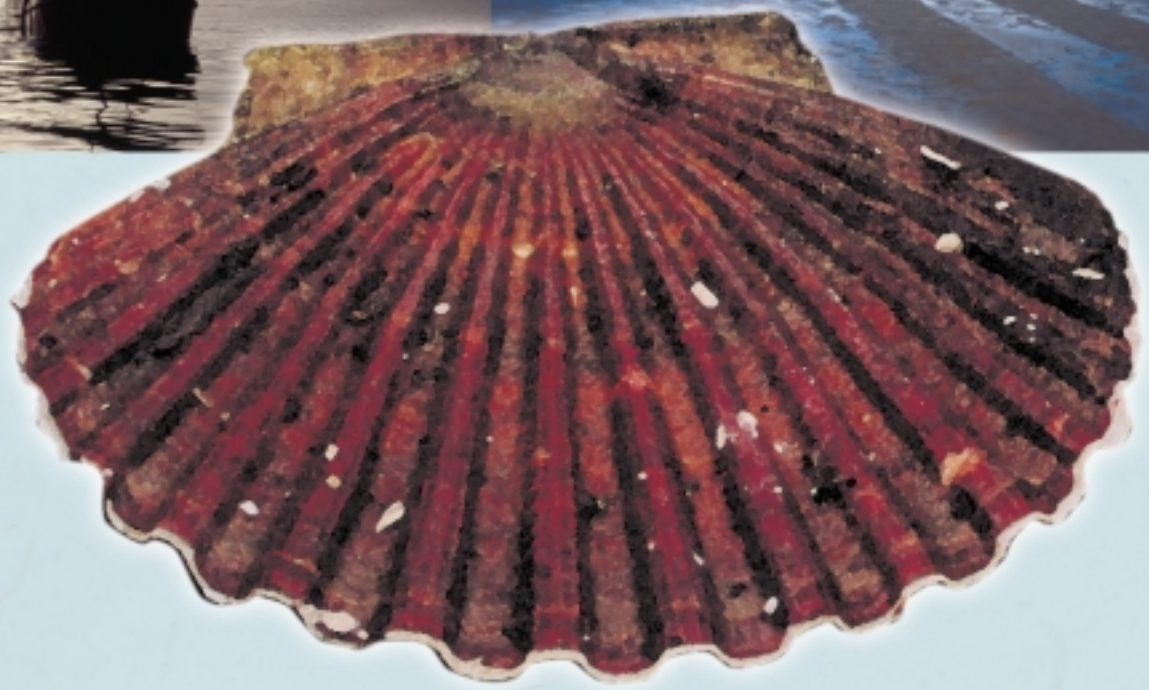
The Shellfish Aquaculture Management Plan for Northern Ireland



Heather Moore[1] and Matthew Service[2]

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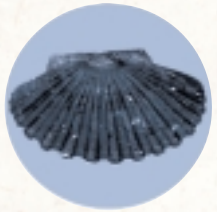


Contents

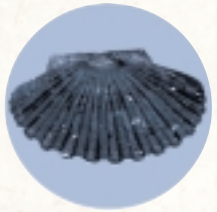
Click on orange button to go straight to page

Cover photographs

Mussel dredger (Belfast Lough)

Manila clam pots (Carlingford Lough)

Oyster trestles (Carlingford Lough).

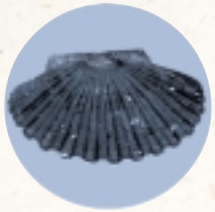


Executive Summary

In order to derive a management plan for the Shellfish Aquaculture Industry in Northern Ireland it was necessary to review the present state of the industry, amass the facts and look at the potential for development.

The review of the present aquaculture industry suggested that there exists an opportunity for diversification of aquaculture species and methods. The report highlights the fact that a sustainable aquaculture industry is only possible with maintenance of a healthy ecosystem. For the upkeep of this dynamic balance between aquaculture and the environment the industry must work with the associated environmental bodies.

In conclusion a set of recommendations have been produced. Further work is required in many areas particularly for the development of a functional carrying capacity model.

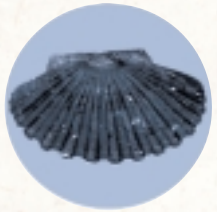


Acknowledgements

To acknowledge all of the people who have helped, supported and advised me throughout the evolution of this report is a mammoth task. I start with DARD Fisheries for their funding and constant support, particularly Mr C. Hunter, Mr J. Hayes, Mr D. Eccles, Mr G. Thompson, Mr T. Gowan, Mr K. Parker and numerous others for good advice. My close link with Fisheries facilitated a variety of site visits, meetings and discussion with many of the aquaculture producers. Through these visits and discussion I have gained some first hand experience of the aquaculture industry in Northern Ireland. I would like to thank Ms T. Johnston, Dr J. Parsons, Mr R. Graham, Mr P. Van Ysseldijk, Mr R. Dougold, Mr G. Golden, Mr D. Gallagher, Mr B. McCoubrey, , Miss M. Clarke, Mr E. Carville, Mr F. Stone, Mr J. Quinn, Mr H. Henning and Mr. N. Stephens. Thanks are also extended to Dr P. Leighton and Dr J. Mercer at Carna.

A vast amount of information was gained from discussions with other related organisations including representatives from the Cross Border Aquaculture Initiative, Environmental Heritage Service Water Quality, EHS Natural Heritage, Queen's University Belfast, The Ulster Museum, C-Mar, Scottish Natural Heritage, DHSS, Ulster Wildlife Trust, The Marine Laboratory Aberdeen, The University of Glasgow, RSPB, Foyle Fisheries, Napier University, Strangford Lough Management Committee, the National Trust and BIM.

Finally, I must acknowledge the patience of all those in AESD who had to answer endless queries, especially Dr M. Service, Dr R. Briggs and Mrs A. McKinney. With a last thank you for practical assistance from Claire, Janine, Mark, Neil and Simon.



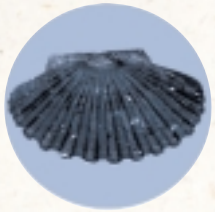
Foreword

The shellfish discussed in this report are mainly bivalve filter-feeding molluscs, these are important components of coastal ecosystems because they remove large quantities of suspended material from the water column and excrete abundant amounts of reactive nutrients. These animals are also the prey for numerous predators including birds, fish, mammals and invertebrates. They are also significant food resources for humans.

Bivalve growth is influenced by temperature, salinity, exposure to air, water flow, food, and water pollution. Shellfish need good water circulation to supply their respiratory and nutritional needs. They also require clean water to maintain a disease free status, production of high quality shellfish promotes a "green image" for an area.

Dense aggregations of filter-feeding molluscs characterise the benthic fauna of many estuarine and shallow coastal regions. These regions meet the light and nutrient requirements for intensive phytoplankton growth which is the basis of food resources for bivalves. Tidal currents transport water masses from a large surrounding area to the sites where banks of bivalve filter-feeders occur and enable a continuous input of fresh phytoplankton

Bivalves feed by filtering microscopic algae (phytoplankton) and organic detritus from seawater. An adult bivalve will pump a large volume of seawater through its body cavity, depending on its size, sea temperature and other environmental and biological factors. The value of naturally occurring food is impossible to evaluate by inspection of water samples, since seasonal abundance and quality of microalgae fluctuate widely. Normally, phytoplankton peak abundance occurs in spring with a lower peak in the autumn. Coastal and estuarine waters generally have sufficient food in relation to prevailing temperature to support reasonable growth. Blooms of unsuitable algae may also occur, usually in response to a combination of certain environmental conditions, and these algae are often nutritionally unsuitable and consequently reduce bivalve growth.



Bivalve molluscs not only remove materials from the water column or benthic-water interface, but they, as a result of feeding and metabolism, generate both particulate and dissolved materials that have an influence on benthic and pelagic habitats. Therefore, specific high quality organic constituents in the form of plankton, detritus, and amino acids are consumed as food, processed, deposited as faeces or pseudofaeces, or excreted as fundamental nutrients to the water column where they can be utilised by the plankton. As bivalves frequently form dense assemblages or communities of organisms in shallow ecosystems, these animals may play an important role in the cycling of nutrients within these systems. Bivalves couple the benthic habitat to the water column, this bentho-pelagic coupling is integral in nutrient cycling in coastal ecosystems and the "health" of the system relies on the balance of this coupling.

Nutrients are required for phytoplankton to grow and phytoplankton are required for shellfish growth. The sea loughs and some coastal areas around Northern Ireland have potential habitats suitable for aquaculture. They also have nutrient inputs from a variety of sources including freshwater inputs from rivers, land run-off, sewage treatment works and the atmosphere. A balance between the standing stock of phytoplankton and the stock of bivalve filter-feeders must be found for sustainable shellfish culture. Over-stocking of an area with shellfish will lead to depletion of the phytoplankton and the nutrients. Excess nutrient inputs to an area will not enhance shellfish production, it will produce phytoplankton blooms which may be toxic to the shellfish and the area may become eutrophic.

The concept that a dynamic balance exists within these ecosystems is stressed and the requirement for a strategic management plan is essential. Good husbandry of the shellfish stocks in parallel to systematic monitoring of the ecosystem is required. The aim of this report is to show the necessity for a management plan, for the expansion and continuity of the shellfish industry and for the environment. It will require shellfish producers and all other interested parties working together within specific regions. A successful management strategy would minimise conflict of water use, environmental impacts, and optimise production.

Chapter One

General Introduction

This paper sets out the view that a scientifically based aquaculture management plan for Northern Ireland represents the most sensible strategy to ensure long term sustainability of our stocks. The concept of sustainable development involves the combined consideration of economic, social and environmental components. Sustainable development in this context is best described as "..development which is meeting the needs of the present without compromising the needs of the future"(Gro Harlem Bruntland, Norwegian Prime Minister).

1 Background

Northern Ireland has several estuaries and sea loughs which are suitable for either the commercial exploitation of native shellfish populations or for commercial semi- intensive rearing of shellfish. Many of these areas are of great ecological significance and protected under EU Legislation (Chapter 2). As the aquaculture industry expands there are increasing pressures from those who would establish commercial shellfish operations to utilise sites in these ecologically important areas.

A five month project was commissioned by the Department of Agriculture and Rural Development to produce a Shellfish Aquaculture Management Plan for Northern Ireland (SAMPNI). The guidelines were produced following a review of the literature and evaluation of existing data. Consultation with user groups, management authorities and other experts was fundamental in the development of the SAMPNI . Current data from a coastal classification and benthic mapping project have provided habitat information, facilitating the investigation into scope for new shellfisheries.

1.1 Aim

To produce a management plan based on scientifically researched fact amalgamating habitat data, shellfish biology, aquaculture methodology and illustrating how the controlled interaction between these factors, promoted through a sound management strategy is the only way to promote a sustainable aquaculture industry in Northern Ireland.

1.2 Objectives

The objectives were to:

- To identify the species and methods best suited to particular areas.
- To identify what scope exists for the expansion of shellfish cultivation.
- To identify potential ecosystem effects from increasing the biomass of shellfish in certain areas.
- Find out if specific sites have a finite carrying capacity in terms of the ability of an areas natural productivity to support growth.
- To identify gaps in our existing knowledge that need to be filled to optimise the management of shellfisheries.

Chapter Two

Legislation

Introduction

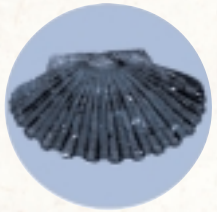
The rapid growth in the aquaculture industry has coincided with a growth in environmental awareness and our greater understanding of the impact that all human activity has on our natural environment. As the industry develops there is an increased responsibility on the industry itself and its regulators to ensure that its growth is sustainable. The natural relationship between environmental sustainability and commercial success is underpinned by good management practices, continuous research and regulatory legislation at national and EU level.

It is important to realise, however, that aquaculture is regulated by a broad range of legislation covering not only the environment, but also the daily operation of fish farms, fish health, public health and water quality.

The Fisheries Act (Northern Ireland) 1966 is the means by which fish farms, including shellfish farms in Northern Ireland waters, are licensed (Appendix 1). Under the Act, it is an offence to operate a fish farm without a fish culture licence. In the case of shellfish farms, an applicant for a fish culture licence may also apply for a shellfish fishery licence. Although this is technically optional, this second licence has a number of advantages. For one thing it effectively gives ownership of stock to the licence holder. In addition to this it makes it an offence for anyone to remove, damage or disturb any shellfish, raft, tray or other structure, or to deposit any substance on the area under licence. Section 11 of the Act deals with the mechanics of the licensing process for the fish culture licence, while Sections 131 to 137 deal with the issues relating to shellfish fishery licences. A fish culture licence cannot be granted without the consent of the Maritime and Coastguard Agency and the owners of the seabed or foreshore (normally the Crown Estate Commissioners) (Hunter, *pers.comm.*). In addition to this, licence conditions can be imposed on operators to ensure that their activities are carried out in an environmentally sensitive manner.

Other Sections of the Act are directly relevant to shellfish farming (Appendix 1). These include Section 13, which allows the Department to prohibit the introduction of any species of fish or shellfish into Northern Ireland if it considers that it would be detrimental to the fishery. Section 14 allows the Department to grant Permits for the artificial propagation of fish, for some scientific purpose or for the improvement of a fishery. Under Section 124, the Department can introduce regulations for the management, protection and conservation of fisheries. An example of this is where Section 124 was used to introduce Regulations, which banned fishing for seed mussels without the authority of a Permit issued by the Department. Section 185A allows the Department to have regard to the preservation of natural beauty and the conservation of flora, fauna and geological or physiographical features of special interest (Hunter, *pers.comm.*).

Fish health is an important area and regulations protect Northern Ireland's very high fish health status. The maintenance of fish health status in the European Union is governed by a number of Directives the most important of which is Council Directive 91/67/EEC as amended, "covering the animal health conditions governing the placing on the market of aquaculture animals and products". Relevant parts of the Directive regulate the transportation of both farmed and wild live shellfish destined for relaying, between one part of the EU and another. It makes it illegal to import any species from a "zone", which has a lower fish health status than the one to which the fish or shellfish are being transported. The maintenance of fish health status is backed by a programme



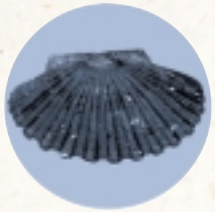
of inspections and the testing of stocks of shellfish within Northern Ireland. The Directive is enacted by the Fish Health Regulations (Northern Ireland) 1998. The Diseases of Fish Act (Northern Ireland) 1967 and the Diseases of Fish (Control) Regulations 1996 are also important tools in the prevention and control of disease.

In relation to public health, the most important piece of legislation is Council Directive 91/492, commonly referred to as the Shellfish Hygiene Directive (This is implemented in Northern Ireland by the Food Safety (Fishery Products and Live Shellfish) (Hygiene) Regulations (Northern Ireland) 1998. Under the regulations, shellfish may only be harvested from an area, which has been designated as a production area. To attain this designation the shellfish must conform to standards relating to the levels of faecal coliforms present in the flesh. They must also satisfy a number of other requirements, which will be dealt with later.

The requirements for shellfish being placed on the market are as follows. In relation to the levels of faecal coliforms, there are three classes of shellfish bed (or "production area"). In a Class A area, the levels of faecal coliforms must not exceed 300 faecal coliforms or 230 *E. coli* per 100 grams of flesh and intravalvular liquid. Shellfish from a Class A area may be placed directly on the market. In a Class B area the levels of faecal coliforms should not exceed 6,000 faecal coliforms or 4,600 *E. coli* per 100 grams of flesh and intravalvular liquid. Before being placed on the market, shellfish from these areas must either be relaid in Class A areas until they have come up to that standard or must undergo a depuration process. Shellfish from Class C areas must not have more than 60,000 faecal coliforms or 46,000 *E. coli* present in 100 grams of flesh and intravalvular liquid. Prior to being placed on the market, these shellfish must be relaid in higher quality waters for a period of at least two months, followed, where necessary by depuration. The alternative to this for shellfish from either Class B or C areas, is for them to undergo an approved process of heat treatment prior to being placed on the market. In reality, this is not an option for species such as oysters, which are sold raw. It would also be a less preferable method of marketing species such as mussels, as the market price for the heat treated product is comparatively low.

The relevant authorities may, at any time designate an area as unsuitable for health reasons, for the production or harvesting of live bivalve molluscs or gastropods (as well as tunicates and echinoderms).

In addition to the requirements relating to faecal coliforms, there are a number of other restrictions placed on shellfish before they can be placed on the market. They must not contain any *Salmonella* in 25 grams of flesh and they must not contain toxic or objectionable compounds in excess of those listed in the Shellfish Waters Directive (79/923/EEC) – this will be dealt with in greater detail later. In addition to this there must be no Diarrhetic Shellfish Poisoning present in the flesh and the levels of Paralytic Shellfish Poisoning must not exceed 80 micrograms per 100 grams of flesh. Separate legislation deals with the levels of Amnesic Shellfish Poisoning. In this case the levels of the toxin must not exceed 20 micrograms per gram of flesh. In the absence of routine virus testing, at present health checks must be based on faecal bacterial counts. In general, the shellfish must also be clean, have normal amounts of intravalvular liquid and show an adequate response to percussion.



The Shellfish Waters Directive 79/923/EEC concerns the quality of shellfish waters ".. needing protection or improvement to support shellfish (bivalve or gastropod molluscs) life and growth and thus to contribute to the high quality of shellfish products directly edible by man."

This Directive gave member states two years from 1979 to designate shellfish waters within their jurisdiction. Designation of shellfish waters in Northern Ireland is now underway.

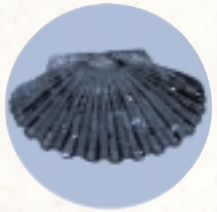
In relation to the quality of the shellfish themselves, limits are placed on the concentration of metals present in the flesh. The Directive also sets standards for levels of salinity, dissolved oxygen, petroleum hydrocarbons, organohalogenated substances, pH, faecal coliforms and substances affecting the taste of shellfish flesh.

The 1990's witnessed a "call to action" for marine biodiversity conservation. The global Convention on Biodiversity, the European Union's Habitats and recent developments to the Oslo and Paris Convention have each provided a significant step forward. In each case, marine protected areas are identified as having a key role in sustaining marine biodiversity.

One initiative underway to help implement the Habitats Directive is the UK Marine SACs LIFE Project, involving a four year partnership (1996-2001) between; English Nature, Scottish Natural Heritage, countryside Council for Wales, Environment and Heritage Service DOE, Joint Nature Conservation Committee and Scottish Association of Marine Science. The overall aim of this project is to promote the implementation of the Habitats Directive in marine areas through trialling the establishment of management schemes on 12 of the candidate marine SAC sites. To support these schemes, the Project is undertaking a series of tasks to collate and develop the understanding and knowledge required. One of the areas for providing guidance to those developing the schemes concerns the interaction between human activities and marine features. Human activities have an important role in the management of marine features and may have both beneficial and damaging impacts. Seven studies have been undertaken bringing together guidance on these impacts and promoting the means of avoiding significant damage to features , including: port and harbour operations, recreational user interactions, collecting bait and other shoreline animals, water quality in lagoons, water quality in coastal regions, aggregate extraction and fisheries.

In May 1992, the member states of the European Union adopted the "Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora". This is commonly known as the Habitats Directive. The main aim of the Directive is to promote the maintenance of biodiversity and, in particular, requires member states to work together to maintain or restore to favourable conservation status certain rare, threatened, or typical natural habitats and species. These are listed in Annex I and II of the Directive respectively, among these are a variety of marine features and SAC's have already been selected for many of these in the UK. To manage specific habitats and species effectively, there needs to be a clear understanding of their distribution, biology and ecology and their sensitivity to change. From such a foundation, realistic guidance on management and monitoring can be derived and applied.

One of the ways in which the member states are expected to achieve this aim is through the designation and protection of a series of sites, known as Special Areas of Conservation (SAC's).



The Birds Directive (Council Directive 79/409/EEC on the conservation of wild birds) complements the Habitats Directive by requiring member states to protect rare or vulnerable bird species through designating Special Protection Areas (SPA's). Together, the terrestrial and marine SPA's and SAC's are intended to form a coherent ecological network of sites of European importance, referred to collectively as Natura 2000.

In the UK the implementation of these Directives has been translated into UK legislation by "The Conservation (Natural Habitats, & c.) Regulations 1994" and by "The Conservation (Natural Habitats, &c.) (Northern Ireland) Regulations 1995", referred to as the Habitats Regulations.

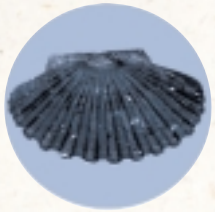
On land, SACs and SPAs are underpinned by Areas of Special Scientific Interest (ASSI) in Northern Ireland. There is no existing legislative framework for implementing the Habitats Directive in marine areas. Therefore the Regulations have a number of provisions specifically for new responsibilities and measures in relation to marine areas.

The Regulations place a general duty on all statutory authorities to exercise legislative powers in accordance with the Habitats Directive. The term European marine site is defined as any SPA and SAC or part of a site that consists of a marine area where marine also includes intertidal areas. The new duties relative to the management of marine sites are summarised in Hailey and Burn (1999). Within the Regulations, the nature conservation bodies have a special duty under Regulation 28 to advise the other relevant authorities (those already involved in some form of relevant marine regulatory function and therefore would be involved in the management of a marine site) as to the conservation objectives for a site and the operations that may cause deterioration or disturbance to the habitats or species for which they have been designated. This advice would from the basis for developing the management scheme for a European marine site (Hailey and Burn, 1999).

Conservation designation

1 Belfast Lough

Belfast Lough is a site of international importance for water fowl. The intertidal mudflats in the upper region are important feeding grounds for internationally important numbers of wintering Redshank and Turnstone and nationally important for another 15 species of waterfowl (Buck and Donaghy, 1996). The innermost parts of the Lough have been designated as Inner Belfast Lough Area of Special Scientific Interest (ASSI) on the basis of its biology (Figure 2.1). The Outer Belfast ASSI, designated for its biological and geological interest, encompasses further areas of intertidal land and islands. The foreshore of the Lough also qualifies as a Ramsar site and as a Special Protection Area (SPA) (Figure 2.2 and 2.3).



2 Strangford Lough

Over 2000 marine organisms have been found, including 72% of all the species recorded from around the Northern Ireland coast. Of these, 28 are found only in the Lough, therefore under EU legislation, this area must be protected. Strangford Lough is of international importance to wintering wildfowl and waders. Between 60 and 75% of the world population of Light-bellied Brent geese (*Branta bernicla hrota*) travel 3000 km from Greenland and Canada to overwinter on the northern mud flats of Strangford Lough, where they feed on extensive eel-grass beds (*Zostera* species). Internationally important populations of Knot and Redshank and 22 other species of national importance also overwinter and breed in the Lough.

In 1995, all waters, seabed and shores up to the high water mark mean tide of Strangford Lough and the mouth of the Lough were designated as the third and largest 'Marine Nature Reserve' (MNR) in the United Kingdom. This follows the designation of much of the foreshore and some islands as an 'Area of Special Scientific Interest' (ASSI), the North Strangford, Dorn, Granagh Bay, Cloghy Rocks and Killard areas as 'National Nature Reserves' (NNR) and the Lough and Lecale coast as 'Areas of Outstanding Natural Beauty' (AONB). Strangford Lough is recognised as a candidate Special Area of Conservation (SAC) under the EC Habitats Directive and has been classified as a Special Protection Area (SPA) under the Birds Directive (Figure 2.1-2.5).

3 Carlingford Lough

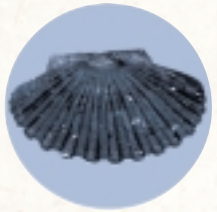
Much of Carlingford Lough's northern foreshore lies within an Area of Outstanding Natural Beauty (AONB), an Area of Special Scientific Interest (ASSI) (Figure 2.1) and the Mourne Environmentally Sensitive Area (ESA). The Lough also qualifies as a Ramsar site and as a Special Protection Area (SPA) (Figure 2.2 and 2.3).

4 Lough Foyle

Magilligan Point, a 57 ha National Nature Reserve is an ASSI (Figure 2.1 and 2.5) and has been proposed as a candidate Special Area of Conservation (Figure 2.5) (Buck and Donaghy, 1996). Other areas of Lough Foyle qualify as Ramsar sites and proposed Special Protection Areas (SPA's) (Figure 2.2 and 2.3).

5 Larne Lough

Larne Lough regularly supports an internationally important population of wintering light-bellied Brent geese, and nationally important numbers of six species of wintering waterfowl. Larne Lough has been designated as an Area of Special Scientific Interest (ASSI) for its biological and geological features (Figure 2.1). Larne Lough and Swan Island meet the classification as a Special Protection Area (SPA) and a Ramsar site (Figure 2.2, 2.3). Swan Island (0.1 ha) has been classified as a National Nature Reserve (NNR) (Figure 2.4) and a RSPB reserve.



6 Dundrum Bay

Part of Dundrum Bay forms Murlough National Nature Reserve, the first Nature Reserve to be designated in Ireland (Figure 2.4), and the majority of the estuary lies within Murlough Area of Special Scientific Interest (Figure 2.1), which was designated for its biological and geomorphological characteristics (Buck and Donaghy, 1996). The western shore of Dundrum Bay lies within the northern edge of the Mourne Mountains and Slieve Croob Environmentally Sensitive Area (Buck and Donaghy, 1996). Dundrum Inner Bay qualifies as a Special Protection Area (Figure 2.3) and a Ramsar site (Figure 2.2) and Murlough has been proposed as a Special Area of Conservation (Figure 2.5) (Buck and Donaghy, 1996). Dundrum Bay is further protected under the Razor Shells (Prohibition of Fishing) Regulations (Northern Ireland) 1998, to prevent an unregulated fishery starting up (see Appendix 1).

7 Killough Harbour

Internationally important numbers of light-bellied brent geese overwinter on the Killough mudflats and feed on the *Entermorpha* spp. Although Killough Harbour and Coney Island Bay meet the criteria as a Ramsar site and a Special Protection Area (Figure 2.3), there are only statutory conservation designations for the SPA.

Figure 2.1
Areas of Special Scientific Interest (ASSI) (courtesy of EHS).

