STRANGFORD LOUGH ECOLOGICAL CHANGE INVESTIGATION (SLECI)

Work Package 8.
Aquaculture Activity in Strangford Lough

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Contents

1 Introduction

The establishment of kelp grids for seaweed cultivation in the 18th Century marks the first aquaculture activity in Strangford Lough. Seaweed cultivation and harvesting for soda production probably continued for over 100 years until its demise in the 1830s when it became uneconomic (McErlean 2002). This period probably represents the greatest impact on the intertidal areas of the Lough in recorded history. Experimental studies into the growth of the oysters *Crassostrea gigas* and *Ostrea edulis* by Parsons (1974) and Briggs (1978) demonstrated the suitability of Strangford Lough for oyster culture and stimulated its development in the Lough. Consequently, aquaculture in the Lough, which started in the 1970s with a few producers, focused initially on oysters (Figure 1). For example, Cuan Oysters, which was established in 1974, played an important role in the development of aquaculture in the UK by pioneering culture methods for very small hatchery-reared oyster seed. Cuan Oysters is currently the major producer of oysters in Strangford Lough, and one of the main producers in the UK, handling over 400 tonnes of oysters per annum (http://www.cuanoysters.com/seafood/index.html). Aquaculture in Strangford Lough continues to focus entirely on bivalves but now includes mussels and scallops as well as Pacific and native oysters. This section reviews the development of aquaculture since the 1970s in the context of recent ecological changes and the Shellfish Aquaculture Management Plan for Northern Ireland (Moore & Service, 2001).

Figure 1. Intertidal bottom cage culture of Pacific oysters (*Crassostrea gigas*) off Whiterock, in the late 1970s

2 Development of aquaculture in Strangford Lough

Over the past three decades there have been major advances in the development of the aquaculture industry and there are currently 22 licensed aquaculture sites in Strangford Lough with one under application (Figure 2, Table 1). Over half of these have only been licensed since 1998; many of these sites are inactive but well within the permitted time scale for development (Griffiths pers. comm.). The sites are licensed for a variety of species and methods including: mussels (suspended cultivation); native oysters (bottom cultivation); Pacific oysters (trestles and mats) and scallops (bottom and suspended cultivation). There are also licenses for culture plots for Manila clams but there is currently no active cultivation of this species. There are approximately 385 hectares under licence within the lough. It is important to note that although the number of licensed aquaculture sites has increased significantly over recent years, the number of active sites has not (Parsons pers. comm.). Fisheries Division use the term ‘active’ in relation to sites producing shellfish commercially; 6 sites are presently ‘commercially active’. The term ‘biologically active’ has been introduced to highlight sites where shellfish are growing as this may have an impact at the ecosystem level. At present there are 12 ‘biologically active’ sites in Strangford Lough (Table 1).

Since 1994, Queen’s Centre for Marine Resources and Mariculture (C-Mar) have conducted a variety of projects designed to assist and evaluate potential opportunities for the development of aquaculture in coastal areas (Heath, 1995, 1999; Heath & Hatcher 1995). Nineteen Section 14 licenses have been granted in Strangford Lough which has targeted a number of the species now cultivated commercially.