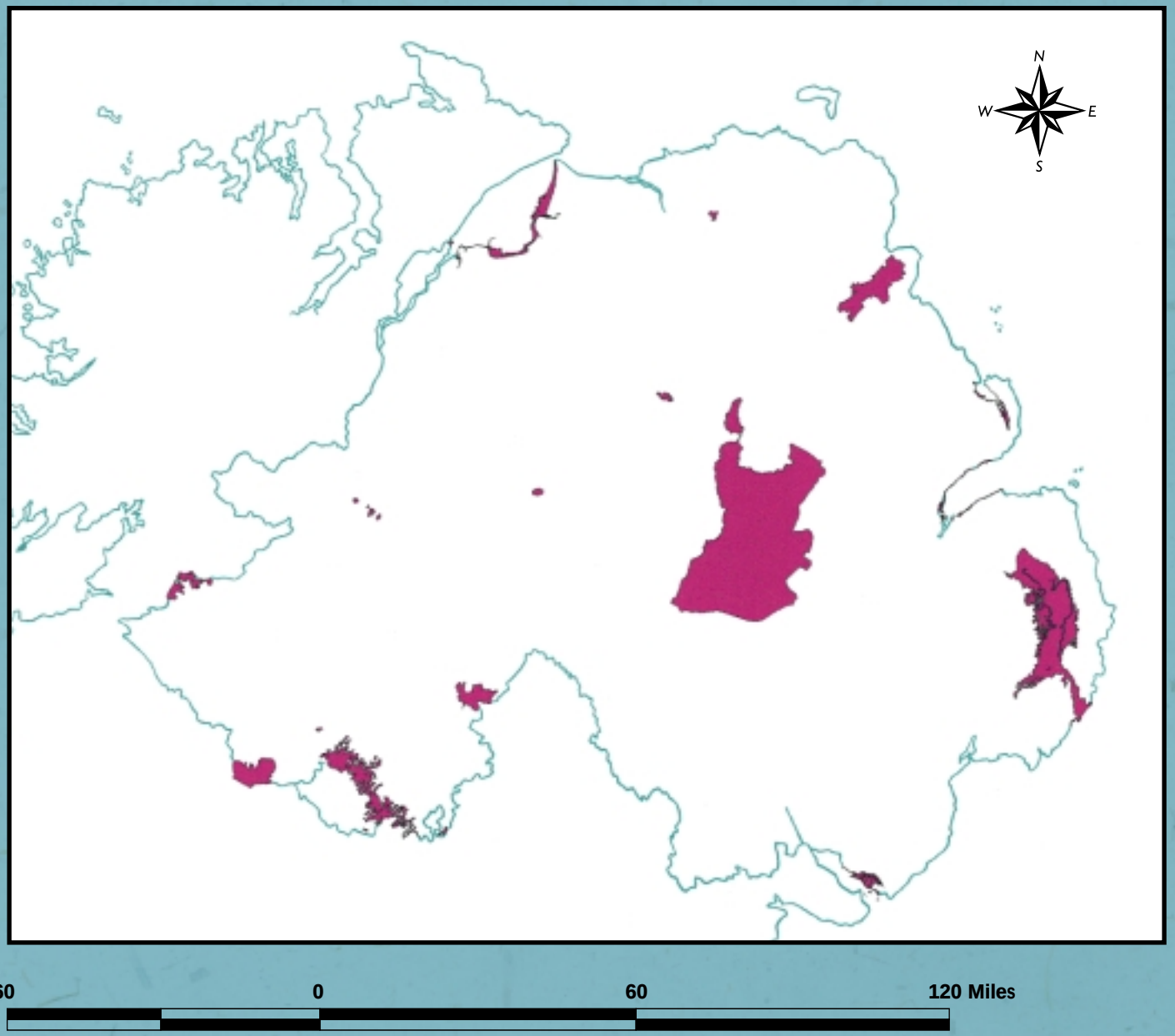


Figure 2.2
Map showing RAMSAR sites around the Northern Ireland coastline (courtesy of EHS).

Figure 2.3
Map showing proposed Special Protection Areas (SPA's) in Northern Ireland (courtesy of EHS).

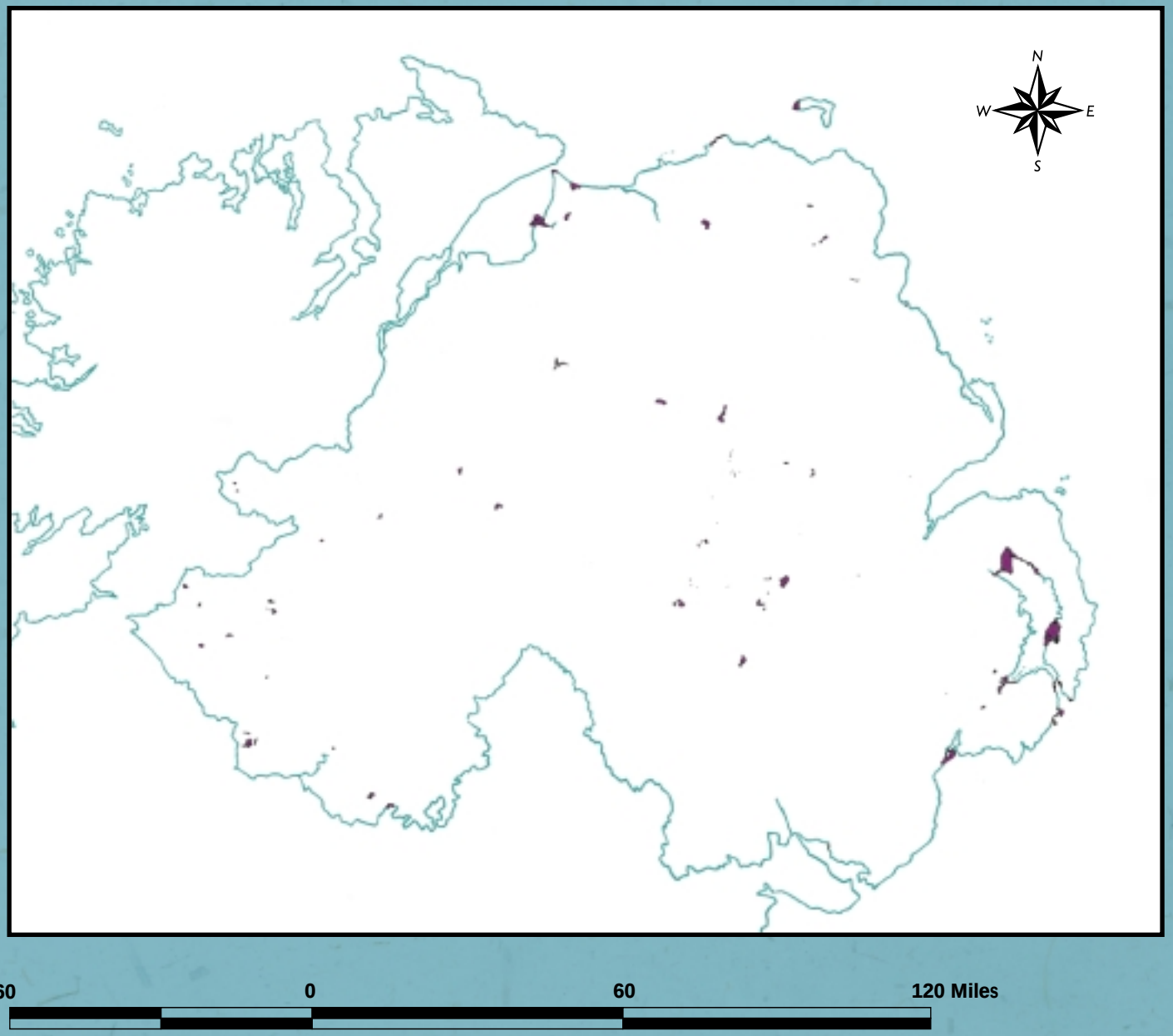


Figure 2.4
Map showing the National Nature Reserves around Northern Ireland (courtesy of EHS).

Figure 2.5
Map showing candidate Special Areas of Conservation (cSAC) (courtesy of EHS)

Chapter Three

Shellfish aquaculture species in Northern Ireland

Introduction

The rapid expansion of aquaculture world-wide has placed increasing importance upon consideration of habitat requirements of aquaculture in coastal management policies. Long-term viability of bivalve culture is particularly dependent upon selection and environmental protection of sites which have biological and physical conditions necessary to promote rapid growth and high survival of cultured species (Brown and Hartwick, 1988). Site-related variations in growth and survival have been demonstrated for mussels, *Mytilus edulis* L. (Incze *et al.*, 1980), soft shelled clams, *Mya arenaria* L. (Appeldoorn, 1983) cited in Brown and Hartwick, 1988), American oysters, *Crassostrea virginica* Gmelin (Mallet and Haley, 1983) and Pacific oysters. *C. gigas* Thunberg (Quayle 1969, 1971 cited in Brown and Hartwick, 1988).

Figure 3.1
The common mussel, *Mytilus edulis*.
(Photo DARD Fisheries).

Target Species

The species discussed in this report were limited to those already being commercially grown in Northern Ireland. A brief description of the biology of these organisms provides the background knowledge required for successful site selection. Potential species for cultivation are discussed in Chapter 6.

1. Mussels

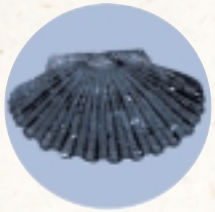
Mussels are one of the commonest shellfish, occurring throughout the world's coastal waters. Mussels are bivalve (two-shelled) molluscs in the family Mytilidae, there are hundreds of marine and freshwater species (few of the latter are of interest commercially). Almost all those of actual or potential commercial interest are in the genus *Mytilus*. There is some occassional interest in horse mussels of the genus *Modiolus*. The most important species is the blue mussel, *Mytilus edulis* (Figure 3.1), which is found in Europe and on both coasts of the United states. The Mediterranean mussel, *Mytilus galloprovincialis*, is another important commercial species and there is considerable doubt whether it is a separate species or simply a geomorph of the blue mussel (Dore, 1991).

1.1 Ecology and life-cycle of the mussel, *Mytilus edulis*.

The present review of mussel ecology concentrates on those aspects of greatest importance to the fishery, for a more comprehensive review of the biology of mussels see Bayne (1976).

1.2 Geographic range

The blue or edible mussel, *Mytilus edulis* (L.), is widely distributed in the northern hemisphere, extending from as far north as the Barents Sea (north of Scandinavia), and south along the west coast of Africa to Senegal (Tebble, 1966). Within the UK, *Mytilus edulis* is frequently found on rocky shores but these individuals are usually small. Their distribution on these rocky shores is usually governed by physical stress and the time available for filter feeding, while their lower limit is usually governed by predators e.g. crabs and starfish, which migrate with the tide. Larger mussels are found in more sheltered areas and under these conditions, may form dense beds in the lower littoral and shallow sublittoral regions but are generally more abundant at or below the mean tide level (McKay and Fowler, 1997). Although the



distribution in estuaries and soft-sediment beaches is also influenced directly or indirectly by the tide, the limits are not as well defined as those on rocky shores.

1.3 Breeding and Growth

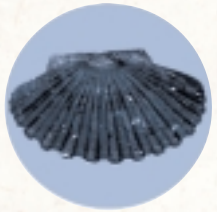
In the common mussel the sexes are separate and fertilisation takes place following the release of gametes into the water column. Although there is spawning activity between early spring until autumn (Seed and Brown, 1977), the main spawning season is in late spring to early summer. Following a planktonic phase of four to six weeks, the spat settle on filamentous algae and hydroids attached to rough substrates (Bannister, 1998). There are actually three distinct stages of spat development in the early life history of the species. Planktonic spat (< 1.5mm) can be subdivided into primary and secondary settlement stage plantigrades. Primary spat (0.25 – 0.4mm) have a brief attachment stage on filamentous materials, mainly in the subtidal. They then develop into secondary spat (0.5 – 1.5mm), which detach and become planktonic again before resettling in the recruitment stage onto hard or creviced surfaces. This stage is collected on ropes for cultivation. Ground spat are secondary spat which have settled (frequently going through a mobile crawling stage at 2 – 5mm in size) and have reached about 15mm in length. A significant gap in knowledge exists in relation to recruitment which is highly variable from place to place and year to year. Spat are often more numerous following 'colder' winters and scarce after 'warmer' winters. It is believed that this may be correlated with the survival of predators e.g. crabs, during the wintering period, however other factors such as, weather, tidal conditions, lack of suitable settlement sites and water quality also interact to affect recruitment (Bannister, 1998).

Growth is season-dependant and is fastest during spring and summer, declining in autumn and almost stopping in winter. Sexual maturity may be achieved during the first year, often at a very small size (Seed and Brown, 1977). A marketable size of 55 mm may be achieved within 2 years but may take considerably longer in the wild (Kelso and Service, 2000).

1.4 Feeding

Mussels are filter feeders which largely eat phytoplankton (zooplankton, if filtered out, are voided as pseudofaeces). A continuous flow of water is drawn into the body cavity through the inhalent siphon and passes across the gill which acts as a filter. As much as 60 litres of water may be filtered per day by a single mussel (Dore, 1991). Diatoms, dinoflagellates and bacteria are extracted within the gill and extraneous matter, together with waste material excreted from the digestive tract, leaves the body in the filtrate which passes out via the exhalent siphon. This material excreted from the mussel often accumulates below the mussels as mud or 'pseudofaeces', particularly in areas where the tidal flow is slow.

As filter feeders, mussels accumulate coleoenteric bacteria and viruses where they are exposed to polluted waters. They also accumulate naturally occurring toxins that are present in plankton blooms and like other bivalves, heavy metals. Because mussels accumulate pollutants, their harvesting and marketing is covered by public health and hygiene legislation (Chapter 2).



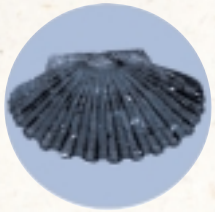
1.5 Predators

Throughout their entire lifecycle, mussels are susceptible to predatory pressure from starfish (Figure 3.2), crabs and birds (Dore, 1991). In sheltered estuaries, the risk of predation is greatest at an early stage in the mussel's life history where the main predator responsible is the shore crab (Snodden, 1994). In other less sheltered areas, the predatory risk is greater for larger mussels because they are more profitable to oystercatchers, herring gulls, crows and eiders (Hilgerloh, 1997). Hooded crows feed on mussels larger than 45 mm, which are individually plucked from the bed and opened by dropping on a hard surface. Oystercatchers usually exploit mussels of 30 – 45 mm shell length (Meire and Ervynck, 1986) and a study carried out in Dundrum Bay estimated that between October and March oyster catchers may consume an average of 165 mussels per day (Snodden, 1994). In many areas including Strangford Lough, the risk of predation from birds, crabs and starfish is so severe that the mussel is threatened with exclusion from the sublittoral and often suffers immense pressure even in the intertidal region (Seed and Brown, 1977).

Figure 3.2
Starfish (mainly the common starfish, *Asterias rubens*) predating bottom cultivated mussels (Photo DARD Fisheries).

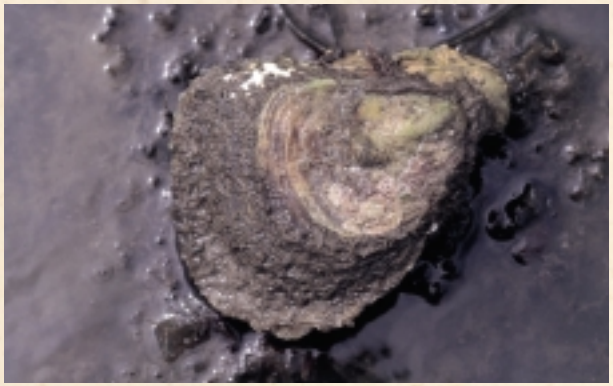
Diving ducks are a major problem for mussel producers worldwide. Ducks consume vast quantities of mussels, recent studies have shown that eider ducks have adapted their feeding strategies to target suspended mussels. Not only do they eat large numbers but they dislodge many more which are then lost to the farmer.

Due to the increasing number of Eider ducks in most of Scotland and the growing problem as the ducks learn to consume mussels from cultivation lines, there has been an increased effort in studying the behaviour and developing new methods to discourage these ducks. Eiders are long-lived birds, capable of learning the best places to feed, and capable of distinguishing between real hazards and ineffective "deterrents". They are also social and can pass on such behaviour to inexperienced birds. Many deterrents have been tried against eider damage. None of these entirely effective, and in most cases a combination of deterrents can be used to minimize the habituation of ducks to harmless threats. Deterrents include anti-predator netting, human activity, boat chasing, laser light, and shooting (blanks or under licence) (Ross and Furness, 2000). Eider ducks are protected by law, and licences to shoot eiders are only issued where it can be demonstrated that reasonable efforts to prevent losses have failed. Chasing ducks by boat is the most commonly practiced method of reducing impact, but it is expensive in time and fuel. Eiders will learn the sound of the chase boat engine and often begin to leave the farm as soon as the engine is started up. In most cases the ducks return quickly and resume feeding. Underwater playback of recorded chase boat noises reduces numbers of eiders feeding on a farm even when no human activity is present. Ross and Furness (2000) suggest that underwater playback is a useful way of protecting the farm during the hours between dawn and the arrival of workers on site. Playback systems are moderately inexpensive but to remain effective, the birds must be chased by the same boat moderately regularly (Ross and Furness, 2000). Although Eiders are currently not perceived as a problem in Northern Ireland, there is evidence to suggest that there has been an extension of their southern limits and an increase in the number found in Northern Ireland (Thompson, D. *pers.comm.*). Therefore it would be important to record the numbers of Eiders and other sea ducks at the mussel



farm sites. The ducks should be counted regularly, to determine whether they show an increasing trend over years, and at which time of the year numbers are high. Counts should be made at a consistent time of the day, preferably early in the morning when human activity on the farm has not yet started in order to obtain counts that reflect eider numbers before disturbance. Steps should be taken to discourage eiders from feeding on the farm before numbers of eiders have increased to "problem" proportions, as it is easier to deter small numbers than to change the established habits of a large flock (Ross and Furness, 2000).

Figure 3.3
The native oyster, *Ostrea edulis* (Photo Graham Day).



2. Oysters

Oysters are bivalve (two-shelled) molluscs in the family *Ostreidae*. There are some 200 species world-wide, but fewer than a dozen are used commercially. Commercial oysters are all from two genera, *Ostrea*, which are the flat oysters and *Crassostrea*, which are the cupped oysters.

The ecology and life-cycle of the flat oyster, *Ostrea edulis*

The present review concentrates on those aspects most relevant to the aquaculture industry, for more detail of the biology of oysters refer to (Heral and Deslous-Paoli, 1991) and (Dore, 1991).

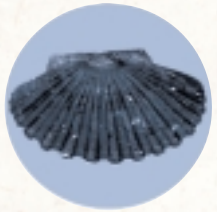
2.2 Geographic range

The European flat oyster is the only indigenous species of true oyster found around the British Isles (Yonge, 1966). *Ostrea edulis* (Figure 3.3) exhibits a wide geographical distribution, ranging along the north-east Atlantic shoreline from Scandinavia to the northeast coast of Africa and through-out the Mediterranean as far as the Black Sea (Alvarez and Zapata, 1989) cited in (Kennedy, 1999). Flat oysters have also been introduced to several areas on the Atlantic coast of north America where they have established natural beds (Hidu and Lavoie, 1991).

Ostrea edulis is a potentially long-lived member of the sessile epibenthic macrofauna, often forming extensive beds in lower intertidal and sublittoral areas down to 30m in depth (Hayward and Ryland, 1995). Sheltered locations such as loughs or estuaries which exhibit a bottom of either stiff mud, sandy mud, fine gravel or shells with a mixture of mud, sand or gravel represent the optimal grounds for flat oyster survival (Cole, 1956 cited in Kennedy, 1999).

2.3 Breeding and growth

Ostrea edulis is dioecious and has been defined as an alternate, continuous hermaphrodite (Korringa, 1952 cited in Kennedy, 1999). On reproductive maturity oysters tend to function as males (Rothschild *et al.*, 1994) before entering a cycle of alternation between sexes which continues throughout life (Kennedy, 1999). The number of sex changes expressed during the breeding season depends on the length of the breeding season, which is itself determined by the ambient temperature regime (Loosanoff, 1962). Consequently flat oysters tend to exhibit a greater number of sexual episodes in any one year in the warmer southern regions of their range (Yonge, 1966).

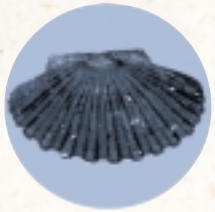


Functional female flat oysters are larviparous and retain up to 1 million eggs within the mantle cavity (Utting *et al.*, 1991). During the spawning period the functional male oysters liberate sperm into the water column; this sperm is then taken up by the female to effect fertilisation of the eggs inside the pallial cavity (Cole 1941 cited in Kennedy, 1999). Developing larvae are retained inside the pallial cavity for a period of 8 - 10 days, before being released as shelled veligers into the water column to undergo a short planktotrophic stage which lasts for around 10 – 14 days depending on ambient conditions (Knight-Jones 1952, Walne 1974 cited in Kennedy, 1999). The planktonic veliger develops into a pediveliger which is capable of attaching to suitable substrata before undergoing metamorphoses into the final benthic stage of the lifecycle (Carriker 1961 cited in Kennedy, 1999). Oysters put considerable physical effort into spawning and a large proportion of the body material turns into either eggs or spawn. While the animals are developing and containing their reproductive material (gametes), the meat loses firmness and flavour, most European and American consumers prefer not to eat oysters in this condition. After they have spawned, oysters are thin and tasteless. As oysters develop and spawn in the summer months, this is one explanation for the old saying "to avoid eating oysters when there is no "R" in the month (Kennedy, 1999).

Kennedy, (1983) noted that overfishing could generate potential problems for protandrous hermaphroditic species like *Ostrea edulis.* In such species, larger individuals exhibit a greater capacity to function as females; the larger size categories of the stock therefore contribute most significantly to egg production. As fishing effort increases, the mean size and age of the population decreases as larger individuals are preferentially removed. This leaves an oyster bed with a lower proportion of productive females and thus the production of eggs per unit biomass of the stock may plummet as the sex ratio changes. In effect, the population suffers recruitment overfishing, in which the spawning stock biomass produces less than the average potential recruitment (Rothschild *et al.*, 1994).

To achieve best fertilisation rates the distance between male and female oysters must be kept to a minimum to effect good transfer of sperm. As the population density falls, due to increased fishing effort, the fertilisation rate declines as the mean distance between compatible individuals increases. Consequent dilution factors rise for transferring sperm resulting in incomplete fertilisation of females and wastage of reproductive effort (Galtsoff *et al.* 1930 cited in Kennedy, 1999).

When the larvae are fully developed they settle on to the surface of suitable material (cultch). Which is often another oyster shell but may be many other substances. They extrude a minute amount of cement, gluing themselves to that one surface for life. The larvae then immediately begin a rapid metamorphosis from larval form into minute oysters. These tiny oysters are called spat, or seed. They grow rapidly, many larvae fail to settle properly, and the spat are easy targets for many predators. Flat oysters are reported to exceed 12 years of age and to reach sizes of 15 - 15.4 cm^2. Flat oysters exhibit slower growth rates than other species (i.e. *Crassostrea*) and reach market size within 5 – 6 years.



The decline of natural oyster beds, together with a failure of natural spatfalls to replenish stock, stimulated the search for hatchery techniques for the production of oyster seed under a fully controlled environment at the Fisheries Laboratory, Conwy. With the appearance of the flat oyster disease (Bonamiasis) caused by infection with the protozoan parasite *Bonamia ostreae* (Pichot *et al*. 1979, cited in Spencer, 1990), in some parts of the country there has been reduced demand for hatchery seed for this species. Bonamiasis has progressively destroyed the flat oyster fisheries of mainland Europe and has had a serious impact on fisheries in Britain and Ireland (Hawkins *et al.*, 1993). Recent trials for the reintroduction of the native oyster in many bays in Ireland has been successful and good husbandry and bay management have proved integral to their reintroduction (Moville, 2000 *pers.comm.*).

Figure 3.4
Harold Henning holding a handful of juvenile Pacific oysters, *Crassostrea gigas* (Photo, DARD Fisheries).

2.4 Feeding

The gills are four crescent-shaped plates which stretch from the mouth for about two-thirds of the distance round the body to the point where the opposite margins of the mantle fuse. This fusion divides the mantle cavity into a large inhalent chamber, containing the gills, and a much smaller exhalent chamber. The gill is made up of many minute filaments which are interconnected at intervals and arranged in groups or plica. Although each plate is basically composed of many individual "V"-shaped filaments, there are so many cross-connections that the whole structure forms a firm lattice work. Water is moved from the inhalent chamber of the mantle cavity into the water tubes by the activity of numerous rows of whip-like cilia located on the filaments. These not only move the water, but also filter from it the small particles which constitute the animals food (Walne, 1974).

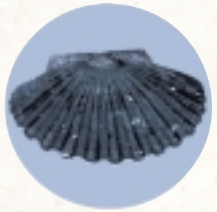
2.5 Predators

Using separated oysters, whether from the wild or from hatchery seed, allows the shellfish grower to use a wider variety of growing techniques, some of which have important advantages. In particular, growing oysters off the bottom protects them from starfish and crab predators. Native oysters are traditionally grown on the bottom, however some are cultivated in bags on trestles.

3. The Pacific Oyster, *Crassostrea gigas*

Crassostrea gigas or the Pacific oyster (Figure 3.4) is both faster growing and more tolerant of a wider range of conditions than the native or flat oyster (*Ostrea edulis*). It is a large cupped oyster with a deep, elongated shell, which is often very irregular. It can grow to approximately 30cm but is normally harvested at less than 15cm.

It is perhaps the hardiest of all commercial oyster species, it has adapted to waters in many parts of the world and seems to suffer much less than other species from predation and disease.



3.1 Ecology and life-cycle of the Pacific oyster, *Crassostrea gigas*

The present review of *Crassostrea gigas* ecology and life-cycles concentrates on those aspects of greatest importance to the fishery, for more information see Dore (1991).

3.2 Geographic range

Pacific oysters originated in Japan. Their natural range also includes parts of China and the Korean Peninsula. In the United States and Canada they were deliberately introduced in the early years of the century. They were introduced to Europe in the 1960s and have thrived in France, Spain and several other European countries. They are now being grown in New Zealand with some success.

C. gigas was brought to Britain by MAFF in 1965. The species was trialled in Strangford Lough by DANI in 1970 and in various sites in the Republic by BIM in 1973. Since then production has expanded steadily (Spencer, 1990). This species has a high growth rate (reach market size in 3 – 4 years), it is produced in a hatchery and responds well to basic husbandry. The industry depends on external sources of seed for survival, this requirement lead to the development of advanced, efficient hatcheries.

3.3 Breeding and growth

In the Pacific oyster the sexes are separate, but as the oyster ages it may change sex with females being more numerous when conditions are favourable. Females discharge millions of eggs into the water column, where fertilisation occurs. The larvae develop within a few hours, swim actively for about two or three weeks, and then settle on material on the bottom, where they mature at the end of the first year.

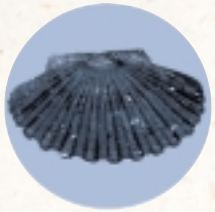
C. gigas does not spawn at temperatures below 20˚C. It is very unusual for Pacific oysters to spawn in Ireland. However they will ripen even in an average summer, and the gonads will become "milky" with eggs or sperm. All Pacific oysters grown in Ireland come from hatchery produced seed (Heath, *pers.com).* Artificial production of seed has lead to attempts to alter the genetic composition of the seed. One common method is the alteration of the chromosome number to produce polyploid oysters. In polyploidy the normally paired or diploid number of chromosomes is increased to sets of three or higher. Oyster triploids are of interest and importance commercially because of their lesser expenditure of energy on reproduction, which tends to lead to better meat condition and growth during the reproductive phase. The treatment to produce triploidy is carried out on eggs in the hatchery. It is not 100% effective and a small percentage of normal oysters are produced as well as triploids.

Differential growth can occur within oysters. One set of environmental conditions can stimulate growth of shell, while another can stimulate meat growth. Warm, shallow bays tend to encourage shell growth, while cooler deeper bays encourage meat growth.

3.4 Feeding

Oysters are filter-feeders, which remove particulate matter from the water around them. Water is pumped in over the gills which collect small particles such as, microalgae and detritus, with the assistance of the palps around the mouth these particles are sorted and ingested. Once the particles have passed into the mouth, they enter a complicated digestive system (Walne, 1974).

Oysters of the genus *Crassostrea* have an additional passage for the exhalent current in the promyal chamber. This is an irregularly shaped pocket between the mantle and the right side of the body into which some of the water tubes open. It has been suggested that the presence of a promyal chamber assists *Crassostrea* to, live in particularly muddy areas.



3.5 Predators

Oysters are commonly grown in bags attached to trestles on the low intertidal zone. The main problem with trestle culture is if mussels settle onto the oysters they can cause clumping with the byssal threads which may smother the oysters. The advantage to trestle culture is protection from predators, particularly crabs and starfish.

Figure 3.5
The King Scallop, *Pecten maximus.*

4. Scallops

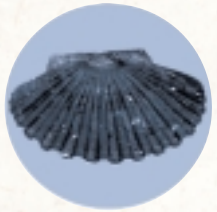
Scallops are bivalve molluscs. The two shells are flat and more or less circular, with a straight edge at the hinge, where they join. The shells are ribbed in a fan-like pattern radiating outward from the hinge (Dore, 1991). There are some 360 known species of scallop (Family Pectinidae) widely distributed throughout the world (Mason, 1983). Due to their rapid growth, early maturity and high market value, scallops are of world-wide economic importance and support both commercial fisheries and mariculture. Various scallop species are already cultivated successfully in a number of geographic locations and mariculture effort is increasing globally (Shumway, 1991). Twenty eight species of scallop inhabit European waters, five of which are exploited commercially. These are King scallop (*Pecten maximus*) (Figure 3.5), the St. James's scallop (*Pecten jacobeus*), the Queen scallop (*Aequipecten opercularis*), the black scallop (*Clamys varia*) and the Iceland scallop (*Clamys islandica*) (Ansell *et al.*, 1991). *P. maximus* and *A. opercularis* together with *C. islandica* account for most of the catches of scallops in Europe (small fisheries exist for *C. varia* in NW France and for *P. jacobaeus* in the Mediterranean). Although both *P. maximus* and *A. opercularis* have been exploited since the 17th century, the fisheries were not of commercial importance until the late 1940s (Mason, 1983).

4.1 Ecology and life-cycle of king and Queen scallops

The present review concentrates on those aspects of scallop biology most relevant to aquaculture. For more detailed accounts refer to (Mason, 1983), (Shumway, 1991), (Shumway and Sandifer, 1991), (Dore, 1991) and (McDonough, 1998).

4.2 Geographic range

The King scallop (*Pecten maximus*) is a large scallop which in most areas will grow to a shell height of 150mm or more (Ansell *et al.*, 1991). Individuals can live for up to 20 years, but the average life-span is much lower than this, even in unexploited populations. The shell is inequivalve, the lower (right) valve being deeply convex and the upper valve being flat, and both valves commonly have 15 to 17 broad radiating ribs. The geographical range of the King scallop stretches on the Euro-Atlantic coast from Northern Norway to the Iberian peninsula and it can occur from just below MLWM to depths of 180m, but is commonest



between 18 and 46m (Mason, 1983). Adult *Pecten maximus* prefer substrata of clean firm sand, fine gravel or sandy gravel and generally recess into the sediment so that the upper, flat valve is level with the seabed and often has a slight covering of sediment. If disturbed, these scallops can attempt to protect themselves by swimming, jumping or simply closing their valves.

The Queen scallop (*Aequipecten opercularis*) is distributed from northern Norway and the Faroes south to the Iberian peninsula, the Azores and the Canary Islands, extending into the Mediterranean and Adriatic. It occurs in depths down to 183m, but is again commonest in depths less than 46m. It is found in the same areas of seabed as the scallop, though it can also live on harder gravel and shelly bottoms because, unlike the scallop, it does not recess into the seabed (McDonough, 1998).

Owing to the availability of suitable substrate both species are essentially coastal, being most abundant just inside or away from strong tidal streams. The distribution of both species is patchy with beds often consisting of a single age group, suggesting that the larvae may be gregarious.

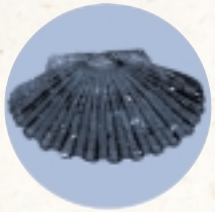
4.3 Breeding and Growth

The family Pectinidae is interesting in that it contains both unisexual and hermaphrodite species. Both the Scallop and the Queen are hermaphrodites, the male portion of the gonad being proximal (testis, creamy-white) and the female part distal (ovary, pink-orange-red). Pectinid reproduction was reviewed in detail by (Barber and Blake, 1991) and (Mason, 1983). Scallops like other marine bivalves, undergo cycles of reproductive activity in which gametes are produced and spawned, fertilisation occurs, and larvae develop. While the process of breeding is basically similar in *Pecten maximus* and *Aequipecten opercularis*, differences do occur which are described in Mason (1983). In general, scallops have a life-cycle very similar to other filter-feeding molluscs. Eggs and sperm mix in the water, and the hatched larvae metamorphose into scallops within a few weeks. Unlike oysters, most scallops do not cement themselves to a single point for life. They attach themselves when they first metamorphose, using byssal threads in a similar manner to mussels. However, after they have fully developed into scallops, they abandon their attachment and thereafter remain as free swimming creatures. Although they are capable of moving reasonable distances by pumping water through their siphons, scallops only seem to move when disturbed or to escape predators. Wild scallop stocks show two peaks of spawning in UK waters. There is a partial spawning in Spring (April / May) and a more complete summer spawning in July / August.

Pecten maximus and *Aequipecten opercularis* are functional hermaphrodites, in which reproductive cells of both sexes are produced at the same time but are not usually discharged together. In *P. maximus*, the products of either sex may be discharged first, but they are discharged within a short period of each other. The same may be true of *Aequipecten opercularis*, however some controversy exists (Mason, 1983).

4.4 Feeding

Scallops are filter-feeders, extracting the plankton and bacteria they need from the water which they pump through their digestive systems. Like other filter-feeding mollusca, they are likely to concentrate biotoxins and other contaminants in their viscera.



4.5 Predators

Starfish and crabs are the main predators of bottom grown scallops. Use of suspended culture techniques (Chapter 4, Section 4) will alleviate this problem.

5. Clams

Clams are bivalve filter feeding molluscs. While oysters attach themselves to a hard surface for life and scallops can move to better locations, clams do not attach to anything, but generally burrow into the seabed (Dore, 1991). Clams are found and eaten in many countries, there are many thousand species, only a few of which are exploited commercially. Almost all clams can dig themselves into the substrate remarkably fast to escape predators. At present the only clam commercially cultured in Northern Ireland waters is the Manila clam (*Tapes philippinarum*) (Figure 3.6). *Tapes philippinarum* is the preferred scientific name, however some confusion exists as it is also referred to as *Tapes semidecussatus, Tapes japonicus, Venerupis semidecussata, Ruditapes philippinarium* or combinations of these. The Manila clam is superficially similar in shape and size to our native clam (Palourde, *Tapes decussata*), but has distinctive black and white shell markings. There are other noticeable differences between the two species. The orange colour of the flesh, especially the foot, of the Manila clam contrasts with the off-white colour of the flesh of the native clam. Also the siphons, seen when the clams are immersed in water and pumping actively, are joined in the Manila clam but are separate in the native clam (Spencer *et al.*, 1991).

Figure 3.6
Manila clam plots on the low intertidal area in Carlingford Lough (Photo, DARD Fisheries).

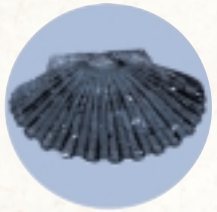
5.1 Ecology and life-cycle of clams

The information in this report is only a brief overview of those aspects most relevant to fisheries, for more detailed reviews see (Dore, 1991) and (Menzel, 1991).

5.2 Geographic range

The Manila clam is native to the waters of Japan, Korea, the Philippines and other far eastern countries. It is now widespread throughout the western world with introductions made accidentally with oysters into North America, and deliberately as hatchery broodstock into Europe (Spencer *et al.*, 1991). It is now found from the southern tip of Southeast Alaska as far south as northern California (Dore, 1991).

The scientific name for the native clam is *Tapes decussatus* or *Venerupis decussata* and it is also commonly known as the carpet shell, butterfish or Atlantic palourde. The palourde is found in sand, mud or gravel, below mid-tide level, and is distributed mainly around the south and west coast of the British Isles. It occurs south along the Atlantic coasts of France, Portugal and Spain to Morocco and Senegal and into the Mediterranean (Tebble, 1966).



5.3 Breeding and Growth

Manila clams do not breed successfully in British waters, therefore the on-grower is dependent on a commercial hatchery for his supply of seed. The seed is available at various sizes, ranging from 4mm to 30mm shell length.

Clams are similar to oysters, mussels and scallops, in that they release spawning material into the water. Clams are usually of separate sexes. The hatched larvae are free swimming for a couple of weeks until they metamorphose into tiny clams. At this point they grow byssal threads and attach themselves to particles of sediment. They soon abandon this, burrowing into the substrate.

MAFF trials with Manila clams in England and Wales show that they grow quickly, reaching a minimum market size of 20g in 2 – 3 years, which is about 1 year less than for the palourde. Their high demand and market value in Europe (mainly France, Spain and Italy), make them a promising economic prospect for cultivation in Northern Ireland.

5.4 Feeding

Clams feed by extending their siphons through the substrate to pump water through their digestive systems. The siphon is the long tube through which the clam sucks and expels water (siphons contain two tubes, an inhalent and an exhalent).

5.5 Predators

Clams have to be well protected from predators, such as starfish, crabs and ducks and this is reflected in the aquaculture methods chosen (Chapter 4, Section 5).

Chapter
Four

Methods used in aquaculture

Introduction

A variety of methods have been developed for use in shellfish aquaculture, techniques that work in one area may not work well in another area. The shellfish farmer must use methods that suit his particular environment. In this section there is an overview of the main methods used and some discussion as to the potential for development.

Figure 4.1
Suspended mussel culture, supported by rafts, in a Scottish sea loch (Loch Etive, Argyll).

Methods

1. Commercial Exploitation of Mussels

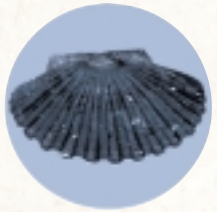
1.1 Intertidal Hand Gathering

Historically, large quantities of mussels were gathered by hand at low tide. It is usually only viable to exploit large individuals although spat may be scraped from the surface of rocks on intertidal rocky shores, to be used as mussel seed (Kelso and Service, 2000). Kelso and Service (2000) discuss the impact of gathering in more detail, briefly there are advantages to harvesting such as, reduction of intraspecific competition for food and space, as well as allowing the young mussels to grow more quickly. Disadvantages include the reduction in number of the large highly reproductive individuals, also reduction in refuge space for spat settlement.

1.2 Suspended mussel culture

Suspended mussel culture systems involve the collection and wrapping of seed mussels on ropes or similar material, which are hung from rafts or floats (Figure 4.1). The mussels are generally collected in situ by settlement from the plankton and grown on the collecting ropes (droppers). As the mussels develop, they are stripped from the ropes, graded for size, tubed (mesh) and resuspended in the water column. Culture off-bottom has a number of advantages, the original one being to avoid predation.

Mussels grown in suspended culture are usually of superior quality with higher meat yields (between 30 and 35%, compared to 20 - 30% for dredged mussels), better shell quality and no sand or grit in the meat (O'Sullivan, 1997). Harvesting usually takes place 18 – 30 months from settlement. Because the suspended mussel culture utilises more of the water column, production of the area is significantly enhanced (Dore, 1991) however there may be increased competition with other wild filter-feeders for available plankton. Such competition would probably only become a problem in areas of poor water exchange, with a



poor supply of phytoplankton (Kelso and Service, 2000). Sub-surface suspended culture, where the ropes are attached to an anchored system, has the advantage of reduced visual impact (Stephens, *pers.comm.*).

In Japan, the accumulation of organic waste beneath shellfish cultures resulted in a reduced rate of production (Arakewa *et al.* 1971 cited in Rosenthal *et al.*, 1988) and forced farmers to rotate culture sites and to dredge the sediment at fallow sites. A reduction in shellfish production due to the accumulation of pseudofaeces has not been recorded within Europe (Gowen *et al.*, 1990).

1.3 Bottom cultivation

Bottom culture of mussels is the simplest method of cultivation and is still widely used. Subtidal mussel seed, approximately 15 – 30mm in length, are dredged from wild beds, sorted and relaid on licensed beds. Modern mussel dredgers use a circulating pump to flush the seed out of the holds onto the seabed, however some of the older vessels use grabs to reseed their sites (Hunter, *pers.comm.*). The standard reseeding rate is 50-100 tonnes per hectare, however individual operators use different stocking densities with variable results. Grow out times vary between 18 – 36 months depending on environmental conditions and they find meat yield exceeding 30% (Hunter, *pers.comm.*). Mussels are marketable from a shell size of 55mm and are harvested by dredging. Bottom culture produces a mussel with better meat quality and yield than most wild mussel fishing. There is still the disadvantage of grit and pearl formation and these mussels are still vulnerable to bottom dwelling predators. So far, it has not been necessary to use hatchery techniques to produce mussel seed, as there are plenty of natural beds, which produce prolific quantities of spat.

The impact of bottom dredging is dependant on the stability of the bed, dredging of unstable intertidal or sublittoral mussel beds in the Wadden Sea had few environmental repercussions (Kelso and Service, 2000). Whereas, in the Netherlands, long term impacts were observed after dredging mature, stable mussel beds, causing the disappearance of the beds and their associated species (Dankers and Zuidema 1995).

2 Flat Native Oysters, *Ostrea edulis*

Native oysters are grown by various methods. Bottom cultivation involves the laying of part-grown oysters on the seabed. These are allowed to grow naturally and are harvested at a shell size between 65-90mm. Larger oysters are not easily marketable, however can be relaid to provide on-site broodstock. Native oysters have also been grown on trestles and in oyster bags on the seabed, with varying degrees of success. The grow out time of a native oyster is 5 -6 years.

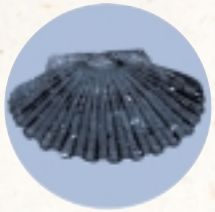


Figure 4.2
Pacific oyster trestle cultivation, on the low intertidal shore in Killough Bay (Photo DARD Fisheries).

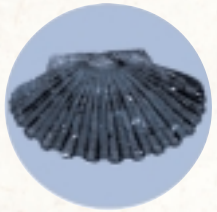
Figure 4.3
Nursery rafts for *Crassostrea gigas* (Larne Lough, Photo DARD Fisheries).

3 Pacific Oysters, *Crassostrea gigas*

Oysters cultured off-bottom are protected from predators. It also tends to produce oysters that are more evenly shaped and less bent and twisted than traditional bottom culture. Another advantage to off-bottom techniques is that they produce faster growing oysters. Oysters which are submerged for their full life-span tend to have softer shells than those which have been "hardened" by exposure to the air at major tides.

Pacific oysters are commonly grown in the intertidal zone in bags, which are set on trestles. The trestles are made of 16mm steel tube and are usually approximately 300mm high and are 2.5 – 3.0 metres long by 1m wide (Figure 4.2). Each trestle will hold 5-6 oyster bags, which are held on by rubber bands and / or hooks. Innovation amongst shellfish producers has lead to modified trestle design facilitating bag attachment and reducing the amount of bag bending (Henning, *pers.comm.*). Oyster seed is bought from commercial hatcheries, normally at a size between 7 and 14mm, although some growers are buying small 2-3mm seed which is usually grown on floating trays or rafts (Figure 4.3) until it reaches at least 7mm (Hunter, *pers.comm.*). Innovation in this field lead Mr R. Graham to inventing a rotor system for growing seed oysters from 2mm to 10mm (Graham, *pers.comm.*). The grow out time to harvest is around three years but this can vary with feeding conditions and husbandry practices. *Gigas* have also been grown on mats (Figure 4.4) in the intertidal area, the oysters would be introduced at a larger size, approximately 40 –50 grammes, as the larger size offers some protection from predators (Parsons, *pers.comm.*).

Figure 4.4
Crassostrea gigas grown on thick rubber mats to prevent sinking into the relatively soft sediment (Strangford Lough, Photo DARD Fisheries).



4 Scallops

Scallops are grown either on the seabed or by suspended cultivation. In bottom cultivation, the scallops are introduced onto the site at 45-55mm and allowed to grow naturally. Scallops grown on the bottom are usually harvested by divers after 2-3 years. Suspended cultivation requires flotation similar to that used in suspended mussel cultivation. Scallops can be ear-tagged, where a hole is drilled through the ear of the scallop and it is attached directly to the line. They can also be kept in lantern nets or stacked trays. The period from spat settlement to harvest will normally be approximately 4-5 years (McDonough, 1998).

5 Manila clams

Manila clams live in the substrate and are grown in plots (Figure 3.6) or parcs. Plots are areas of the intertidal zone protected by netting. The netting reduces predation by green crabs and some wading birds. Parcs differ, as the cultivated area is surrounded by a wall of plastic mesh, approximately 300mm high. This keeps out crabs and bird predation is reduced by cover netting. The plot is more commonly used in Ireland. Clam seed is bought in from commercial hatcheries and is usually placed in floating trays for a time before being introduced to the substrate. Harvesting usually takes place after 3-4 years, using a modified potato harvester towed behind a tractor. Hand picking and suction dredging have also been used as harvesting methods. Some producers have achieved growth rates, which allow them to harvest in two years (Hunter, *pers.comm*.).

Chapter
Five

Existing Shellfisheries

Introduction

There are a variety of environmental factors which will have an effect on bivalve growth and should be considered for successful site selection (Table 5.1), these can be separated into three categories: physical, biological and chemical. Physical factors include: seawater temperature, salinity, exposure to air, wind and currents and substrate type. The biological factors include: primary productivity, seed supply, predators, competitors, fouling organisms, bacteria and viruses and toxic algae. Chemical factors include: dissolved nutrients, oxygen and pollutants.

Existing Shellfisheries

There are a number of areas suitable for shellfish production around the coastline of Northern Ireland. The main areas discussed are the five sea loughs, Killough Bay and the Copelands with a brief mention of the potential of Ards Peninsula and the North Coast.

1 Belfast Lough

Belfast Lough is a shallow, semi-enclosed bay (13,480 ha) and almost 96% of the Lough is subtidal. The total catchment of Belfast Lough is 900 km^2 and encompasses the city of Belfast and also drains some of the most productive agricultural land in Northern Ireland. The sediments within Belfast Lough range from mud or heavily silted gravel to clean sands. Intertidal mud flats are found in the uppermost part of Belfast Lough, while the outer shores of the Lough are more exposed and rocky (Kelso and Service, 2000).

The River Lagan is the principle water course and enters the Lough at Stranmillis (Figure 5.1). The River Lagan drains approximately 609 km^2 of agricultural land and is 70 km in length to the Stranmillis Weir, from this point downstream it is estuarine.

The estuary is stratified, whereby the saline water tends to be trapped as a layer under the freshwater, which causes significant water quality problems (Charlesworth and Service, 1999). The natural tidal fluctuations are restricted for 5 km downstream of the Stranmillis Weir due to the newly constructed Lagan Weir. Belfast Harbour is the site of two large STWs which discharge to the Inner Lough, and major process industries including a fertiliser plant. Belfast also operates as an important port, which is currently dredged approximately every five years. The influence of freshwater on the harbour is slight and only significant in high flow, ebb tide conditions (Charlesworth and Service, 1999).

The Lough bottom slopes gradually from Belfast where there are extensive mud-flats, to a depth of 20 m at the outer limit. Tidal currents are weak and oscillatory in the Inner Lough, whilst a clockwise rotatory current has been found to occur in the outer Lough (Parker *et al.*, 1988). The hydrography of the Lough shows that lower salinity water occurs towards the southern shore due to the tidal currents spreading the freshwater from the River Lagan along the southern shore of the Lough with little lateral mixing; possibly the Coriolis' force could be acting to promote this effect (Parker *et al.*, 1988). The Lough is of importance, recreationally, commercially and environmentally and is protected under EU legislation (Chapter 2). Existing wild fisheries are mainly for lobsters, buckie whelks and crabs with winkle and scallop fisheries in the outer lough. The expansion of aquaculture in the lough concentrates on bottom-cultured mussels (Chapter 6).

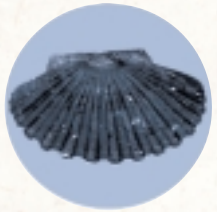
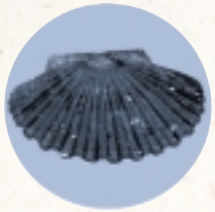


Table 5.1
Summary of site requirements of shellfish species (Heath, *pers.comm.*)

Species	Sea temperature	Salinity	Exposure to air	Exposure to wave action	Bottom type
Mussels	Normal sea temperatures	Wide salinity tolerance	Subtidal and lower shore	Resistant to moderate exposure	Medium to hard bottom
Flat Oysters	Normal sea temperatures	Sensitive to low salinities	Subtidal and very low shore	Low exposure	Limited
Pacific Oysters	Normal sea temperatures	Wide salinity tolerance	Subtidal and lower shore	Resistant to moderate exposure	Medium to hard bottom
Scallops	Sensitive to extreme temperatures	Sensitive to low salinities	Subtidal	Low exposure	Medium to hard bottom
Clams	Normal sea temperatures	Wide salinity tolerance	Very low shore	Low exposure	Medium bottom



2 Strangford Lough

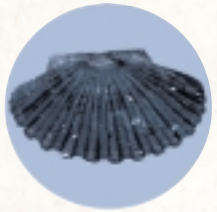
Strangford Lough is a large marine inlet (14,513 ha), situated on the east coast of Northern Ireland (Figure 5.2). Almost land-locked, the lough is connected to the Irish Sea by the Strangford Narrows, an 8 km long channel which in some parts, is less than 1 km wide. Strangford Lough is 30 km from north (head) to south (mouth) and up to 8 km wide, with some 240 km of intricate coastline and a maximum charted depth of ≈60m. The two main freshwater inputs into the lough are the Quoile estuary, which opens into the Lough in the south-western corner and the Comber River at the extreme north-western corner. These appear to have only a localised effect on salinity the Lough is therefore entirely marine in nature with salinities ranging from 32 to 34 psu. Summer temperatures and water turbidity are higher in the upper half of the Lough compared with values found closer to the Lough entrance (Boyd, 1973). Tidal currents can reach 3.5 ms^{-1} in the Narrows and the influence of this tidal regime can be seen throughout the southern and central areas of the Lough. Much of the character and importance of this sea Lough is dependant on its topography. There are a large number of islands, many of these consist of drumlins which are submerged at high tide, and known locally as pladdies. Tidal currents decline in strength with distance from the Narrows as one moves further into the Lough. This results in a complex succession of bottom substrata and associated benthic communities (Erwin *et al.*, 1986, Magorrian, 1995).

Strangford Lough is relatively sheltered from wave action in comparison with the coast. Approximately 5,200 ha of the Lough is intertidal flat, most of which is concentrated at the northern end. The greatest diversity of sheltered sedimentary habitats, including wide mud flats, muddy sand flats and shores of mud, sand, gravel and pebbles found along the Northern Ireland coastline is contained in Strangford Lough (Wilkinson *et al.*, 1988). The complexity of these sediments and habitats is reflected in its biodiversity, where more than 2,000 species of organisms have been recorded. The most abundant foreshore habitat in Strangford Lough is composed of boulders and is commonly covered in extensive beds of knotted wrack. Rich communities of other seaweeds, winkles, worms and sponges are associated with this habitat. The northern mud flats support large areas of eelgrass and saltmarsh which are host to vast numbers of polychaete worms, ragworms, molluscs and crustaceans. Coarser sediments support cockles, razor shells and other burrowing species, providing food for large marine animals and birds.

Wild shellfisheries include; scallops, queenies, lobster and nephrops, with some hand-picked cockles and winkles. There are also significant aquaculture initatives (Chapter 6).

3 Carlingford Lough

Carlingford Lough is the most southern of the five sea loughs around the coastline of Northern Ireland (Figure 5.3). The lough drains an area of 474 km^2, encompassing six small towns and the larger town of Newry. CORINE (Co-ORdination of INformation on the Environment scheme) land cover data indicate that the land in the immediate vicinity of the Lough supports a mixture of forest, rough and improved grazing and small areas of agricultural land (Taylor *et al.*, 1999). It is a 5,315 ha sea lough which straddles the international border between Northern Ireland and the Republic of Ireland. Carlingford Lough extends in a north-west – south-west direction from the Clanrye or Newry River which is the major freshwater source, to the shallow mouth which is



guarded by a chain of limestone islands. The Lough is approximately 15 km in length from the mouth to Warrenpoint and 4 km at its widest point (Wilkinson *et al.*, 1988). The Lough is generally shallow with the average depth between 2-10m, although the narrow channels that run along the centre of the Lough may be as deep as 25m. The Lough is generally well mixed (Ball *et al.*, 1997). At low tide, an extensive area (14.9 km^2) of intertidal area is exposed. The upper reaches of the Lough are extremely narrow due to land claim occurring south of Newry. The greatest tidal movements occur in the narrow channels that run along the centre of the Lough.

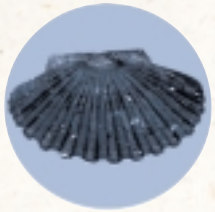
The upper regions of Carlingford Lough are shallow and are dominated by a fine muddy sand bed while the substratum at the entrance of Carlingford Lough is mostly boulder and cobble, mixed with patches of bedrock. The sediments in the central part of the Lough are widely varied. Carlingford Lough is host to aquatic estuarine fauna of considerable interest, including extensive beds of sea-pen (*Virgularia mirabilis*) at the mouth of the Lough, sand and rock reefs in the central section and fast-water communities near the mouth. The Lough supports a number of noteworthy marine species, some of these being warm-water species which in Northern Ireland, are only found at this location (Kelso and Service, 2000).

Carlingford Lough, traditionally supported native oysters, mussels and winkles, for more detail see Chapter 6 and (Kelso and Service, 2000).

4 Lough Foyle

Lough Foyle is a coastal embayment, which lies on the North coast of Ireland. It is the largest of all Northern Irish sea-loughs (20,692 ha) and differs from the others in that freshwater inputs have a considerable effect on the salinity of the main water body (Service *et al.*, 1998). The Lough straddles the international border between the Republic of Ireland and Northern Ireland. The mouth of Lough Foyle is constricted by Magilligan Point, one of the largest depositional shoreline features in the British Isles (Buck and Donaghy, 1996). Although it is relatively sheltered, the sands are almost devoid of mud (Consultants, 1995). Lough Foyle is a wide shallow basin with an average depth of 5m, interspersed with a series of deep narrow channels, the most significant of which runs from Culmore Point along the coast to Magilligan Point at the mouth of Lough Foyle (Bates, 1996, cited in Charlesworth and Service, 1999). Intertidal mudflats predominate on the east and south coast and cover 20% of the 179 km^2 area. With the exception of the mudflats the sediments of the Lough are composed of poorly sorted sand and gravel.

The main freshwater sources to Lough Foyle are from the Rivers Foyle, Faughan and Roe, these rivers are augmented by several small streams that enter along the sides of the Lough. The tidal range of the Lough is small compared to other Northern Irish sea-loughs with a mean spring and neap tidal range of 2 and 1m respectively, which varies slightly with distance from Magilligan Point. During ebb and flood conditions the main flow occurs within the deep channels in the north-west of the Lough (for more information see Charlesworth and Service, 1999). The catchment of Lough Foyle is one of the largest of all Irish sea-loughs covering 3,700 km^2 with 75% of the catchment of Northern Ireland (Foyle Catchment Consultants (F.C.C.) 1995 cited in Charlesworth and Service, 1999). Landuse within the immediate catchment is predominantly agriculture and forestry.



The only commercial fin-fishery in Lough Foyle is the salmonid, with a total contribution to the economy of approximately £4m per annum. The largest natural beds of the common mussel (*Mytilus edulis*) in Ireland occur in Lough Foyle (Briggs, 1982). Large beds of native oysters are also found, other shellfish include cockles, periwinkles, whelks, native and razor clams. There is also a small fishery for lobsters, brown crabs and velvet crabs.

5 Larne Lough

Larne Lough is a sea lough (1,189 ha), enclosed to the east by the peninsula of Islandmagee, situated on the east coast of Northern Ireland (Figure 5.4). Much of the estuary is shallow, having become extensively infilled with sediments of fine muddy sand, and at low tide the largest areas of intertidal flats are exposed in the south of the estuary. The northern parts of the estuary are wider and relatively deep, especially at the mouth where dredging is regularly carried out to maintain the shipping channel to the port of Larne.

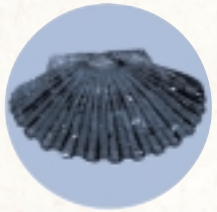
In the upper reaches of the Lough at Ballystrudder there is an area of saltmarsh. As the effects of salinity and differing tidal inundation's are not greatly felt at these upper parts of Larne Lough, the saltmarsh zonation patterns are not distinct and the main vegetational interest lies in the transition to non-saltmarsh plant communities.

6 Dundrum Bay

Dundrum Bay, is located on the south east coast of Northern Ireland, between Strangford and Carlingford Loughs and extends over an area of 1,117 ha (Buck and Donaghy, 1996). Although the eastern part of the bay is dominated by bedrock and boulders, the majority of the bed within Dundrum Bay is dominated by stable sand, graded with depth and changing to fine sands and muddy sand offshore (Erwin *et al.*, 1990). These sandy sediments support a rich fauna, characterised by *Echinocardium cordatum*, the heart urchin, and the brittlestar *Amphiura brachiata* (Erwin *et al.*, 1990).

7 Killough Harbour

Killough Harbour is a small estuary (213 ha) located on the south coast of Co. Down, Northern Ireland. Most of the Harbour dries at low water neap tides except for a fresh water stream which runs from North to South through the Harbour. The estuary is very silted and an extensive area of intertidal mudflat is exposed at low water in the innermost harbour and along the shore of Coney Island Bay. A firm mixture of sand and mud with small stones forms the substrate for most of the harbour. However areas of soft mud occur at the head of the bay and around the piers at the south of the bay. Areas of rocks occur throughout the harbour and an area of clean sand is present on the west shore near the harbour mouth. Macro-invertebrate fauna in the bay are relatively sparse and varies with substrate type. In muddy areas an increase in numbers of worm casts is apparent, where as in the firmer sediments sand mason tubes are common along with occasional cockles. On rock substrates limpets, dogwhelks and winkles can be found amongst the attached brown algae (Clarke, *pers.comm.*).



8 Off-shore areas

The rocky shores of the outer Ards Peninsula are of particular interest for winkle gathering and are amongst the most species rich open coast sites in Northern Ireland. There is a great diversity of intertidal algae associated with the mid and lower shore rock pools, found on the creviced bedrock substrate (Wilkinson *et al.*, 1988).

The north coast of Northern Ireland (between Ballycastle and Portstewart) is exposed to wave action from the Atlantic Ocean. Large areas of mobile sand occur offshore and sand scour dominates the epifauna present on rocky substratum. The sand supports a relatively poor species richness and diversity and is usually dominated by sand eels and hermit crabs. More rocky areas support a diverse fauna including a number of species which are only found in Northern Ireland within this region. Wild fisheries include scallops, lobster, brown crab, salmon, occasional herring, mackeral and whitefish, buckie whelks and some trawling for turbot.

Off-shore from the Copelands there is one suitable site presently utilised for bottom culture of Scallops. Wild fisheries include crabs, lobsters and buckies.

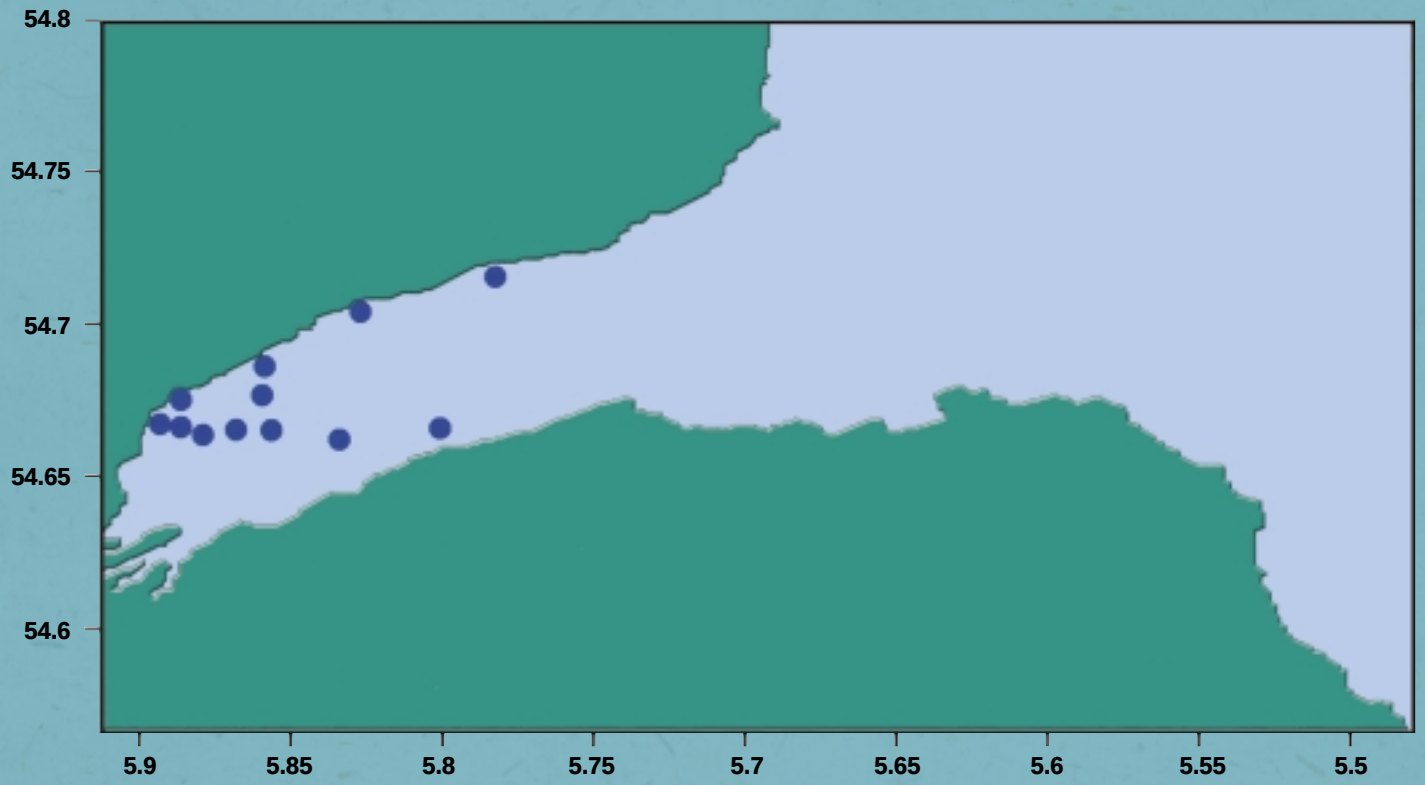


Figure 5.1
Map showing the main aquaculture areas in Belfast Lough.

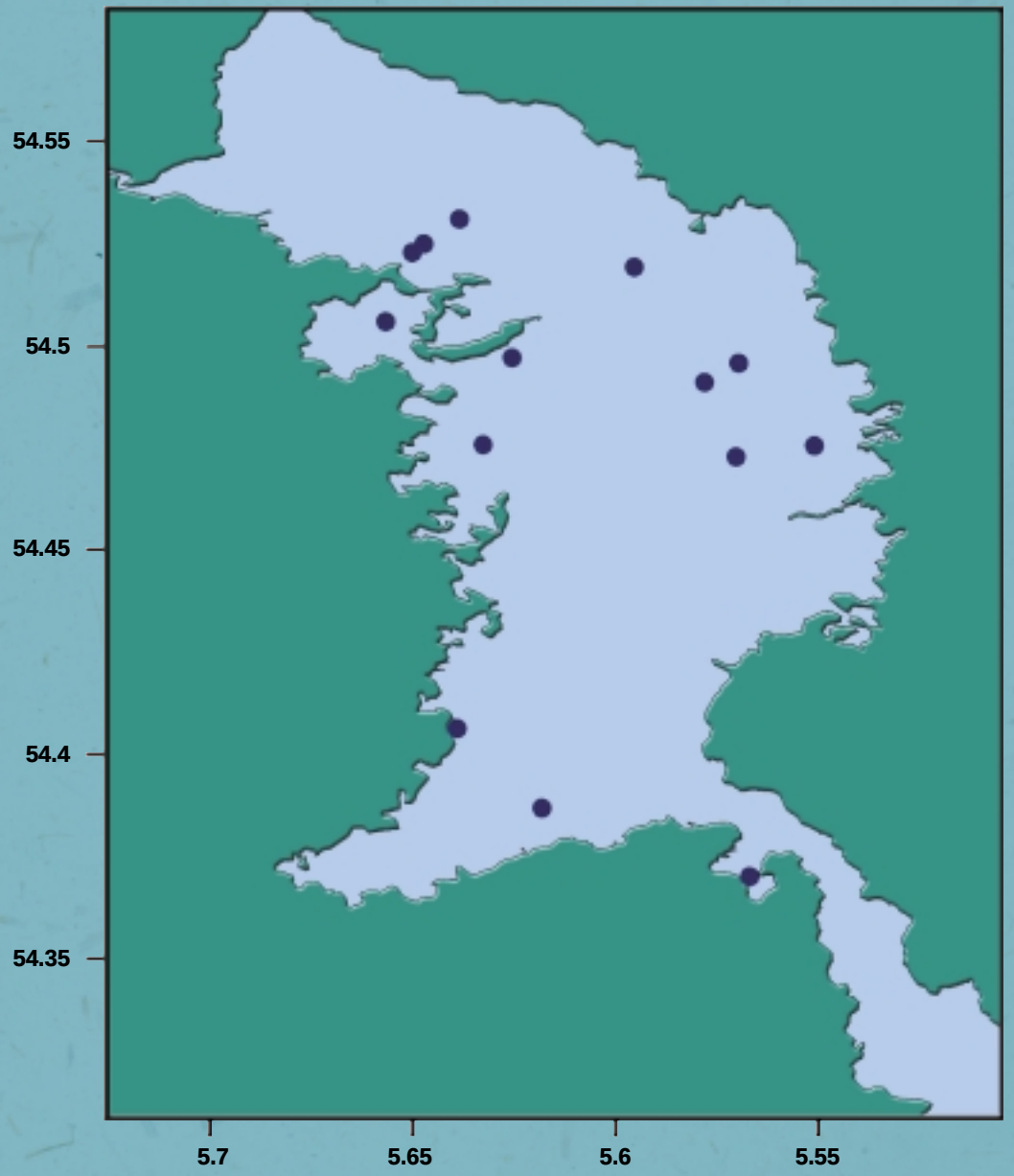


Figure 5.2
Map showing the main aquaculture areas in Strangford Lough.

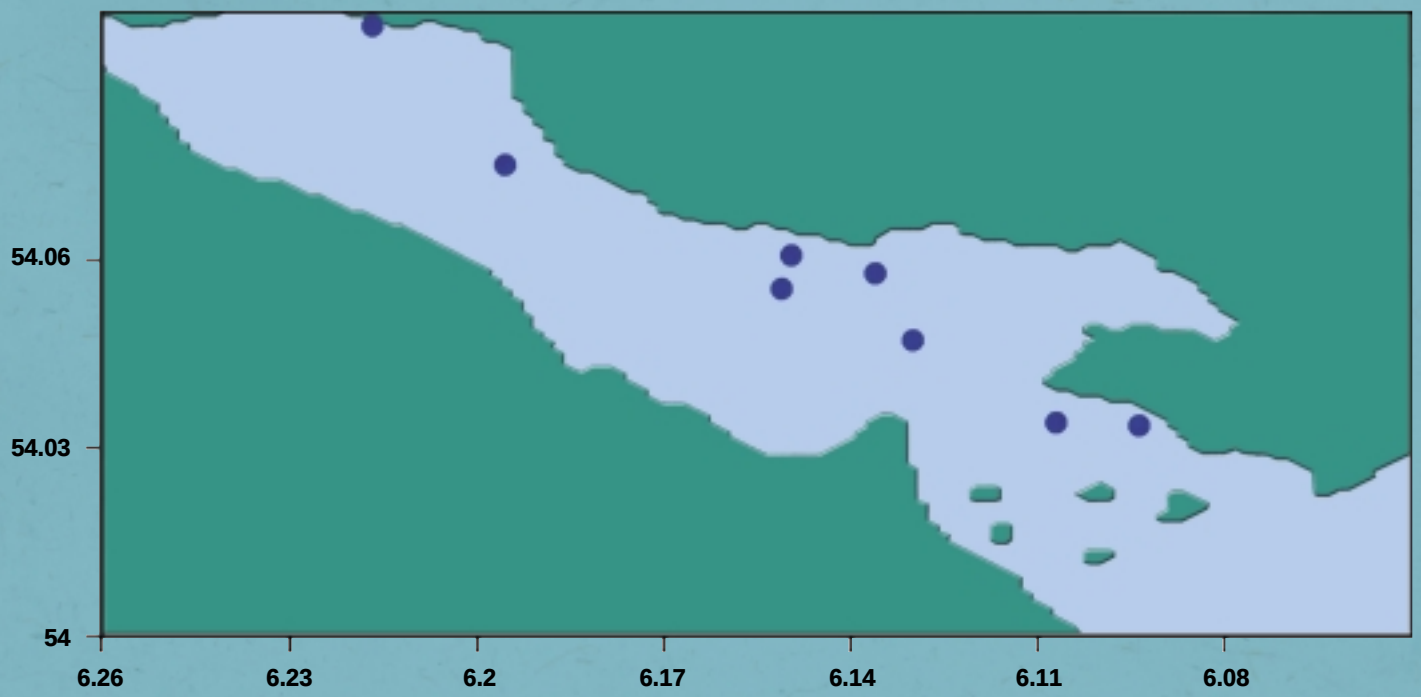
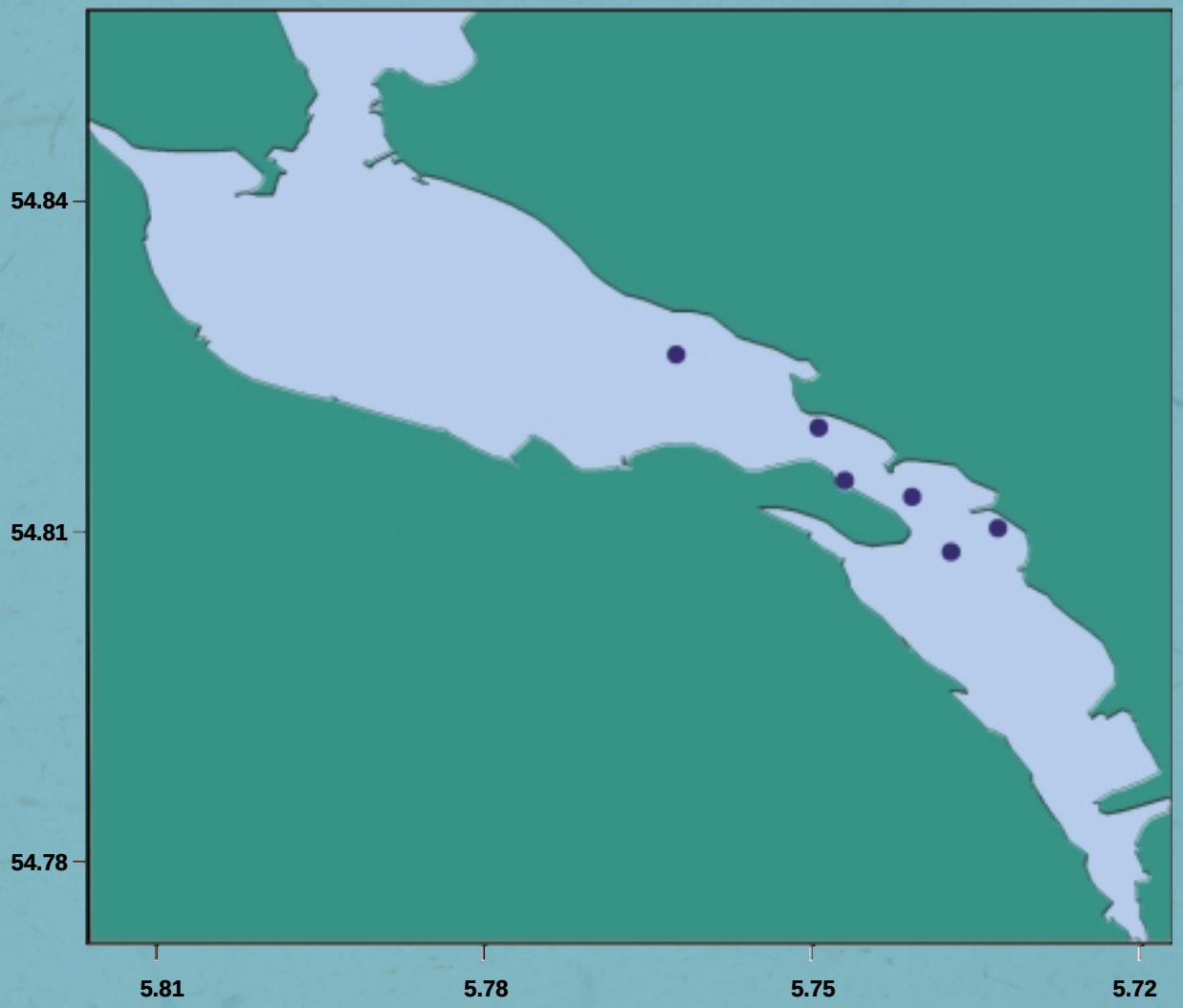


Figure 5.3
Map showing the main aquaculture areas Carlingford Lough.

Figure 5.4
Map showing the main aquaculture areas in Larne Lough.



Chapter
Six

Scope for expansion

Introduction

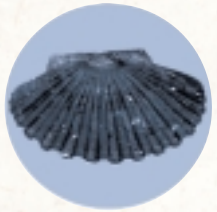
Shellfish Aquaculture in Northern Ireland has expanded over the past three years. The number of aquaculture licensed sites and the area under cultivation has increased dramatically and there are frequent applications for new licences. Further expansion of the aquaculture industry in Northern Ireland is practical, however good management practices must be followed, to ensure that further development is managed to favour both the environment and industry. There are many advantages to shellfish aquaculture including: relatively cheap or natural (free) seed supply; natural food production; a wide range of culture techniques and very adaptable (therefore suitable methods for variety of sites) and good shellfish markets. Another advantage to shellfish aquaculture is the different levels of entry into the industry, ranging from the small farmer producing 10 tonnes a year to mussel dredging operation with the potential of producing over 1,000 tonnes per year.

Development of shellfish aquaculture using established species and methods is limited by the availability of suitable sites (Heath, *pers.comm.*). Future progress through development of numerous small scale farms for oysters, scallops and rope grown mussels would be practical. Expansion of extensive mussel cultivation is presently underway, and is limited by site availability. Ongoing surveys to identify potential new sites and fishery resources of seed will be of great value to the expansion of the industry.

For Northern Ireland to succeed in the market place the industry must develop a reputation for a high value, high quality product meeting the demands of both the bulk and niche markets. Production of a high quality product with continuity of supply to meet the demands of all these markets is of the utmost importance. To meet the quality criteria there are requirements for high standard grading and depuration equipment, along with good shellfish handling facilities (Seafish, *pers.com*).

Northern Ireland is well equipped in terms of industrial and research expertise with which to adopt and adapt new and existing aquaculture technologies. Expansion of modern on-shore aquaculture techniques using pump ashore and recirculated sea water systems has the potential to remove many of the barriers of site limitation (Heath, *pers.comm.*).

Concerns over environmental impact were mainly based upon problems associated with more intensive aquaculture activities, such as, salmon farming. It is becoming recognised that shellfish aquaculture is less intensive and has only limited environmental impact, with visual amenity often the main concern. This is reflected by the fact that shellfish farms are excluded from the requirement to produce an EIA, under the Environmental Impact Assessment (Fish Farming in Marine Waters) Regulations (NI) 1999 No. 415. It is increasingly important for the industry to identify that it is not having a significant impact in order to obtain an aquaculture licence. Environmental impact assessments (EIA's) require the appointment of independent consultants and this would add considerable financial burden to the set up cost of small aquaculture ventures.



1 Existing Areas of Aquaculture

1.1 Belfast Lough

Belfast Lough was seen as one of the main areas for expansion of aquaculture in Northern Ireland, with great potential for bottom dredged mussel cultivation. Since the end of 1998, the number of licensed areas has increased to 12 (approximately 749 hectares), three of these sites cover 300 hectares and are under active mussel production. A reasonable estimate of the potential for bottom dredged mussel production would be around 6,500 tonnes per annum. Seed mussels (15-30mm) are dredged from waters adjacent to Belfast Lough, sorted and relaid on licensed beds at a variety of stocking densities depending on the individual operator (Chapter 4).

Perwinkles are the other species gathered around Belfast Lough and there is at present one licensed aquaculture site for Periwinkle ongrowing. Recent surveys have shown large populations of *Psammechinus miliaris* and areas of juvenile cockles plus seed mussel of varying size categories.

There was a traditional flat oyster fishery in Belfast Lough, with beds situated at the mouth of the Lough between Whitehead and Bangor. These beds deteriorated during the 19th century and at the time this was blamed on pollution from sewage and dye stuffs emitted from Belfast (McConnell, 1932 cited in Kennedy, 1999).

1.2 Strangford Lough

There are fourteen licensed sites in Strangford Lough, over half of these have only been licensed since 1998. The sites are licensed for a variety of species and methods including: mussels (bottom and suspended culture); native oysters (trestles and bottom culture); Pacific oysters (trestles and mats) and scallops (suspended culture). There are also licenses for culture of Manila clams, however growing this species in Strangford has not been successful to date. There is approximately 385 hectares under licence.

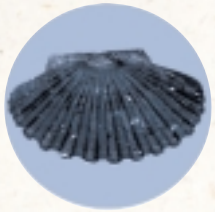
Historically Strangford Lough supported a productive flat oyster fishery with many areas being associated with oyster production (Kennedy, 1999). The Strangford fishery was already in decline by 1877, when reduced catches were attributed to intense all year round fishing practices.

Although the Strangford Lough flat oyster beds were commercially extinct by the turn of the century, a residual stock was thought to have persisted. In recent times this idea seems to be justified with a number of recordings of live specimens, before the increase through aquaculture.

1.3 Carlingford Lough (north of the dredged channel)

There are eight licensed sites on the north side of Carlingford Lough, most of these have only recently become active. The sites are licensed for a variety of species including mussels (suspended and bottom), scallops (suspended), Manila clams (plots), Native oysters (trestle) and Pacific oysters (trestle). There is approximately 264 hectares under licence.

Flat oysters were abundant in Carlingford Lough, which supported a thriving oyster fishery, with oysters renowned for their quality, until 1875. The collapse of the fishery was largely due to overfishing (Douglas, 1992). The fishery recovered to some extent when dredging pressure was relaxed and by 1903 the beds were being actively dredged. Overfishing led to depletion and by 1914 the industry was in total



decline. An effort was made to revive the industry in 1970 and 1971 by BIM, with Clarinbridge oysters relaid, which showed rapid shell growth and excellent meat condition. These trials were superseded in 1973 and 1974 by growth trials with the Pacific oyster *Crassostrea gigas*. Recent cultivation of flat oysters on the northern side of the lough have experienced good growth rates and meat content in their stock.

1.4 Lough Foyle

There are a number of aquaculture sites in Lough Foyle, covering approximately 50% of the seabed. At present there is no legislation covering these areas and no licensing and therefore no control. This is being addressed through amendments to existing legislation Experience gained in other Irish bays, where the uncontrolled expansion of shellfish aquaculture became detrimental to the shellfish, increasing outbreaks of disease, highlighted the requirement for a management strategy.

Lough Foyle has supported a number of shellfisheries for at least 150 years, with fluctuating production levels. The most commonly occurring shellfish species of commercial viability, are the native oyster and the blue mussel (Friel and O'Sullivan, 2000). It is estimated that the oyster beds cover an area of 1673 hectares, or 8.4% of the Loughs seabed (Friel, 1997 cited in Friel and O'Sullivan, 2000), while the wild mussel beds cover an area of 1250 hectares or, 6.25% of the seabed (Cunningham, 1991 cited in Friel and O'Sullivan, 2000).

The largest natural beds of the common mussel (*Mytilus edulis*) in Ireland occur in Lough Foyle (Crowley and Briggs, 1977). These are regularly fished and have been the subject of a number of investigations (Crowley and Briggs, 1977), Crowley *et al.*, 1985). The main beds were found at Ball's Point, Longfield Bank, Ballykelly Bank, Ture Point and Quigley's point. Recently moves towards the commercial exploitation of this resource within the Lough has lead to surveys of the sediment/benthic classification undertaken by the acoustic ground descrimination system RoxAnn (for details see Magorrian, 1995). Other shellfisheries in the Lough include the native oysters, which are harvested annually (with harvests ranging from 40-400 tonnes) and a recent increasing interest in crabs, winkles and whelks (Charlesworth and Service, 1999). A more recent and extensive RoxAnn survey (Figure 6.1) has indicated that >50% of the sediments of Lough Foyle are covered by shellfish beds.

1.5 Larne Lough

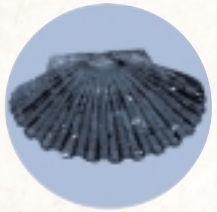
There are six licensed sites, four of which are active, they produce Native and Pacific oysters (trestle) and mussels (bottom). There is approximately 89 hectares under licence. There is some debate as to the water quality in the Lough and this may have an impact on the shellfish cultivation.

1.6 Killough Harbour

The Killough site (3 hectares) is licensed for trestle culture of Pacific oysters and has only recently come into production, with the harvest predicted in Autumn 2001.

1.7 Dundrum Bay

There is one licensed site producing mussels (bottom culture) and Pacific oysters (trestles). The site lies along the channel in the inter-tidal area of Dundrum Bay, with an area of 22 hectares under cultivation. There are razor clams in the outer bay, however this area is protected as a nursery for juvenile fish under the Inshore Fishing (Prohibition of Fishing and Fishing Methods) Regulations (Northern Ireland) 1993. No. 155 and the Razor Shells (Prohibition of Fishing) Regulations (Northern Ireland) 1998.



1.8 Copelands

One site (2.8 hectares) licensed for the production of scallops (bottom) has only just been approved, production has not yet started. Potting for crabs and lobster is common in this area. The area is relatively exposed and therefore not suited to long line culture.

2 Scope for expansion - Areas

Currently much of the expansion will take place on existing sites.

2.2 Belfast Lough

One of the main physical limitations is suitable habitats, a recent RoxAnn survey of Belfast Lough has shown different sediment types (Figure 6.2). Future expansion of the aquaculture industry in Belfast Lough must also take into account the carrying capacity estimates discussed in Chapter 8.

2.2 Strangford Lough

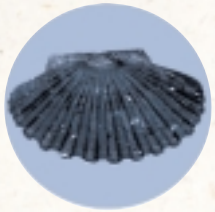
Flat oysters were once widespread in Strangford Lough, therefore reintroduction would have significant conservation value, with a return to the former structure of the "original" benthic community. The great variety of epifaunal and infaunal organisms associated with oyster beds (Korringa, 1952) would increase the biodiversity and enhance the benthic habitat. One option to protect and develop the native oyster populations with a view to commercial exploitation would be, to set aside areas of the oyster beds closed to dredging, for the establishment of broodstock. Expansion of suspended mussel culture is limited by the availability of sites and by licence conditions. The mussels produced using suspended culture are of high quality and show the potential for expansion of mussel cultivation. The sub-aquaculture methods used are innovative and fitting for an area of such great conservation interest. A recent survey using RoxAnn shows the diversity of habitats found in the lough (Figure 6.3) (Service, *pers.comm.)*. At present, good quality Pacific oysters are produced on mats covering otherwise unsuitable substrate and there may be potential to develop this technique.

2.3 Carlingford Lough

At present the management of aquaculture in Carlingford Lough is divided, with the Department of Marine responsible for licensing on the southern side of the channel and DARD Fisheries responsible on the northern side of the channel. With the transfer of powers to The Foyle Carlingford and Irish lights Commission (FCILC) there will be an opportunity for the implementation of a co-ordinated management strategy and development of the industry. An updated RoxAnn survey may be required to locate suitable shellfish areas. Figure 6.4 shows the result for the most recent survey carried out in July 1997.

2.4 Lough Foyle

As the largest of the sea loughs, the scope for development of aquaculture and wild fisheries under a managed scheme would be advantageous to both. A contemporary survey of the existing shellfish areas is required, to highlight areas suitable for expansion. There is also scope for expansion on the inter-tidal zone, however, SPA's and roosting sites must be considered. With the transfer of powers to FCILC there will be the opportunity for the introduction of a management strategy considering the whole lough system.



2.5 Larne Lough

There is some potential for the expansion of oyster culture and bottom dredged mussels. A recent RoxAnn survey (Figure 6.5) shows the different sediment types. Water quality has proved a limiting factor, but the rate of development is increasing at present.

2.6 Killough Harbour

There is potential for expansion of the oyster cultivation beyond the present site, however the impact of expanding would have to be evaluated before any development could take place. Further development will be limited by the topography of the Bay.

2.7 Dundrum Bay

Space again becomes a limiting factor in an ASSI, cSAC and a NMR (Murlough). A recent RoxAnn survey (Figure 6.6) could be expanded to look for potential sites in this area. The area available for aquaculture is limited as much of the bay is uncovered by water for a considerable part of each tide.

2.8 Off-shore areas

Recent developments, including sub-sea rafts for mussel cultivation and artificial reefs have expanded the potential to utilise off-shore areas. Off the Skerries there is potential for bottom culture of mussels. There may also be scope for the introduction of artificial reefs for culture of lobsters and sea urchins.

3. Scope for expansion - species

Shellfish aquaculture thrives as growers provide high quality shellfish to the market on a regular basis. In this section, both development of certain native shellfish as aquaculture species and the introduction of "novel" species are discussed.

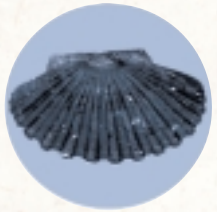
This includes a brief mention of some novel methods (recirculation systems) and promotes the concept of mixed mariculture systems.

3.1 Mussels

Mussel fisheries operate world-wide and are of ever increasing economic importance, with a thriving market for both fresh and processed mussels. The expansion of mussel aquaculture requires finding new areas suitable for cultivation. To supply a safe, hygienic product, it is likely that the development of aquaculture will focus on unpolluted areas (Kelso and Service, 2000).

Conditions in many of Northern Irelands loughs are well suited to mussel cultivation and expansion of the industry is actively encouraged. Large-scale mussel culture will have an impact on the immediate area (Chapter 7) and due to the conservation designations of many of these areas, careful management of the fishery is essential.

Expansion of bottom mussel culture is limited by available space and seed supply. Suspended culture may be the way to expand, however higher setup and maintenance costs may be prohibitory, also the availability of suitable sites is still a limiting factor with suspended cultivation.



3.2 Oysters

Flat oysters

In the last century the flat or native oyster (*Ostrea edulis*) was one of the commonest edible shellfish in Europe. By the 1920's major outbreaks of disease and heavy overfishing and pollution had dramatically reduced stocks throughout the range of this species. The market niche for flat oysters was filled by non-native cupped oysters of the genus *Crassostrea*, firstly American and Portuguese oysters and later Pacific oysters. None of these species reproduce in Irish waters as they are native to warmer waters. Reclamation of old Native oyster beds should be promoted and developed commercially as these are of high monetary value and there is a good French market. Great care must be taken when choosing sites as flat oysters are more susceptible to siltation than Pacific oysters.

Pacific Oysters, *Crassostrea gigas*

C. gigas is a member of the genus *Crassostrea* or cupped oysters, several species of which are commercially important world-wide. *C. gigas* is more tolerant of a wider range of environmental conditions than *O. edulis*, which belongs to the more marine genus *Ostrea*. It has an optimal salinity range of 25 – 35 ppt, grows over a wide range of temperatures from 8 – 30˚C with an optimal range of 15 – 18˚C, and, as would be expected of an estuarine species, is adapted to high silt loading. It is also tolerant to a certain degree of exposure to air unlike the native oyster and has a higher growth rate. *C. gigas* is viewed as a main player in the shellfish aquaculture industry and will frequently be chosen as the set-up species for new operators. Northern Ireland must produce at least 1000 tonnes to provide continuity of supply and quality on a scale, which will be of interest to the wholesale and retail industries.

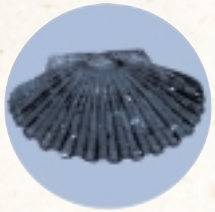
3.3 Clams

There would be potential for expansion of clam cultivation, for native clam, Razor and Manila clams, with high market value. Again limitations include suitable space and also access to intertidal sites.

3.3.1 Razor clams

Hydraulic dredging is the main method of collecting razor clams although traditional dredging, diving and hand gathering in the intertidal zone at low water may also be employed (Howard *et al.*, 1998). In hydraulic dredging, water jets are used to fluidise the sediment immediately ahead of it and a hollow blade which penetrates 30cm into the sediment is subsequently used to extrude the razor clams from the sediment. A backwater jet is then used to lift the clams into a collecting cage (Bailey *et al.*, 1998). This is a very rapid and vigorous method but one which may have serious repercussions for the environment. In 1998, the emerging razor fishery in the Wash was banned, following advice from English Nature 'that a prospective new unrestricted fishery for razor shells could lead to habitat damage within the Wash, a Special Area of Conservation (SAC) under the EU Habitats Directive.

To prevent a new unregulated fishery commencing in Dundrum Bay, part of Northern Ireland's eastern coastline, the Department of Agriculture for Northern Ireland issued the Razor Shells (Prohibition of Fishing) Regulations (Northern Ireland) 1998. These regulations prohibit (subject to certain exemptions), any boat from fishing for razor shells using any type of dredge or suction dredge and for retaining on board razor shells caught as a by-catch, while fishing with the above techniques, within Dundrum Bay, a potential razor fishery. The enforcement of these regulations were brought into operation on the 1st January, 1999 but are subject to review, pending scientific advice.



Detailed assessments of the razor shell stock, potential effects on the sediments and on invertebrates are essential to determine how a razor fishery might be both sustainable and compatible with conservation interests (Dunn, 1999). Recently, research projects have been set up by Seafish looking at various aspects of razor clam fisheries. This research is supported by the Marine Institute, BIM, DARD and C-MAR.

Figure 6.7
The Japanese cold water Abalone, *Haliotis discus hannai* grown in recirculation tanks at the Shellfish Research Laboratory at Carna

3.4 Periwinkles

Hand-gathering of winkles occurs on most accessible rocky shores along the Northern Ireland coast, over the past decade there has been a major expansion of the winkle fishery with local produce exported to France, Holland, Spain and Portugal. To prevent over exploitation of winkle populations and to provide continuity in supply, ongrowing of periwinkles may provide future aquaculture diversification.

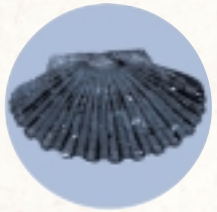
3.5 Novel species

The development and introduction of new species in Northern Ireland would enable the industry to make use of available resources and to fulfil its potential for supplying high quality produce to niche markets. Development of both the aquaculture potential of native species (such as, razor clams, squat lobsters, sea urchins and algae) and the introduction of non-native species already established in aquaculture elsewhere (for example, abalone and tropical prawns). There may also be some scope for the expansion of ranching and further stock enhancement projects for oysters, scallops, razors clams and lobsters. Ranching involves supplementing existing natural populations or wild stock and as such is not covered by the legislation.

Potential for the introduction of other non-native species in closed recirculation systems must be examined for future expansion of the industry. Closed recirculation systems, recycle and clean the water, they can be maintained at an optimum temperature and reduce the risk of introduction of alien species to the marine environment.

Successful trials for the cultivation of Abalone in reciculation systems have been carried out at the Shellfish Research Laboratory, Carna, Co. Galway (Figure 6.7). Abalone are marine gastropods which feed on seaweed and two species (*Haliotis tuberculata*, the European species and *Haliotis discus hannai*, the Japanese cold water abalone) have been sucessfully spawned and reared in recirculaton tanks at Carna (La Touche *et al.*, 1993). Abalone cultivation is attractive as good quality Abalone are undersupplied in the market place and command a high price by growers. There would be potential to develop Abalone aquaculture in Northern Ireland.

Polyculture systems have been investigated (SAMS, Carna) and have great potential for future development. For example, work on breeding and growth of the green sea urchin (*Psammechinus miliaris*) at Carna has



illustrated the potential of this species for farming. Researchers at SAMS have established hatchery / nursery protocols for producing *P. miliaris* spat. Research conducted at Joseph Johnston and Sons has shown that *P. miliaris* thrives in salmon cages, where they graze on salmon feed and cage fouling. Methods for polyculture of urchins with Atlantic salmon have been developed. The urchins are contained in separate cages where they remain accessible but cause a minimum of interference to fish husbandry. This research has shown market sized urchins (40mm diameter) with high quality roe and a value of approximately £20 / kg can be produced in a two year growth cycle (Kelly, *pers.comm.*). Urchins would reduce levels of organic enrichment beneath salmon cages.

Ongoing research into seaweed cultivation has shown the potential for growth in Northern Irish waters (Heath, *pers.comm.)*.

3.5 Novel Methods

Recirculation systems are a novel method for the expansion of the aquaculture industry in Northern Ireland. Recirculation systems in aquaculture have traditionally been used for high value marine and freshwater finfish, however increasingly interest is being shown in this method of production for shellfish such as abalone.

The basic principle behind recirculation is that a continuous process is established whereby effluent water leaving the growing tank is reconditioned by the removal of waste feed and metabolic by-products. This is followed by the sterilisation and re-oxygenation of the water, prior to its return to the growing tank.

Recirculation has a number of advantages in that it allows control of the environmental factors in which the fish or shellfish are to be produced in such a way as to achieve maximum productivity from the unit. Being an enclosed system, it can also guarantee that there will be no escape of stock into the wider environment.

In addition to this, the fact that the system is enclosed, means that the production unit is not dependent on a continuous supply of seawater and therefore does not have to be located on the shore. This is particularly true of shellfish production, which involves comparatively small quantities of water.

Traditionally the high costs of these systems made it unlikely that shellfish production would be viable. Recent developments have lead to a considerable reduction in the cost of these systems and the potential for aquaculture diversification is vast. Sub-sea rafts are also a relatively novel method and both of these developments are in early stages but could have potential within the next ten years. The use of ladders to grow mussel seed is also developing rapidly and has many advantages over ordinary long-lines (such as, increased production and decrease in loss of mussel).

Figure 6.1
A RoxAnn survey showing main habitats in Lough Foyle, August 1996.

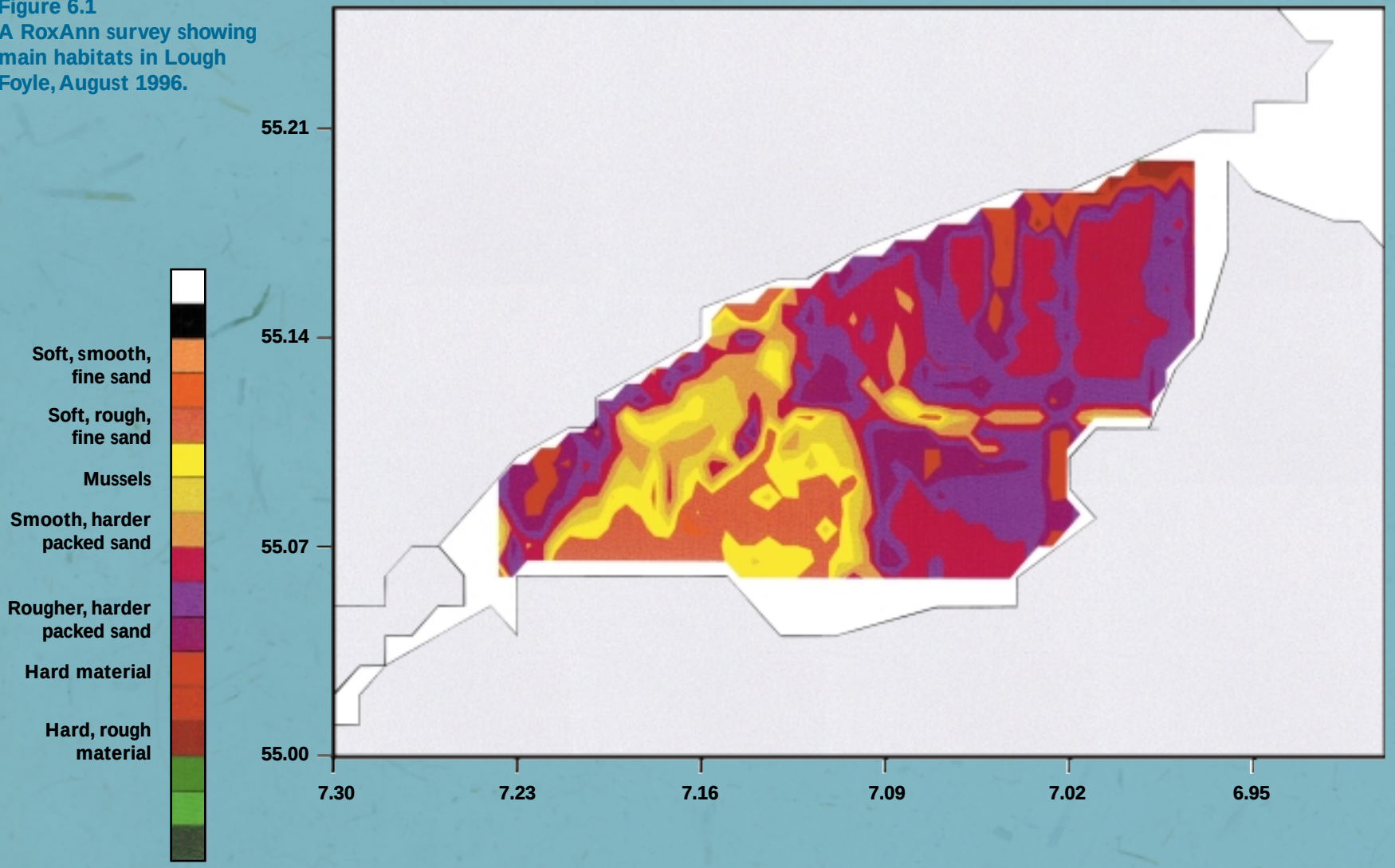
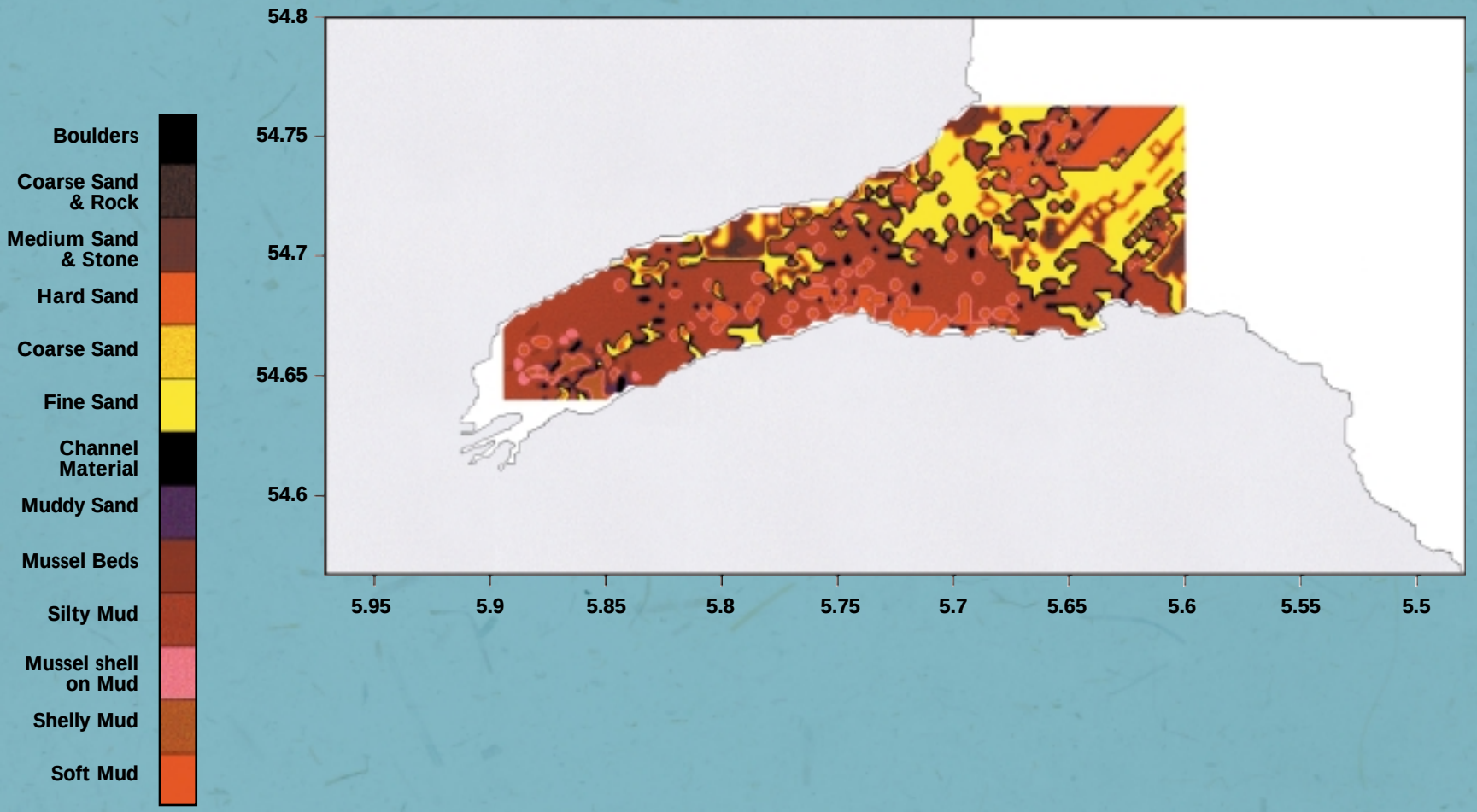


Figure 6.2
A RoxAnn survey of Belfast Lough (March 2001).



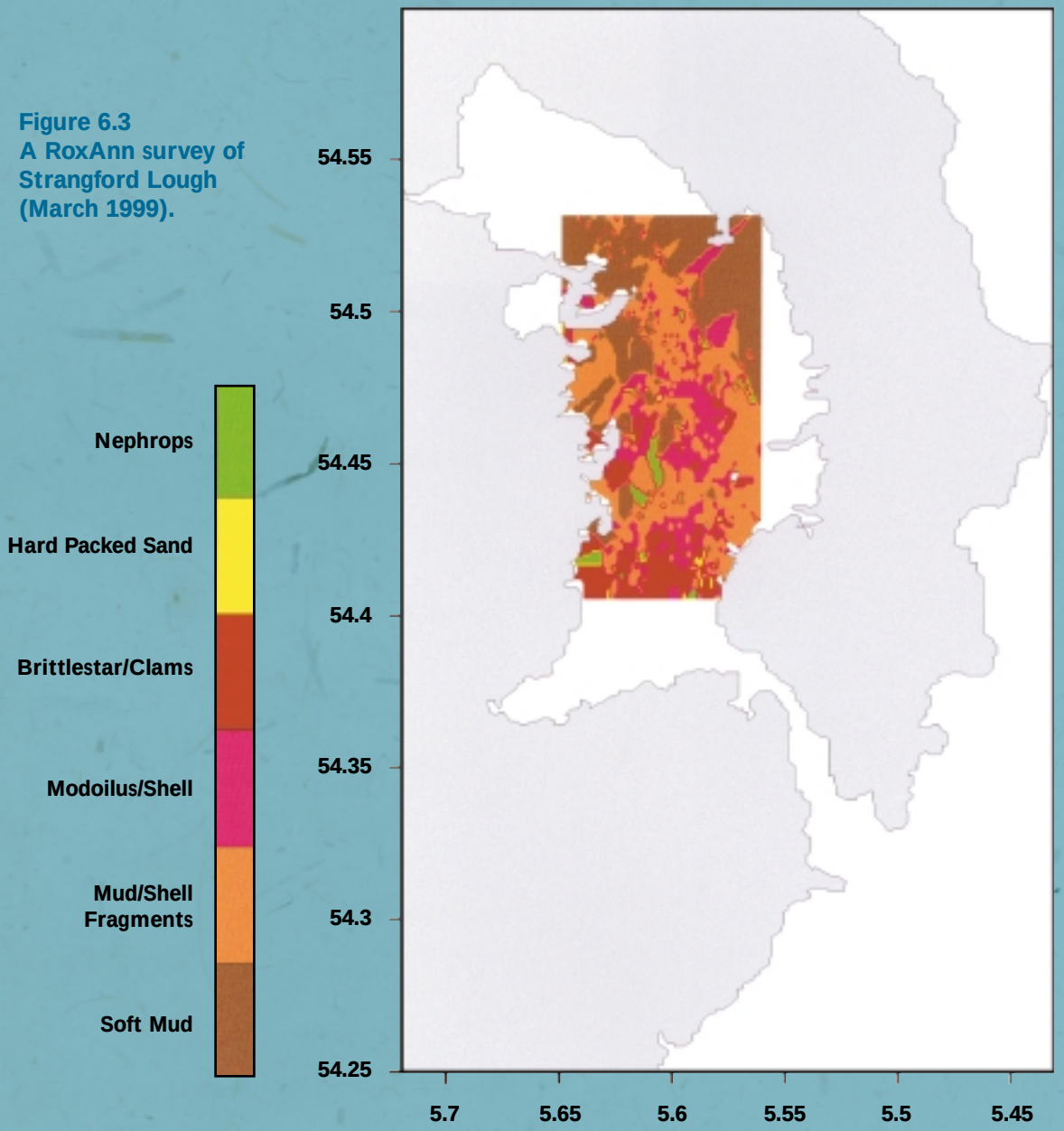


Figure 6.3
A RoxAnn survey of Strangford Lough (March 1999).

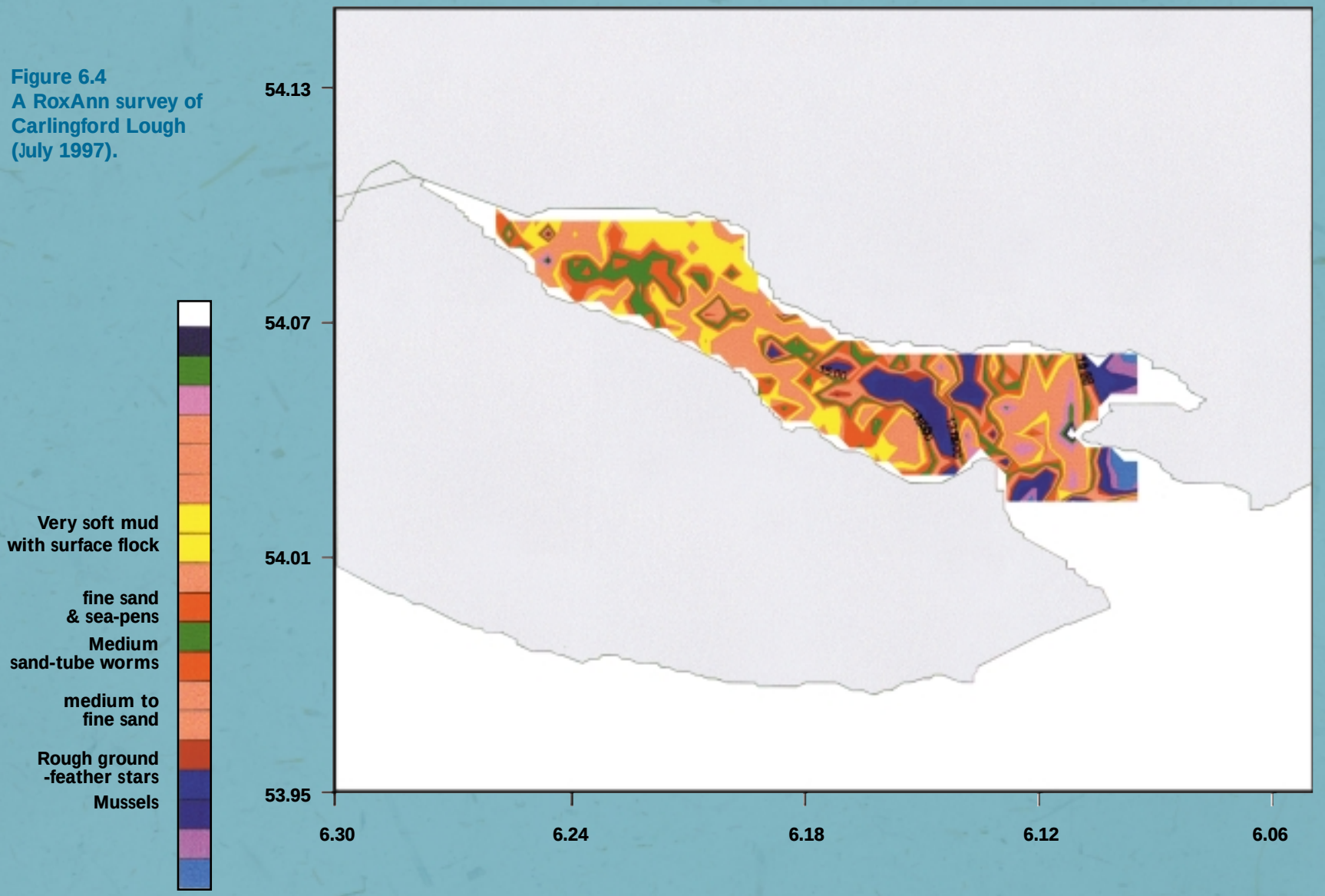
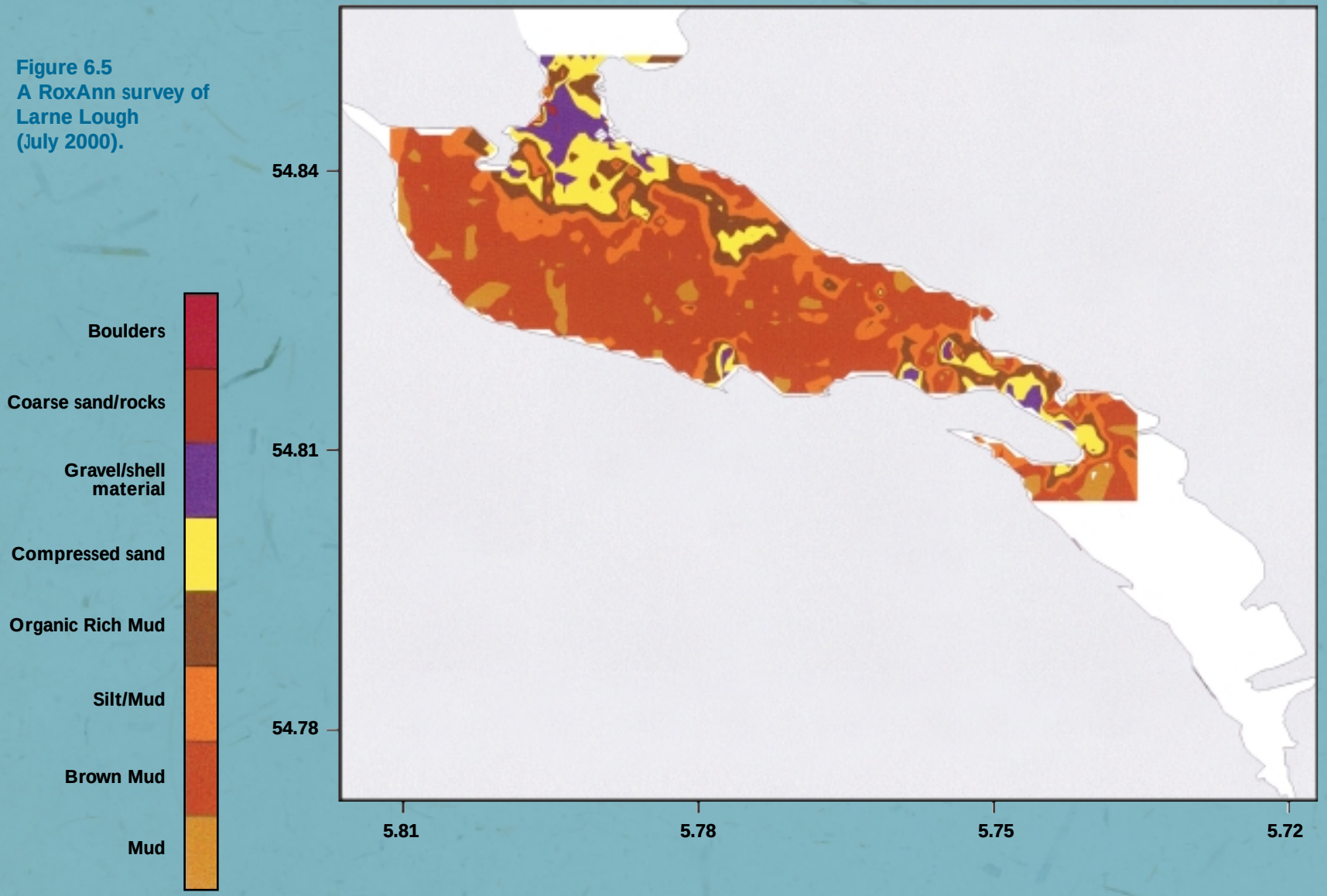


Figure 6.4
A RoxAnn survey of Carlingford Lough (July 1997).

Figure 6.5
A RoxAnn survey of Larne Lough (July 2000).



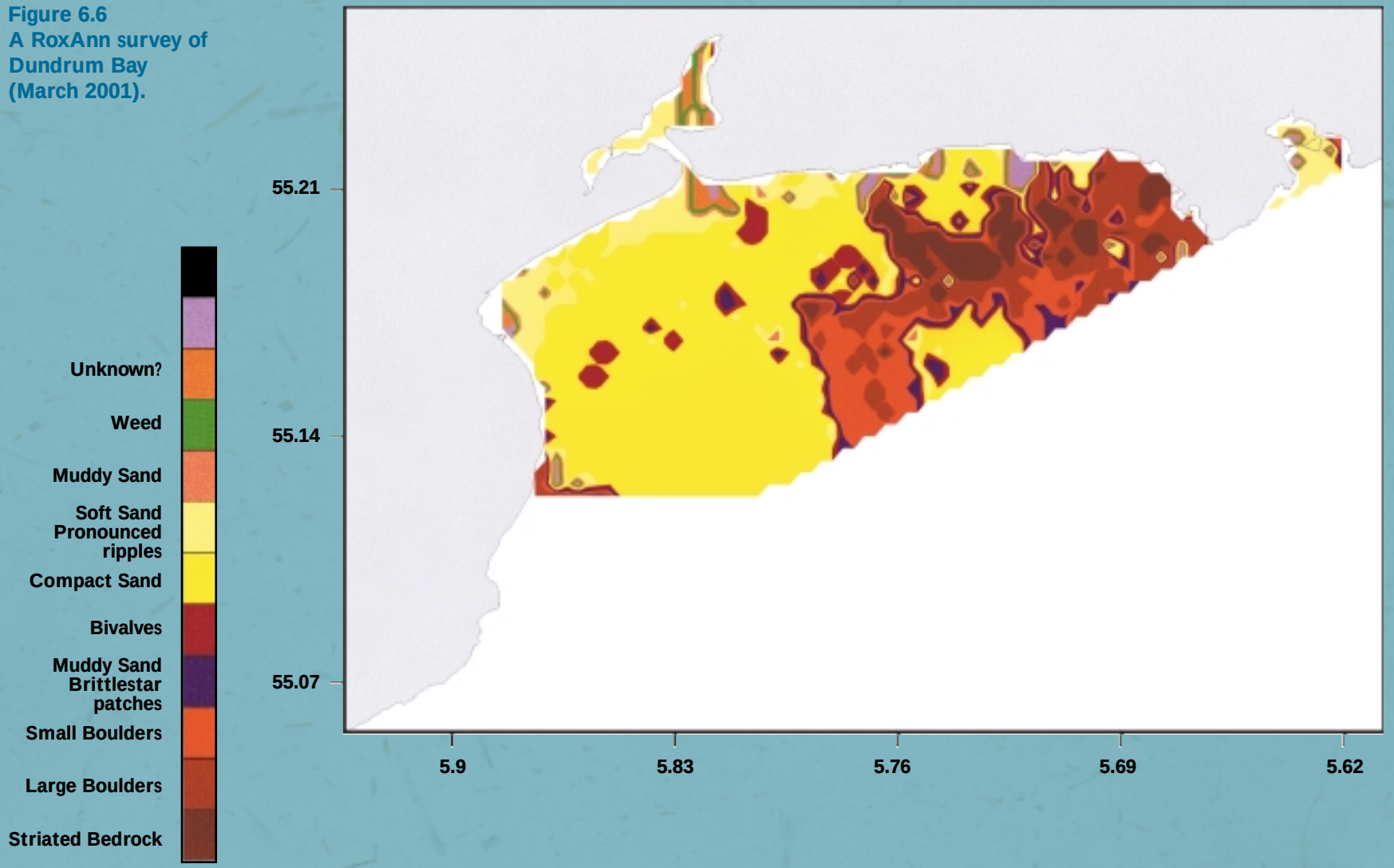


Figure 6.6
A RoxAnn survey of Dundrum Bay (March 2001).

Chapter
Seven

Ecosystem impact of Aquaculture

Introduction

Shellfish farms are dependant on clean water supplies and a healthy environment. This is particularly important where the produce may be eaten raw. Shellfish rely on food naturally occurring in the water column and do not require the feeding or antibiotic care necessary on fin fish farms. As the aquaculture industry continues to expand there is increasing competition with other users of the aquatic environment, there is also concern as to the environmental impact of this industry upon its surrounding environment. In a review on the environmental impact of mariculture, (Rosenthal *et al.*, 1988), suggested that since mariculture operations are structured around the use of natural waters, consideration must be given to their wider environmental impact and that in some cases ecological change had become a risk factor to the industry itself. With respect to ecological change, management strategies should be based on an understanding of the interaction between a particular form of aquaculture and the aquatic environment. Consideration of the potential impact of aquaculture should be assessed to minimise ecological change and to ensure long term viability of farming operations.

The range of potential environmental impacts reputed to be caused by aquaculture is diverse, being dependent on the form of aquaculture activity and the physical, chemical and biological characteristics of the location in which cultivation takes place (Gowen *et al.*, 1990). It is difficult to extrapolate these direct effects and to interpret their longevity due to the lack of comparison with similar unfished areas, however knowledge of these effects provides the basis for making management decisions. Potential indirect effects have not been studied in detail but must be considered, these include concerns about aquaculture activities leading to imbalances in ecosystem function with changes in trophic and competitive interactions and consequently knock-on effects on non-target species. Depletion of prey for birds and marine mammals, and species replacement leading to shifts in community structure have been noted, however evidence is unclear and interactions complex and difficult to quantify (Jennings and Kaiser, 1998). A detailed discussion of the potential direct effects of aquaculture is found in (Gubbay and Knapman, 1999) and accounts of the impact of harvesting cockles, oysters, mussels, clams and scallops are discussed in (Gubbay and Knapman, 1999) and (Kelso and Service, 2000) and are not considered here.

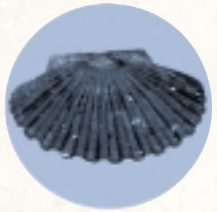
Aquaculture sites are usually close inshore and are often located in European marine sites which are protected as discussed in Chapter 2. A broad overview of the potential environmental impacts of aquaculture are presented in this chapter.

1 Impacts of shellfish cultivation

A number of different methods of shellfish cultivation are used in Northern Ireland waters (Chapter 4) with issues for consideration at the seed collection, on-growing and harvesting stages of the process. The environmental impacts of each cultivation stage will vary depending on the species in question and the techniques used.

1.1 Seed collection

Some commercial species are reared as seed in hatcheries prior to seeding, with minimum effects on the environment. Some seed species are collected from the wild using benign techniques, such as spat collectors, whilst others are extracted using intrusive devices such as dredges. In the UK this dredging for seed mussels is not considered to have an environmental impact, as it is not extensive and only licensed from

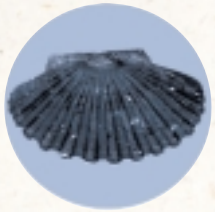


unstable beds which would only have a short life-span if left unfished (Kaiser *et al.*, 1998). A growing number of studies of the ecological effects of mechanical collecting devices have demonstrated direct mortality of non-target species in other countries. For example, the mass mortality of eider ducks associated with reduced mussel stocks after spat harvesting, and the destruction of suitable settlement substrate or habitats in the Wadden Sea (Black, 1996 cited Gubbay and Knapman, 1999). Other species, such as birds, crabs and starfish, may be deprived of valuable food resources and habitat as a result of the mechanical harvesting of bivalve seed. Collection of juveniles from the intertidal area may result in adverse effects from trampling and also disturbance of foraging birds. There is also concern over the unintentional introduction of alien species on shellfish which are imported as seed stock for cultivation, however other transfer vectors must also be considered e.g. ships ballast. The introduction of alien species can have various levels of impact. First, inadvertent co-introductions of harmful organisms associated with the target species; second, the ecological and environmental impacts of introduced species; thirdly, the genetic impact of introduced and transferred species on indigenous stocks. Introductions of algae, including toxic dinoflagellates, have generally been attributed to resting cysts in ship's ballast waters. However, transfer of shellfish stocks from one area to another followed by relaying or storage in open basins can provide another mechanism for transfer.

1.2 Ongrowing

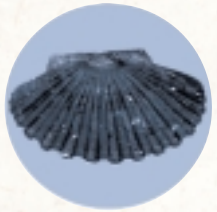
One of the main advantages of bivalve species for aquaculture is that they are on-grown to market size in the natural environment making use of an unsupplemented natural food supply. Ongrowing will require the introduction of structures into the marine environment on or from which the bivalve are supported or suspended (Kaiser *et al.*, 1998). The introduction of such structures has an immediate effect on local hydrography and provides a new substratum upon which epibiota can settle and grow. In addition the introduction of high densities of cultivated organisms increases local oxygen demand and elevates the input of organic matter into the immediate environment. Where there is a high density of bivalve stock the larval settlement of other benthic species may be reduced, some larvae are filtered and digested. Others pass through the digestive system alive, but are rejected and bound in the faeces or pseudofaeces (Baldwin *et al.*, 1995 cited in Kaiser *et al.*, 1998). Although there is increasing evidence showing the effects on the ecosystem through commercial cultivation of bivalve mollusc stocks, it is important to remember that natural beds of these animals were once extensive and played a vital part in the functioning of the local ecosystem, processing excess phytoplankton and cycling organic material. Overharvesting, disease and pollution almost destroyed these native populations and the introduction of commercial cultivation may be no more than re-establishment of the status quo. A review of the literature on the role of bivalve molluscs in estuarine ecosystems shows that they are an essential part of healthy estuaries around the world in which they fulfil an important role in the retention of nutrients (Dame *et al.*, 1989).

The effects of on-growing depend on the habitat, type and scale of cultivation. On-growing involves either suspended culture subtidally, trestle culture intertidally or cultivation directly on/in the ground (Chapter 4). Many of the environmental changes that occur result from their filter feeding activities that produce faeces and



pseudofaeces. This can lead to depletion of phytoplankton in densely cultivated systems and accumulation of silt/pseudofaeces beneath suspended cultures that then often results in locally anoxic environment and faunal impoverishment. There are many examples of this, in Arcachon Bay, France, 10 km^2 of the lower intertidal is occupied by oyster parks, this constitutes approximately 7% of the total intertidal area within the Bay (Castel *et al.*, 1989). Oysters are grown by either relaying them directly onto the substratum or growing them in net bags (poches) suspended above the substratum on trestles. The trestles and poches often become fouled with green algae, which will further increase levels of organic enrichment when it dies back in autumn and winter. Castel *et al.* (1989) found that the presence of densely stocked oyster parks elevated oxygen demand and produced anoxic conditions. As a result meiofauna increased in abundance by a factor of 3-4, whereas macrofaunal abundance decreased by nearly a half. The structures used during the cultivation process can cause environmental change. For example, the use of netting to protect clams from crab predators leads to siltation and accumulation of sediment. Parks of trestles can drastically alter the water flow regime leading to changes in sedimentation rate and oxygen exchange within the system. Similar observations were recorded under mussel cultures. The effects on the sediment under the culture were reduced grain size, high organic content and a negative Redox potential, changes to the benthic fauna only showed limited recovery after 6 months (Gubbay and Knapman, 1999). Even relatively small-scale operations show environmental changes, for example, Nugues *et al.* (1996) studied a small oyster farm in the River Exe, England. They found that the abundance of macrofauna beneath trestles decreased by a half and that water currents were significantly reduced in close proximity to oyster trestles where sedimentation rates doubled. There was an increase in the organic content of the underlying sediments, which lead to a reduction in the depth of the oxygenated layer of the sediment (Nugues *et al* 1996 cited in Kaiser *et al.*, 1998). Cultivation of Manila clams usually involves some habitat modification in the form of adding gravel and crushed shell, placing protective plastic netting over seed clams, or laying clams directly onto the sediment in poches. Such habitat modifications lead to alterations in the local environment and consequently faunal composition. Relaid mussels lead to the development of mussel mud beneath the mussel bed as the filtration and feeding activities of the mussels increase sedimentation rate. These deposits are composed of dead shells, silt, and pseudofaeces that persist in excess of 18 months after the mussels have been removed. The cohesive nature of the mussel mud is degraded by a combination of bacterial activity and wave erosion.

Suspended rope culture had only minimal visual impact on the landscape, however, the large biomass of cultivated and fouling organisms suspended beneath rafts and buoys have a major effect on phytoplanktonic, benthic, and hydrographic processes in close proximity to the cultivation site. For example, studies carried out in the Spanish Rias showed that suspended mussels provide a complex surface area on which dense epifaunal communities consisting of over 100 species can develop. Fallen mussels attract other predators, such as crabs which are in turn fed upon by opportunistic fish species (Lopez-Jamar *et al.*, 1984). Mussels excrete high levels of ammonia (Tenore and Gonzalez, 1976 cited in Kaiser *et al.*, 1998), which promotes high levels of productivity in algae attached to mussel lines, so great is the



productivity that there was speculation as to the enhancement of inshore fisheries by the bedload transport of organic rich sediment into coastal areas. Cultivation sites that are well flushed by tidal currents, as in the Spanish Rias, do not encourage the accumulation of pseudofaeces beneath the mussels (Rodhouse and Roden, 1987).

Whereas, Dahlbäck and Gunnarsson (1981) demonstrated sedimentation rates of 2.4 - 3.1 g organic C $m^{-2}d^{-1}$ beneath mussel longlines, this was double the amount found in adjacent uncultivated areas. This organic enrichment was associated with anoxic sediment and bacterial mats of bacteria, *Beggiatoa* spp., which developed beneath the longlines. In this situation the benthic infauna had low diversity and biomass, which is a well-documented response to polluted sites.

There is an increasing body of literature discussing the impacts of mariculture on the ecosystem. At present the production levels in Northern Irish waters are relatively low and the examples are given to highlight some potential consequences if site selection is not controlled. Recent developments, such as DEPOMOD (a validated particle tracking and resuspension model, which can be used to predict the deposition of waste solids from fish farms and associated benthic effects) (Cromey, *pers.comm.*) may be useful for planning and monitoring at aquaculture sites. Such a model may help optimise location selection and carrying capacity at potential sites.

Figure 7.1
Dredging for seed mussels (Photo DARD, Fisheries).

1.3 Harvesting

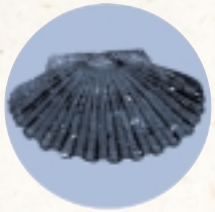
The final stage of cultivation involves harvesting, in many cases this will have minimal impact and involves emptying the bivalves from poches or lifting ropes. Where the species is cultivated within the sediment, or relaid on the seabed, harvesting involves the use of more intrusive techniques. Studies have shown that both dredgers (Figure 7.1) and suction devices cause disruption of the sediment and kill or directly remove non-target species. The time required for a community to recover will vary, depending on a number of factors, such as the cohesive properties of the sediment and the aspect of the site and the longevity of the non-target fauna. The effects of harvesting have been reviewed in detail by Kelso and Service (2000) and are not discussed here.

2 Ecosystem impacts of shellfish cultivation

Many of the areas suited to shellfish aquaculture are surrounded by large intertidal areas, which provide habitats for a number of bird, fish, invertebrate and algal species. The intertidal flora and fauna are often protected under EU legislation (Chapter 2) and this will affect proposals for aquaculture in the area. The ecological impacts discussed in two categories; subtidal and intertidal aquaculture.

2.1 Subtidal Aquaculture

Firstly, looking at subtidal aquaculture, impact may be observed at three levels, the benthic level, the pelagic or water column and the ecosystem level.



2.1.1 Impact on the benthos

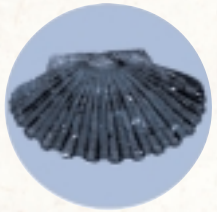
Mussels initially destabilise sediments by decreasing the critical bed shear stress. Sediment erosion therefore occurs at lower current velocities. Animals cause local scour around their shells. This is shown by the small horseshoe shaped grooves which occur at velocities greater then critical erosion velocity. Mussels increase the bed roughness of sediments and this in turn lowers the critical erosion velocity of the sediment (Shand, 1987). Shand (1987) observed that mussels under laboratory conditions destabilised the sediment, whereas in the field, areas of *M. edulis* beds appeared to stabilise sediments by protecting the underlying sediment and increasing the boundary layer. The apparent contradiction between laboratory and field observations is explained by differences in density, where dense mussel beds protect the sediment. Sediment scour would still occur around the edges of such beds but the area beneath the animals will be protected as long as the bed remains intact. The dense network of threads attached to stones and to other animals will further protect the sediment.
A significant impact on the sediment stability and the benthic community will be observed when large numbers of mussels are relaid in an area; the process of harvesting will therefore impact the whole sediment community causing a further shift in ecosystem equilibrium. The idea of rotational seeding and harvesting on different areas of a licensed site may offset any detrimental effect of harvesting.

Another problem with both suspended and bottom culture is organic enrichment beneath the shellfish culture. Problems from organic enrichment of the benthos has already resulted in reduced production in shallow embayments in Japan (Arakawa *et al.*, 1971 cited in Rosenthal *et al.*, 1988). The actual impact of increased organic deposition on the seabed will depend on the tidal and current conditions, although there is some controversy as to the extent of this impact (Chamberlain, *pers.comm.*). Bivalve bio-deposits have a higher nutritive potential to browsing organisms, modify the physical and chemical characteristic's of the sediment, allow the establishment of diverse benthic groups, and provide a substrate for bacterial development.

2.1.2 Impact on the water column

There will also be an impact on the water column (pelagic ecosystem) as the increased number of filter-feeders will control the phytoplankton (Cloern, 1982) and filter out seston (Asmus and Asmus, 1993). Some studies have suggested that large beds of filter-feeders may control eutrophication (Officer *et al.*, 1982). Large-scale cultivation of bivalves will consume large quantities of phytoplankton. Laboratory studies indicate that the reduction in phytoplankton can be sufficient to cause a reduction in growth of bivalves downstream (Wildish and Kristmanson, 1984). The historic records from the Bay of Marennes-Oléron in France, illustrate that the growth rate of oysters is related to the population density (Héral, 1986 cited in Rosenthal *et al.*, 1988).

Bivalves may also transform nutrients by changing their chemical complexity and by changing the particle size distribution in the water column (Dame, 1996). Also, particulate organic matter is consumed and dissolved inorganic materials released as a part of bivalve metabolic processes. In addition some bivalves may filter different portions of the suspended particulate



size spectrum and this may also change material surface area-to-volume relationships. Finally, small particles in the water column are aggregated into the bodies of benthic bivalves and the relatively large size particles of their faeces and pseudofaeces.

2.13 Impact on the ecosystem

For the purpose of this report, Odum's (1983) definition for ecosystems has been adopted: an ecosystem is any unit that includes all organisms that function together in a given area interacting with the physical environment so that the flow of energy leads to clearly defined biotic structure and cycling of materials between living and non-living parts (Odum, 1983).

Changes in the benthic and pelagic systems, as discussed above, will have a direct effect on bentho-pelagic coupling and the interactions occurring at the benthic boundary layer. With the uptake of particulate organic matter and release of dissolved inorganic nutrients by bivalve beds. This may result in eutrophication control as well as promotion of primary production (Smaal and Prins, 1993).

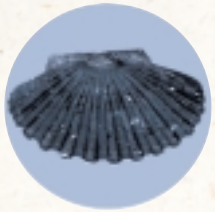
Smaal and Prins (1993) suggest that the impact of bivalve filter feeders extends to various scales. They assume complete mixing and the impact varies depending on total volume and residence time of the water mass. These scales are the scale of the bivalve bed, the scale of the defined estuary or bay, and at the scale of the land-ocean interface. In those systems with low bivalve biomass-to-water volume ratios, for example, Killary Harbour, the residence time of the water mass is less than that of the potential clearance time, and thus bivalve influences are probably limited to the level of the bed or community (Dame, 1993). Systems with higher bivalve biomass to water volume ratios cleared larger volumes of water in less time than the water mass turned over (Smaal and Prins, 1993). In these systems, for example, Marennes Oléron, bivalve control of phytoplankton biomass was much more likely at the level of the bay or estuary when dry body bivalve biomass was in the range of 2 to 8gm^{-3}, water mass residence times were long (sometimes called slow systems), and filtration pressure was high. Filtration pressure (F/P) is the ratio of average system phytoplankton primary production (P) to average system filtration (F) or uptake of phytoplankton by bivalves. Filtration pressure represents the proportion of phytoplankton primary production that is harvested by bivalves in a given system (Dame, 1996). Phytoplankton biomass in short residence time systems (fast systems) could still be controlled by bivalves if their biomass: volume ratio is high, >8gm^{-3}.

2.2 Intertidal Aquaculture

For intertidal aquaculture, impacts derive mainly from the requirement to place structures on the shore to contain the shellfish, and from people working on the shore to tend the farm and in some cases there may be problems with vehicular access to a site. Impacts are observed at many levels, a brief discussion of some relevant issues follows.

2.2.1 Birds

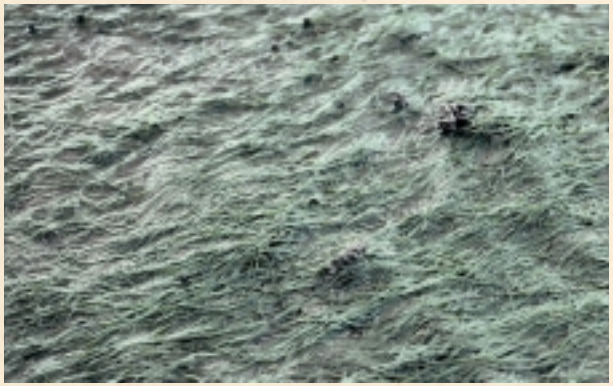
Risks to bird communities from onshore developments can be considered in two categories, loss of habitat and disturbance. Bird disturbance would be one of the principal impacts, affecting feeding times and in some cases roosting. A number of studies have illustrated that birds become habituated to certain "types of disturbance ", including machinery and people bait collecting or hand-picking shellfish (Ross and Furness, 2000). Effects on



birds are varied. A simulation model tested on the Exe estuary has been developed to explore the consequences of changes in fishing activities and bird numbers on commercial shellfish stocks and on the birds themselves (Stillman *et al.*, 1996).

At the whole lough level, there are a variety of impacts from aquaculture. In Scotland the increase in rope culture of mussels has attracted increased numbers of Eider and Goldeneye. These ducks have adapted their feeding habits to strip the thin- shelled, high meat, non-gritty mussels from the lines and have caused considerable losses in certain areas (Ross and Furness, 2000). The increase in Eider and other duck populations around bivalve cultures has an obvious disadvantage to the shellfish grower, it also illustrates an ecosystem imbalance. Overall deterring the build-up of duck populations is the best solution. At present Eider ducks are not perceived as a problem in Northern Ireland, however there is evidence to suggest an increase in Eider duck numbers over the last couple of years (Thompson, *pers.comm.*).

Figure 7.2
Zostera beds (Photo, Julia Nunn).

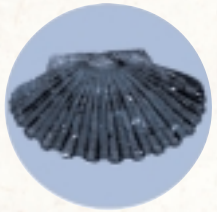


2.2.2 Plants

Seagrasses often grow in dense extensive beds or meadows, creating a diverse habitat that provides shelter for a wide variety of other plant and animal species. Seagrass beds constitute an important reservoir of coastal biodiversity. In addition the beds provide food for wildfowl and for the juveniles of some commercially important fish and crustacean species. *Zostera* beds are very productive and are a major source of organic matter in the coastal ecosystem (Figure 7.2). The dense root networks of the plants stabilise the underlying substratum and act to reduce coastal erosion (Davison and Hughes, 1998). Three species of eelgrass of the genus *Zostera*, were once common around British coasts, however their abundance was severely reduced during the 1920 – 1930 period by a wasting disease and recovery of these beds has been slow and all three species are now considered nationally scarce in the UK (Portig, 1997, Davison and Hughes, 1998). Wildfowl (ducks and geese) are among the few animals which graze directly upon *Zostera* and are able to digest its leaves. In Britain, *Zostera* is an important constituent of the diet of two sub-species of Brent geese (*Branta bernicla*), wigeon (*Anas penelope*), mute swans (*Cygnus olor*) and whooper swans (*C. cygnus*). Teal *(Anas crecca*) are reported to consume eelgrass seeds (Tubbs and Tubbs, 1983). *Zostera* is found in five out of the seven Annex I habitats defined in the habitats Directive, and 10 of the demonstration SAC's considered by the UK Marine SAC's Project. These plants flourish in accessible nearshore margins, and are therefore susceptible to many forms of coastal development, including aquaculture. At present there is no conflict between licensed aquaculture sites and *Zostera* beds and with correct management there should be no future discrepancy.

2.2.3 Fish

Intertidal areas are well-defined as juvenile fish feeding areas (Costa and Elliott, 1991 cited in Elliott *et al.*, 1998). Mud and sandflats are important nursery areas for plaice (Elliott *et al.*, 1998) as well as feeding areas for other fish. These points must be considered when planning new or expanding existing aquaculture sites.



2.2.4 Human Use

Human use can be divided into several categories including: recreational and commercial boat use; leisure (amenity), i.e. dog walking, bird watching; whelk and winkle harvesting; bait collecting and impacts on any structure of archaeological importance. The impact of such activity range from direct i.e. removal of target-species and effects on sediment community, to indirect impacts which are very subjective by nature i.e. disturbance caused while carrying out an activity.

2.2.4 Navigational consideration

Shellfish farms utilising submerged solid structures such as oyster trestles must be clearly marked. The Maritime and Coastguard Agency must give specific approval to each application and appropriate users informed.

2.2.5 Visual Impact

Visual impact on the environment is a major concern when sighting fish or shellfish farms in rural areas. The low height and dark colour of oyster trestles makes them blend into the shoreline when not covered by the tide. This makes oyster farming one of the least visually intrusive forms of mariculture. There is a belief that the public in general may prefer to see that an area can be productive and that as long as there is not excessive use of fluorescent markers and buoys some evidence of activity is acceptable.

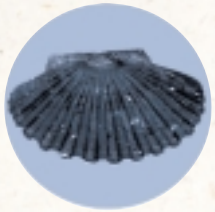
3. Discussion

3.1 Impact Assessment

This overview of bivalve aquaculture impact shows the potential effects on the ecosystem, however it must be stressed that such effects vary significantly due to the type, location and size of culture operation. Monitoring the key ecological parameters is an important part of managing the environmental impact of an aquaculture operation. If the results of monitoring indicate that the degree of ecological change is greater than that predicted, it may be necessary to modify the operation to reduce the impact. Data from monitoring may be valuable in good husbandry and in research. There is controversy regarding which key parameters should be monitored to assess a given impact and frequently statutory monitoring is not sufficient.

Environmental Quality Standards (EQS) have been derived which relate to changes in the benthos at UK sewage-sludge disposal sites. Adopting a similar approach to the sampling carried out in compliance with that for EQS would be useful in monitoring effects of shellfish farms. Monitoring involves comparisons between "treatment" and "reference" sites and is summarised below. EQS1 is monitoring for acceptability of change within the sphere of influence, looking at "ecosystem maintenance". EQS2 involves monitoring for compliance with the status quo outside the sphere of influence, namely the "preservation of the environment". Acceptability of change at the sites are quantified, for example, Garroch Head data, 1983 values suggest the faunal variability in an area resulted in species numbers increasing by 50%, abundance's by 200% and biomass by 50% which would represent an unacceptable level of change (MAFF, 1993). When we compare such values with the potential impact of handraking for cockles (50% change) with a recoverability of six months; we see the minimal impact of aquaculture.

Another tool applicable to assessment of aquaculture development is the Environmental Risk Assessment package produced by ABP Research. The Conservation (Natural Habitats & c.) Regulations 1994, define a process which has to be followed when seeking planning permission for developments which are likely to significantly affect a



Special Protection Area (SPA) or a Special Area of Conservation (SAC). Figure 7.3 shows the procedure for the consideration of development proposals affecting SPAs and SACs as described in the Government's Policy Planning Guidance Note 9: Nature Conservation. In this process the decision-maker or assessor (relevant authority) and the developer had to make judgements and decisions that were frequently open to debate. Problems arose with this process due to lack of disclosure of this decision-making process and the associated scope for disagreement between interested bodies. In response ABP research & Consultancy Ltd have developed the Environmental Risk Assessment (ERA) package which formalises the approach to assessing and documenting the likely significant effects of proposed developments with the aim of introducing greater clarity and consistency into the decision-making processes (ABP, 1997).

The ERA package provides a framework for the assessment of the consequences of environmental impacts of proposed development projects in or adjacent to European sites (SPAs/SACs). The process of assessing proposed developments requires judgements to be made on the basis of knowledge and experience on a case-by-case basis. The aim of the ERA is to formalise and document this process, quantifying the impacts as much as possible to provide a

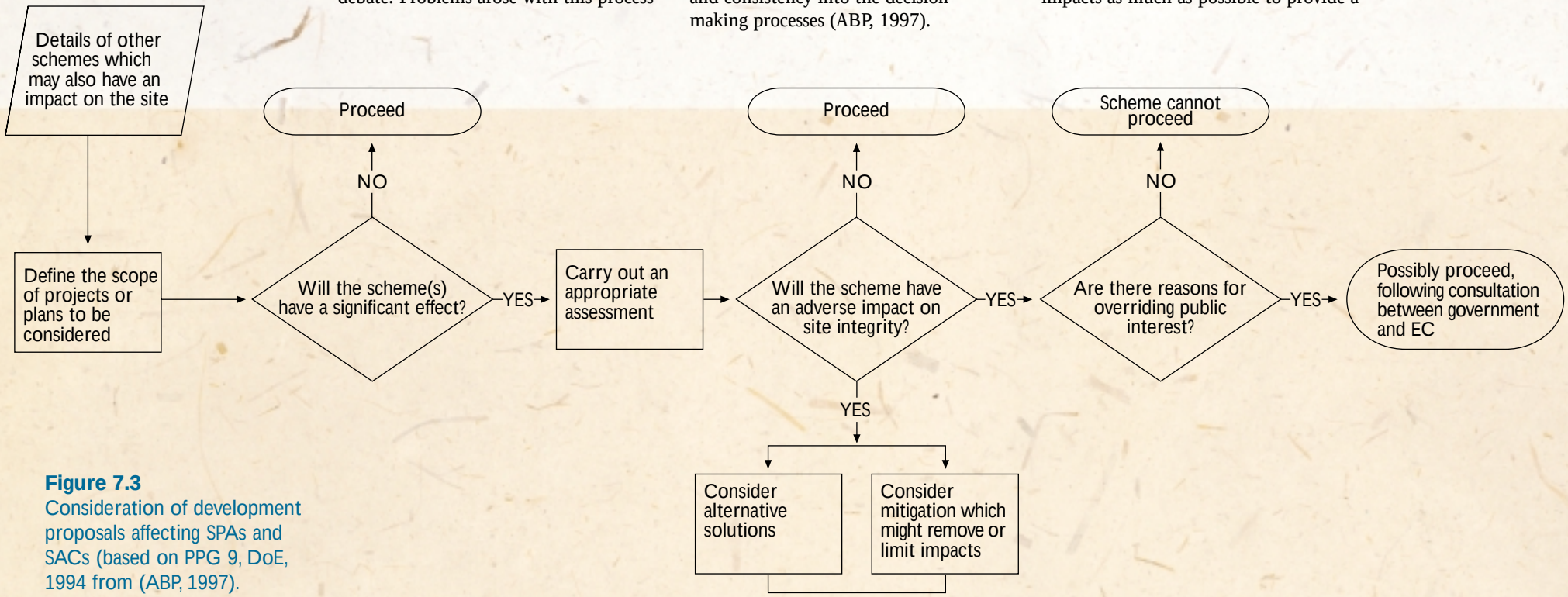
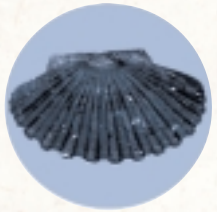


Figure 7.3
Consideration of development proposals affecting SPAs and SACs (based on PPG 9, DoE, 1994 from (ABP, 1997).



basis on which any decision-making and judgements can be made in determining whether a project or plan is likely to have a significant effect and/or will adversely affect the integrity of the site.

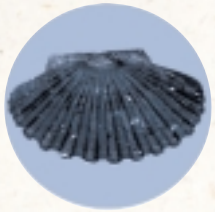
The eight step approach of the ERA was based on the principles and text of the DoE publication "A Guide To Risk Assessment and Risk Management for Environmental Protection". The steps are as follows: 1. Description of Project or Plan: 2. Identification of possible impacts: 3. Identification of consequences: 4. Estimation of magnitude of consequences: 5. Estimation of the probability of consequences: 6. Relevance of consequences: 7. Assessment of risk: 8. Overall Assessment .

The ERA package is capable of handling a wide range of projects and would be a valuable tool in site assessment for new aquaculture leases. The package allows a project assessment to be reviewed by all relevant or interested parties, who can make their own assessment of the likely impacts and consequences of the proposed development. Assessments can easily be compared and attention can be focused on those areas where there is some degree of disagreement on potential effects. Also the compilation of project assessments in a database facilitates the requirement to consider cumulative effects of a number of proposed developments on a SPA or SAC.

Another significant development is the Marine Life Information Network for Britain and Ireland (MarLIN). This initiative provides a structure for linking available data on marine life around Britain and Ireland. MarLIN has a core network team and three sub-programs, one of which covers the assessment of habitat, community and species "sensitivity". The Biology and Sensitivity Key Information Sub-program aims to: "Identify key information on the biology and sensitivity of seabed habitats, biotopes and species that can be applied in a practical way to environmental protection and management (Hiscock *et al.*, 1999). A variety of indices for assessing sensitivity and recoverability of marine species and biotopes exist and the relevance of integrating such indices in aquaculture site assessment may provide another method of accountability.

3.1 Methods of reducing the environmental impact of aquaculture

The main method for reduction of the impact from extensive aquaculture operations is by matching the aquaculture operation to the location in which it is sited. The movement or rotation of shellfish trestles and longlines to allow the benthos to recover has been suggested as a method for reducing environmental impact. However, this may only disperse the impact over a larger area (Gowen *et al.*, 1990) and requires further research. Other methods include reducing potential for sediment accumulation by careful placement of trestles to minimise their effect on tidal flows, careful management of the farm and good husbandry is also important. To reduce the impact of farmed versus native species, there must be limitation on the farm size, fallow areas between farmed sites also reduce impacts. Access to sites, particularly intertidal areas should be controlled and the impact of vehicles on the shore may be reduced by slow speeds, careful driving and keeping to pre-defined tracks that avoid soft or vulnerable areas.



3.2 Management considerations

Harvesting mussel seed mechanically is managed by issuing licenses to dredge defined areas, to constrain any habitat modification. This will prevent the overexploitation of seedbeds and decrease the likelihood of any knock-on-effects such as those observed in the Netherlands (Kaiser *et al.*, 1998). Section 14 Permits (Chapter 2) do not allow dredging of seed mussels within a SPA/SAC and therefore this should not become a major problem in Northern Ireland. Relaying of cultch should be constrained to certain areas, as it can lead to habitat modification. The effects during on-growing will vary according to the nature of the habitat and the extent of cultivation. Areas of intense aquaculture or where expansion is probable may require the development of energetic models to help manage the ecosystems. The impact of disturbance during practices related to intertidal cultivation are variable, a predictive model has been developed to explore the effect of different shellfishery management options on the mortality rates of migratory birds. This model has been tested on the Exe estuary and there is potential to develop it for the estuaries in Northern Ireland.

3.3 Beneficial effects of Mariculture

It is important to remember that there are also positive aspects to coastal shellfish cultivation such as the provision of hard substrata and shelter in otherwise barren sites and the possibilities of using the cultured organisms as environmental sentinels.

The use of bivalve beds in the control of eutrophication may be beneficial in areas where intensive fish farming could have undesirable effects. It has been proposed that integrated fish/bivalve mariculture systems can ameliorate the effect of organic enrichment, as the bivalves reduce algal densities and nutrients, which are effectively removed when the bivalve product is harvested. The idea of mixed sea urchin and salmon culture will have a similar effect. Another benefit is the use of vast areas that are not particularly suited for other activities.

4 Conclusions

In general, bivalve culture was viewed as extensive aquaculture, however recent findings suggest that where bivalve culture is very "intensive" the potential impact may be greater. In the present Northern Ireland situation, impacts from aquaculture are small-scale and localised by comparison with large-scale dredge operations. For example the removal of approximately 3.75 million tonnes of dredge spoil from the Victoria Channel in Belfast Lough will have a significant impact in comparison to the small-scale dredging required to harvest bottom-cultured mussel beds.

Chapter Eight

Carrying capacity

Introduction

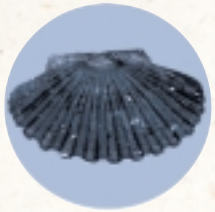
The cultivation of marine bivalves occurs throughout the world and the industry has expanded over the last decade. Acceptable culture sites are limited due to habitat suitability, access and competing recreational or commercial use such as wild fisheries. As available space becomes filled up with stock, there may be a depression of individual bivalve growth rate and an increase in mortality caused by a variety of factors associated with overcrowding. Filter-feeders have a huge capacity to filter the water column, such that they are food limited at high culture density in certain areas (Navarro *et al.* 1991 cited in Grant *et al.*, 1993). Research has also demonstrated major site differences in growth rate confirming that environmental conditions can regulate shellfish production. High culture biomass may produce a negative feedback to the local environment through organic loading and anaerobic conditions beneath culture leases, which may lead to degradation of culture environments (Chapter 7).

A means to predict the ability of coastal environments to sustain bivalve culture is required for successful development of the industry; one method to assess the impact is to look at the carrying capacity of an area. The concept of carrying capacity of an ecosystem for natural populations is derived from the logistic growth curve in population ecology, and defined as the maximum standing stock that can be supported by a given ecosystem for a given time. This definition needs to be modified for the exploitation of ecosystems; carrying capacity for exploitation is defined as the standing stock at which the annual production of a marketable cohort is maximized. For bivalve suspension feeders, the dominant factor determining the exploitation carrying capacity at the ecosystem scale is primary production. At a local scale carrying capacity depends on physical constraints such as substrate, shelter and food supply by tidal currents (Dame, 1996).

It is important to assess the carrying capacity of an area prior to the establishment of large-scale shellfish cultivation, to ensure an adequate supply of phytoplankton for the anticipated production and to avoid or minimise the ecological impacts described in Chapter 7. Where historic records show that over-stocking can result in reduced production, the records can be used to regulate stock size in order to maximise production. In areas where no records exist it is necessary to measure the amount of particulate material which is potentially available and relate this to the amount required per unit biomass of shellfish.

Grazing is a system level process that directly connects the herbivores (bivalves), to the food source or primary producers. This process directly reduces the standing crop of primary producers through consumption and results in nutrition to the bivalves, while changing the community and population structure of the algae. Grazing control on the primary producers is often depicted as a top-down process generated by herbivores higher up the food chain. In contrast, nutrient or resource enrichment or limitation and competition are termed bottom-up control on phytoplankton. Both bottom-up and top-down controls probably take place at the same time (Dame, 1996).

The approaches to investigating the question of carrying capacity may be characterised into three categories: empirical studies, calculation of budgets and simulation modelling. All cases involve determination of bivalve growth based on at least food and temperature, the two most important factors, which regulate growth in both cultured and natural populations. (Bayne and Hawkins, 1992).

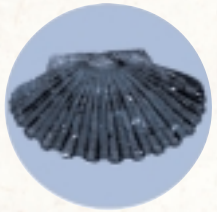


Empirical studies are largely based on correlations between bivalve growth and single or multiple environmental factors. There are numerous examples of this approach in the literature identifying the environmental variables important in bivalve growth (Grant *et al.*, 1993). Such findings verify that the prediction of bivalve growth as a function of the environment is feasible, and that more complex models are worthwhile. An extension of this approach involves habitat suitability indices, where environmental factors known to be important in bivalve habitats are scored between 0 and 1 and used to produce a composite value that then comprises the index. This index is then verified against field growth trials and population surveys (Brown and Hartwick, 1988). Although this is an effective approach in terms of habitat suitability and aquaculture site selection, it is only a "snap-shot" and does not allow temporal resolution of growth or calculation of carrying capacity.

A second way to estimate the capacity of the environment to support aquaculture production is through a partial ecosystem budget (Rodhouse and Roden, 1987; Smaal, 1991). Phytoplankton standing stock or production may be compared to ingestion requirements of bivalve populations over daily, seasonal or other time scales to determine the biomass of shellfish that can be sustained in a given system. For example, Carver and Mallet (1990) assess blue mussel (*Mytilus edulis*) carbon requirements based on an energy budget, in relation to tidal fluxes of food in a small Nova Scotia embayment (Carver and Mallet, 1990). There are also more complex ecosystem budgets which consider a variety of components such as benthos, zooplankton, detritus, etc (Rodhouse and Roden, 1987). These types of calculations are partially the basis for the notion that bivalve populations or communities have the ability to impact or even deplete the water column of seston by filter feeding. The disadvantage to a budgeting approach is it uses an averaged and long-term time-scale (annual), and cannot incorporate feedback from the ecosystem (Smaal, 1991).

The third approach, is the use of simulation models in which the culture system is viewed as distinct compartments or state variables (e.g. shellfish, phytoplankton). Flows of energy or material between compartments are quantified based on internal biological fluxes (e.g. ingestion) mediated by external forcing functions (e.g. temperature). The model can be represented by a set of differential equations, which correspond, to a theoretical perception of which factors are important in bivalve growth, including parameterisation of exchange processes (Figure 8.2). Concurrent field studies are used to verify the importance of these factors. There are numerous examples of simulation models in marine ecology in various forms of box-modelling or network analysis (citations in Grant *et al.*, 1993).

The prediction of growth and carrying capacity of cultured bivalve populations is important to the continued development of the shellfish industry. Equally important is sustainability of the ecosystem, using the monitoring protocols and Environmental Risk Assessment packages described in Chapter 7. In this chapter we estimate carrying capacity using the ideas of Carver and Mallet (1990) and present a conceptual perspective of growth in relation to environmental factors of a generic bivalve.



1 Carbon Budgets

Carver and Mallet (1990) assessed carbon requirements based on an energy budget, in relation to tidal fluxes of food in a small Nova Scotia Bay. In the present study we have applied their ideas to provide preliminary estimates of carrying capacity for Belfast Lough. The food supply to the system was determined from measurements of tidal exchange and particulate organic matter over the period of 1992 to 1996. The food demand or the mussels ration was obtained from the literature. Filtration rates will vary from one area to another, they also vary with changing conditions at a site, temperature and amount of food available will also have an effect. In the absence of extensive field studies at each site we have chosen a default value for filtration rate of 1.7 l / h / mussel or per unit shellfish (Karayücel and Karayücel, 1998). Estimates of the mussels' daily ration were required (11 to 41 mg POM / mussel per day). Food supply (g POM / week) was divided by food demand (g POM / kg mussels week) to obtain weekly estimates of carrying capacity for the system.

Table 8.1
Characteristics of the boxes used in the model (Charlesworth and Service, 1999).

	Volume ($106m^3$)	Mean Depth (m)	Sampling Stations	Nutrient Inputs
Tidal Lagan	1.2	2.9	T.L. 1,8	R.Lagan Blackstaff R.
Harbour	18.9	9.4	1,2,3,4	Connswater R. Industry
Inner Lough	90.5	3.7	5,6,7,8,9,10,11,12	Duncrue Kinnegar Newtownabbey
Mid Lough	269.2	7.4	13, 14, 15,16	Carrickfergus
Outer Lough	818.5	13.5	17,18,19,20,21,22	

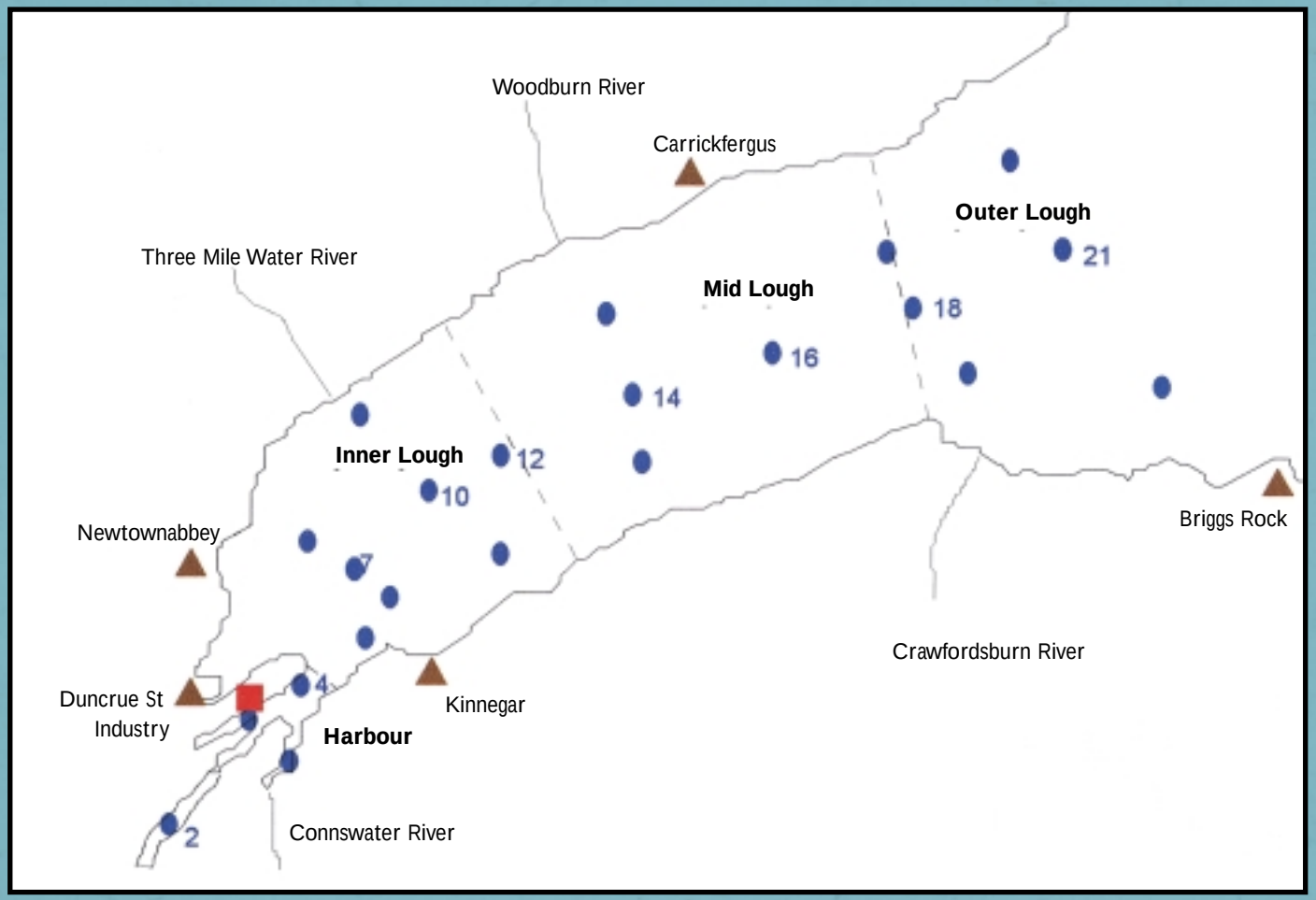
Location - Belfast Lough

The study area (Figure 8.1), is a shallow semi-enclosed marine bay located on the eastern coast of Northern Ireland (54˚40 N, 5˚52 W). The lough is connected to the Irish Sea at the mouth. The principal watercourse is the River Lagan, which enters at Stranmillis, the recently constructed Lagan Weir reduces most of the freshwater influence on the Harbour. There are two major sewage treatment works (STWs) and one main industrial input. At the time of the study there were three large licensed aquaculture sites in production for bottom cultured mussels with an expected harvest of approximately 8 -10,000 tonnes.

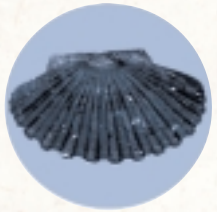
Tidal exchange

To estimate the volume of the Basin, the lough was partitioned into four boxes defined by natural geometry, and mixing of the system (Tidal Lagan, Harbour, Inner Lough, Mid Lough) (Figure 8.1). All geomorphological characteristics are based according to water height at Ordinance Datum and are shown in Table 8.1. The surface area of each zone was then determined and multiplied by its average depth to give an approximate volume. The three estimates were summed to give the volume of the basin.

Figure 8.1
Belfast Lough and Harbour. Stations are for 95-96 B.L. Survey.



Volumes	**(Million cubic metres)**
Tidal Lagan	1.2
Harbour	18.9
Inner Lough	90.5
Mid Lough	269
Outer Lough	818



The hydrodynamic model produced by Charlesworth and Service (1999) provided values for tidal prism and from this we calculated the volume of water flowing in and out of the system on each tidal cycle (Dyer, 1973). Water exchange (%) was calculated as the outflow volume divided by the volume of water in the Basin at high tide.

Sampling program

The data for the hydrodynamic model was compiled from bi-weekly samples collected at the 22 sampling sites shown on Figure 8.1.

Temperature and salinity measures were recorded and samples for suspended particulate matter and chlorophyll "a" were obtained from each site.

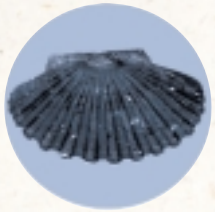
Water samples were filtered. Chlorophyll "a" samples were extracted and measured using the Standard Operating Protocol (SOP), BO 2122. The samples for particulates were dried for 2 days and weighed to obtain values for TPM (total particulate matter), and then combusted at 500˚C for 2 hours, and re-weighed to estimate PIM (particulate inorganic matter) and POM (particulate organic matter) following the SOP, BO 2124.

Carrying Capacity

Multiplying the weekly tidal volume by the appropriate POM concentration gave estimates of food supply. Inner Belfast Lough is a highly productive area and water entering the Lough on each tide will dilute these highly productive waters. Estimates of food supply in each box take account of the dilution by incoming seawater. A simplistic first level model is already available, using the hydrodynamic models developed by Charlesworth and Service (1999) and adding in a "loss factor" for bivalve filter feeding. A more advanced model would focus on the data required to fill the following spreadsheet extracted from the study by Carver and Mallet (1990) (Table 8.2). Although the data is available for many areas, there are still gaps in data sets that would require further work. The basis for these models exists and it is a strong recommendation of the report that more work be carried out to complete the model component.

Table 8.2
Example of weekly estimates of tidal volume, POM supply, POM demand and carrying capacity for the month of July 1986 (data extracted from (Carver and Mallet, 1990)) relating to a bay in Nova Scotia.

Date 1986	Tidal volume (m^3x10^6/ week)	POM Level (mg/1)	Food Supply (g POM x 10^6/week)	Filtration Rate (l /h)	Food ration Mussel (mg POM / week)	Food demand per kg mussels (g POM / week)	Carrying Capacity (kg mussel x 10^5)
04.07	6.92	0.68	4.70	1.33	21.7	12.2	3.9
11.07	7.50	0.62	4.65	1.50	22.3	12.5	3.7
18.07	9.59	0.56	5.37	1.60	21.5	12.0	4.5
25.07	6.41	0.51	3.27	1.71	20.9	11.7	2.8



The Conceptual Model

Models are simplified versions of the real world. In science informal models may be graphical as in a diagram or picture, or verbal as in a description of a process or cycle. These types of model present a concept in its most basic form. Many informal ecological models are transformed into formal models with statistical or mathematical representations that allow quantitative predictions of the processes and states within the model system. These models formally relate ecological interactions, both biological and physical through specific mathematical relationships.

Background

The development of models begins with the construction of a conceptual diagram, flow chart or box model. At this level of development there are four basic components of the model (Figure 8.2).

1. *Forcing functions* or properties outside the system of note that drive, regulate or control the system.

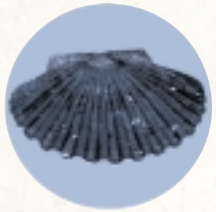
2. *State variables* or components that describe what we see in the model, i.e. populations, trophic levels etc.

3. *Flows of materials* or energy between the various components often depicted as arrows.

4. *Interaction functions* that formalise how interaction modify, amplify, or control flows (Odum, 1983).

Good models describe the space or boundaries of the system, the important subsystems in the larger system, and the time interval of the model. Once a simulation model is built, it must be validated by comparing the model outcomes to independent observations of the real system (Dame, 1996).
A number of models have been examined during the literature review and a combination of approaches would be suggested for future model development. The conceptual model illustrated here forms the basis for a simulation model that would be feasible if more time were available. It would encompass three sub-models: physical, phytoplankton and bivalve sub-models.

At present AESD have developed physical models for four of the sea-loughs. These allow evaluation of the exchange and transport coefficients for particles (food) at the aquaculture sites. Nutrient, chlorophyll "a" and suspended solids data have been collected for a number of locations over a long time scale. This would provide some baseline data before the introduction of the large-scale aquaculture operation. On going monitoring in certain areas would provide evidence for any changes since the introduction of commercially cultured bivalves. Default values collected from the literature would permit the running of a simulation model suitable for prediction of change due to expansion of aquaculture. Commercially available ecosystem model packages have also been investigated (e.g. ECOPATH). Such packages were not produced specifically for aquaculture however they provide an excellent framework to experiment with the data from Northern Irish estuarine systems.



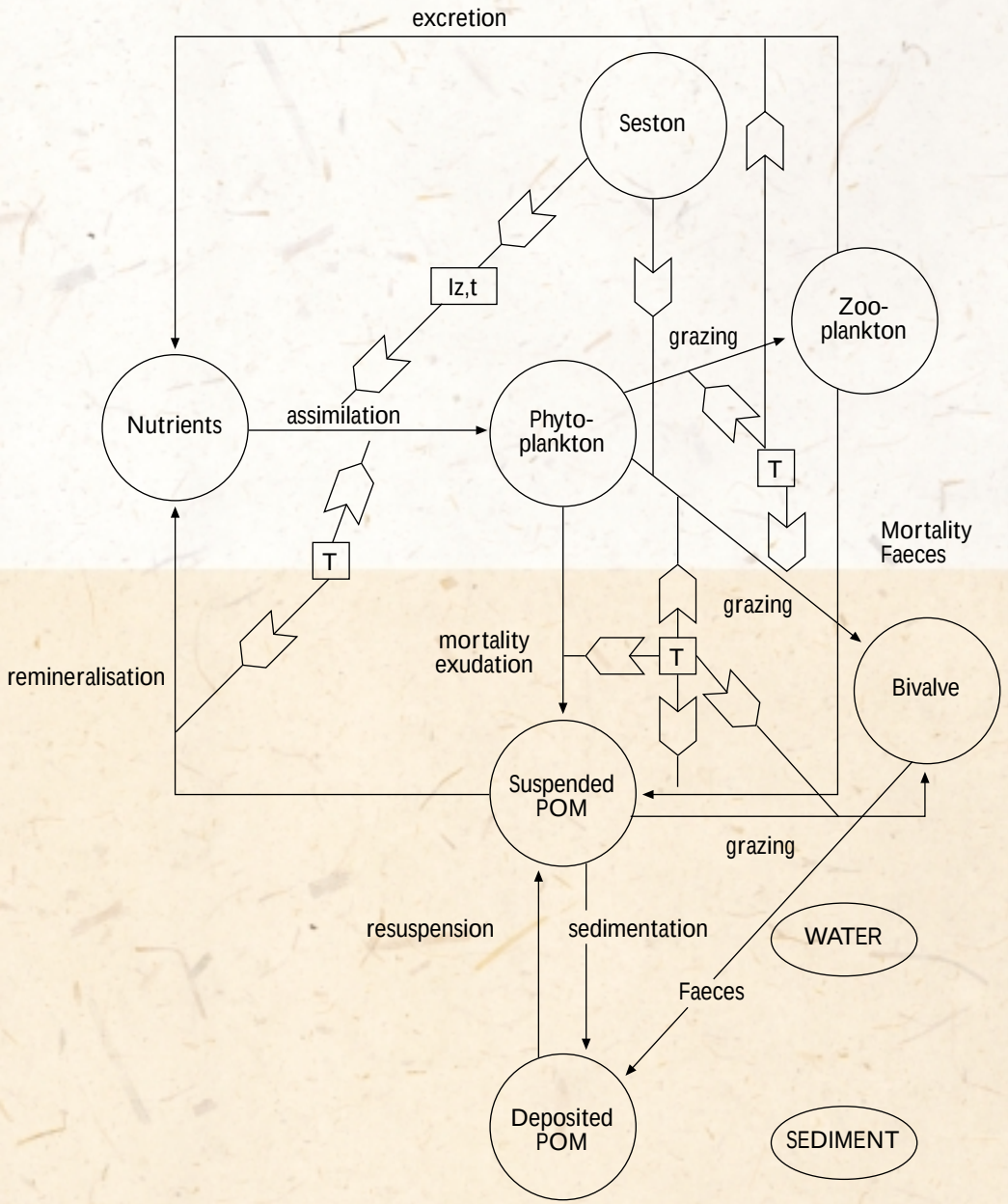


Figure 8.2
Process diagram for the conceptual model.
Iz,t: light at depth z and time t;
T: temperature;
POM: particulate organic matter
(after Raillard and Ménesguen 1994)

Chapter Nine

Gaps in Knowledge

Introduction

This chapter has been divided into two themes, firstly, highlighting future work through a series of recommendations. Secondly, looking at the research required to fill gaps in existing knowledge and facilitate the smooth implementation of the shellfish management plan in Northern Ireland.

Strategic Recommendations

SR1

Future development of strategy should involve an industry representative body. An Aquaculture Producer's Representative Body would allow a unified approach to government. To address issues to enable the systematic development of a sustainable industry.

SR2

The risk assessment presently carried out by DARD Fisheries Division should be developed using a recognised Environmental Risk Assessment package, such as the ABP package (Chapter 7).

SR3

DARD Fishery Division should have shared input and access to the coastal GIS (Geographical Information System) system presently under development in AESD.

SR4

Aspire to have all shellfish waters classified under the Shellfish Waters Directive.

SR5

Sampling procedure requires a comprehensive review. An enhanced monitoring protocol is required, with sampling from statutory sites and routine determination of key environmental parameters.

SR6

Publication of verified results from sampling programme and dissemination of results to industry and interested parties.

SR7

Assess the potential for shellfish hatchery based in Northern Ireland.

SR8

Assess the potential for the introduction of novel species in recirculation systems.

SR9

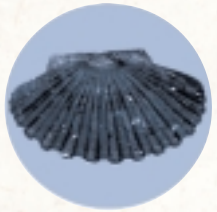
Complete work on a working carrying capacity model.

SR10

Code of good practice developed by Shellfish Producers promoting good husbandry: set down guidelines for husbandry techniques to be carried out in best possible manner, emphasising the need to operate in harmony with the environment and other activities. This process would require support from the environmental organisations.

Future Research Objectives

There are many areas linked to bivalve culture where further research would be beneficial, from investigating gaps in biological knowledge (e.g. *Ensis* reproduction) to collation of field data to validate carrying capacity models. All of the gaps in knowledge highlighted throughout this report require further research. The lack of data requires comprehensive field and laboratory work, or collaboration with other laboratories where model development is ongoing. Links have been forged,



however the time-scale of the present project did not permit full appreciation of such collaborative effort. The prominent areas requiring research are discussed in the subsequent paragraphs.

The relationship between the environmental levels of coliforms and the values detected in shellfish tissues requires more detailed study. A revised effort should be concerted to investigate virus and other contaminants in shellfish tissue.

The instigation of a sampling programme to collect the data required for validation of a carrying capacity model. Monitoring predator numbers at standard stations would be important for the development of the industry in the different areas. Laboratory and field based studies are needed to examine predator control methods, with the aim to devise procedures that are ecosystem friendly. In accordance with SR5, the monitoring and sampling protocols for shellfish areas should be co-ordinated.

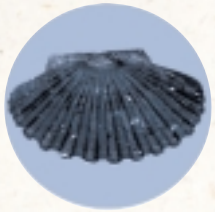
Similar principles are associated with the different areas where shellfish are grown; the main factors are availability of space and food. Where available space is determined by hydro- and geo-dynamic factors and food availability depends on primary production and transport processes. It is generally accepted that in many estuarine and coastal systems, physical factors constrain bivalve populations at a local scale, while primary production limits them at the ecosystem scale (Herman, 1993). It is apparent that such factors will vary significantly from one lough to another, therefore management must be viewed on a single-lough basis. This is reflected in the differences observed during the development of the hydrodynamic models for the different loughs (Charlesworth, *pers.comm.*). This illustrates the need to investigate the biology of these loughs on an individual basis, as the evaluation of each model sub-unit would rely on site-specific inputs.

Research into new cultivation techniques is required, to take shellfish farming offshore and assess the role of these techniques in the development of the industry.

Conclusions

In conclusion the development of the aquaculture industry in Northern Ireland requires the implementation of a management strategy. Such a strategy should encompass all the recommendations highlighted at the start of this chapter. An on-going research programme should be executed to build-up a database for the development of an ecophysiological carrying capacity model capable of predicting changes at the various aquaculture sites. Such a model would be an invaluable tool in maintaining a sustainable aquaculture industry. Coupling such a model with one looking at bird disturbance (e.g. the Stillman model) would further promote the eco-friendly image of the industry.

The aquaculture industry evolving at present in Northern Irish waters thrives on the innovation and persistence of the producers involved. The success of this developing industry relies on the ability of the growers to sustain what they have cultured with minimal negative impact on the ecosystem. Implementing the recommendations suggested in this report will help promote an improved industry for everyone involved.



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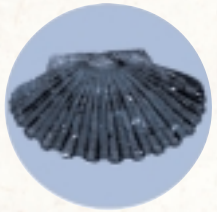

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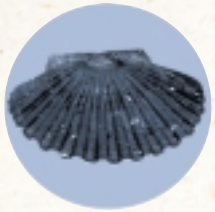

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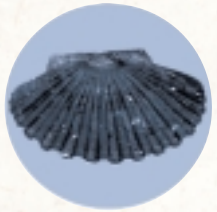

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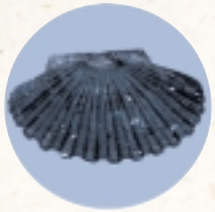

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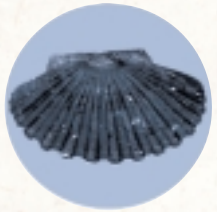

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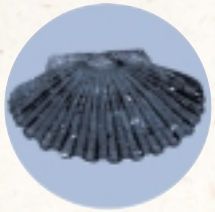

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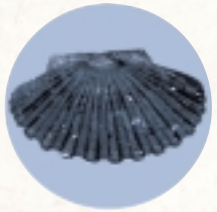

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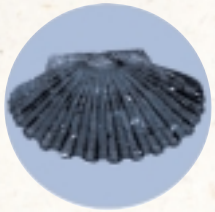

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Glossary

ASP Amnesic Shellfish Poisoning: A biotoxin produced by *Pseudo-nitzschia* spp. Once accumulated in the shellfish, causes in mild cases: nausea, vomiting, diarrhoea and abdominal cramps. In severe cases can cause decreased sensitivity to deep pain, dizziness, hallucinations, short-term memory loss and seizures.

Benthos or benthic organisms: The plant and animal life on the seabed.

Benthic zone: One of the two basic subdivisions of the marine biome; includes the sea floor and bottom-dwelling organisms.

Bentho-pelagic coupling: The system coupling productivity in the pelagic system to that in the benthic system.

Bloom: See phytoplankton

Conservative: Without losses or gains.

Diatoms: A single celled microscopic marine plant whose body wall is impregnated with silica.

Dinoflagellates: Flagellates of a specific group some of which are associated with the production of poisonous substances.

DSP or Diarrhetic shellfish poison: A harmful substance produced by specific members of the phytoplankton, which when accumulated by filter-feeding molluscs such as mussels and eaten by man can cause severe diarrhoea.

Ecosystem: An assemblage of different types of organisms that co-exist together with the physical and chemical components of their environment.

Euryhaline: Organisms have wide limits of salinity tolerance, usually because they can osmoregulate.

Eutrophication: The process of enrichment of seawater with nutrients, especially nitrogen and phosphorus, leading to increased production of phytoplankton. The meaning is sometimes extended to include enrichment by certain organic substances or even changes in species composition.

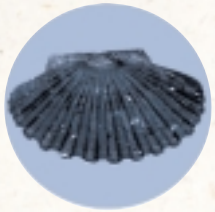
Heavy metals: A general term for those metals that are toxic when present in elevated concentrations. These include elements such as zinc, copper, cadmium, lead, nickel and mercury, all of which are commonly used in industry.

Neap tides: Small tides that occur when the attractive forces of the moon and sun are not acting together.

Nutrients: Elements, principally nitrogen and phosphorus, that are required for growth by phytoplankton. One group of phytoplankton, the diatoms also require silicon.

Phytoplankton: Marine plants (algae), usually of microscopic size, which drift with the surrounding water. Numbers and species composition vary with season, being more abundant during the warmer months. Where there are large numbers an "algal bloom" is said to occur. Requires the presence of nutrients, solar radiation and elevated water temperatures for rapid growth.

Pollution: The terms "pollution" and "contamination" are often confused. The term "pollution" is clearly defined in several of the international conventions, but in everyday language the term is used in another sense. The Paris Convention, for instance, defines pollution as the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as hazards to human health, harm to living resources and to marine ecosystems, damage to amenities



or interference with other legitimate user of the sea. On the other hand, "contamination" is caused by substances not normally present in the marine environment (or present in higher concentration than normal) that *do not apparently cause ill effects*. In popular usage, and in many languages other than English, this distinction does not exist, and pollution is often used to mean any abnormal concentration of a substance in the environment.

Primary productivity: The first stage in the production of organic matter in the sea, mainly as a result of phytoplankton growth. A measure of the fertility of a water mass, leading to secondary productivity, e.g. production of small herbivorous animals and ultimately the growth of larger organisms (fish, seabirds, mammals).

Pseudofaeces: Undigested particulate matter, filtered by the bivalves but ingested, ejected with exhalent current.

PSP Paralytic Shellfish Poisoning: A biotoxin produced by certain members of the phytoplankton. PSP can accumulate in shellfish and cause headaches and numbness in mild cases when consumed by man. In severe cases it may lead to muscular paralysis, respiratory difficulties and death can occur 2-24 hours after ingestion.

Salinity: Can be used as an index of mixing between fresh water (salinity 0) and seawater (salinity 35). For example, a mixture of equal volumes of fresh and seawater would have a salinity of 17.5.

Spring tides: Large tides occurring when the attractive forces of the moon and the sun are working together.

Stenohaline: These organisms have narrow limits of tolerance and little or no ability to osmoregulate.

Suspended solids: Fine particulate solid matter, of organic or inorganic origin, held in suspension within a volume of water.

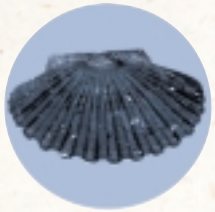
Tidal cycle: The time between successive low or high waters, typically about 12 hours 30 minutes.

Tidal range: The difference in height between low and high water.

Appendix One

Guidelines to Shellfish Aquaculture Legislation in Northern Ireland

SUBJECT		LEGISLATION	Sections
Licensing	Fish Culture Shellfish Fishery Marine Fish Fishery	Fisheries Act (Northern Ireland) 1966 (as amended) Fisheries Act (Northern Ireland) 1966 (as amended) Fisheries Act (Northern Ireland) 1966 (as amended) by Article 23 of the Fisheries (Amendment) (Northern Ireland) Order 1991	11, 11A, 11B, 11C 131 to 137 137A
Ownership of Stock		Fisheries Act (Northern Ireland) 1966	131 - 137
Water Quality Public Health	Category A, B,C and Biotoxins & Contaminants Biotoxin closure	Council Directive 91/492/EEC, The Shellfish Hygiene Directive *(Happy People)* Council Directive 91/492/EEC, The Shellfish Hygiene Directive Food Safety (Fishery Products and Live Shellfish) (Hygiene) Regulations (Northern Ireland) 1998 Food and Environmental Protection Act (1985)	
Aquaculture products		Council Directive 91/492/EEC and 91/493/EEC laying down the health conditions for the placing on the market of bivalve molluscs and fishery products respectively	
Shellfish Health	Water quality	Council Directive 79/923/EEC, The Shellfish Waters Directive *(Happy shellfish)* The Surface Waters (Shellfish)(Classification) Regulations (Northern Ireland) 1997	
Environmental	Birds (SPAs) Habitats (SACs) Northern Ireland Implementation Release of non-native Species	Wild Birds Directive (79/409/EEC) Habitats Directive (92/43/EEC) The Conservation (Natural Habitats, & c.) (Northern Ireland) Regulations 1995 The Nature Conservation and Amenity Lands (Northern Ireland) Order 1985	 The Wildlife (NI) Order 1985



SUBJECT		LEGISLATION	Sections
Fish Health Status	Fish/Shellfish Movement & Disease Control	Fish Health Regulations (Northern Ireland) 1998. Council Directive 91/67/EEC as amended	
		Fisheries Act (Northern Ireland) 1966 (as amended) Import permits	13 and 14
		Molluscan Shellfish (Control of Deposit) Order (Northern Ireland) 1972	
		Risk of infection (Oysters) Order (Northern Ireland) 1973	Dis-applied in EU
		Prohibition of Introduction of Fish Order (Northern Ireland) 1979	
	Destruction and removal of diseased fish	Diseases of Fish (Control) Regulations (Northern Ireland) 1996	
Mussels	Seed	Mussels (Prohibition of Fishing) Regulations (Northern Ireland) 1999	
Razor Shells	Dundrum Bay	Razor Shells (Prohibition of Fishing) Regulations (Northern Ireland) 1998	
	Minimum size	Council Regulation (EC) No 850/98 as amended	
Scallops	Minimum size	Council Regulation (EC) No 850/98 as amended Conservation of Scallops Regulations (NI) 1997 No 89	
Strangford	Suction-dredging	The Inshore Fishing (Prohibition of Fishing and Fishing Methods) Regulations (Northern Ireland) 1993	
Research trials Anthropogenic inputs		Fisheries Act (Northern Ireland) 1966 Urban Waste Waters Directive	14
Water status		Water Framework Directive	

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