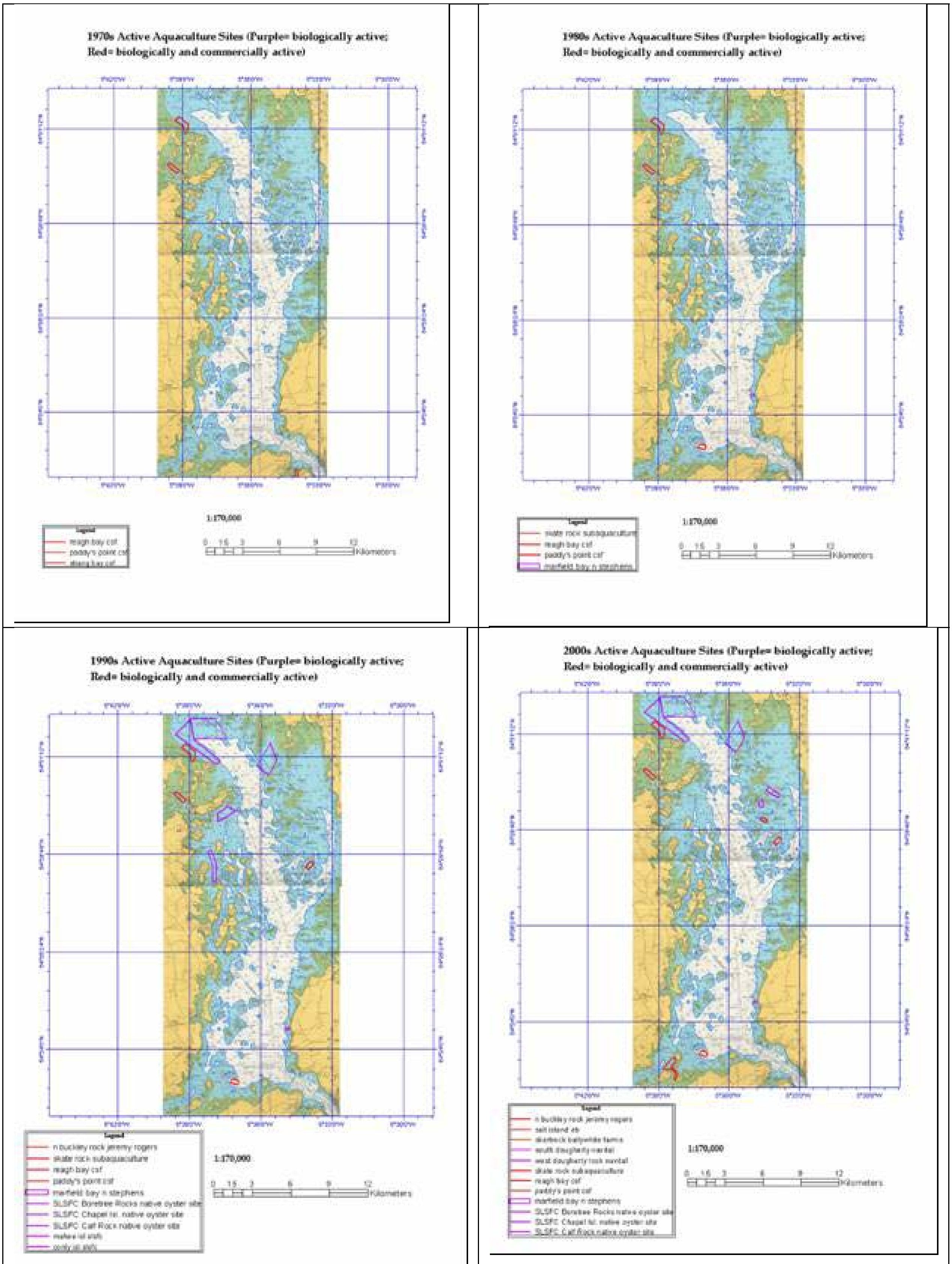

Figure 2. Development of licensed aquaculture sites in Strangford Lough 1970 – present (see Appendix 1)

Table 1. Aquaculture sites in Strangford Lough.

Site name	Licence holder	Date site active	Commercially active	Biologically active Comments
Strangford Bay	csf	1970s	Not active	Biologically active in 1970s
Reagh Bay	csf	1970s	active	Biologically active (Pacific & native oysters)
Paddy's Point	csf	1970s	active	Biologically active (Pacific & native oysters)
Marfield Bay	Subaqua	1980s (sec 14) 2003 Licensed	Not active	Biologically active since 1980s (mussels & scallops)
Skate rock	Subaqua	1986 (sec 14) 1995 Licensed	active	Biologically active (mussels & scallops)
W. Sheelah Is	NWS	2002	Not active	Not active
W. Dougherty Rock	Navital	2002	Not active	Biologically active, seed on ropes (suspended mussels)
S. Dougherty	Navital	2002	Not active	Biologically active (suspended mussels)
Skartrock	Ballywhite farms	2001	active	Biologically active (suspended mussels)
Salt Is.	EB	2002	active	Biologically active (native oysters)
N. Buckey Rock	JR to navital	1998 (sec 14) 2002 Licensed	active	Biologically active (suspended mussels)
S. Buckey Rock	JR	1998 (sec 14) Old Cmar site	Not active	Not biologically active. Rope on site.
Mahee Is	slsfc	ongoing	Not active	Not biologically active
Conly Is	slsfc	ongoing	Not active	Not biologically active
Chapel Is	slsfc	ongoing	Not active	Biologically active (native oysters)
Calf Rock	slsfc	ongoing	Not active	Biologically active (native oysters)
Boretree Rocks	slsfc	ongoing	Not active	Biologically active (native oysters)
E Sheelahs Is.	nws	2002	Not active	Not biologically active
Dunsy Is.	Strangford mussels	2001	Not active	Not biologically active (suspended mussels)
Bullock pladdies	Ballywhite farms	2001	Not active	Not biologically active (suspended mussels)
Bird Is. Passage	AY	2003	Not active	Not biologically active (suspended mussels)
E. of Gabbock Is.	Cully	2003	Not active	Not biologically active (suspended mussels)

3 Legislation and management

The Fisheries Act (Northern Ireland) 1966 is the means by which fish farms, including shellfish farms, are licensed in Northern Ireland (Appendix 1). Shellfish producers must have a Fish Culture Licence and although optional, there are many benefits to holding a Shellfish Fishery licence too. 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) (Moore and Service 2001). Applications to set up fish or shellfish farms go through a full public consultation process; notice of the application is placed in at least two newspapers and a list of interested parties, including Environment and Heritage Service (EHS), is consulted.

In relation to public health, the most important 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. Because the Lough is the site of shellfish farming operations six areas have been classified under the Shellfish Hygiene Directive (91/492/EEC); three as class A and three as class B. The Pacific oyster (*Crassostrea gigas*) farming activity in Ardmillan Bay is so situated as to take advantage of the class A waters in this area. This designation, which is rare in England and Wales, means that shellfish grown in such waters may be sold direct to the public without depuration.

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). In addition to this there must be no Diarrhetic Shellfish Poisoning present in the flesh and the levels of Paralytic Shellfish Poisoning toxin must not exceed 80 micrograms per 100 grams of flesh (WP9). Separate legislation deals with the levels of Amnesic Shellfish Poisoning (WP9). 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.

Out of 232 sites designated under the Shellfish Waters Directive (79/923/EEC) in the UK, only 9 sites are currently designated in Northern Ireland; 3 of these are in Strangford Lough (Ardmillan Bay, Marfield Bay and Skate Rock).

4 Species cultivated

4.1 Oysters

Oysters are bivalve 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 (Figure 2). 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).

Like other bivalves, 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.

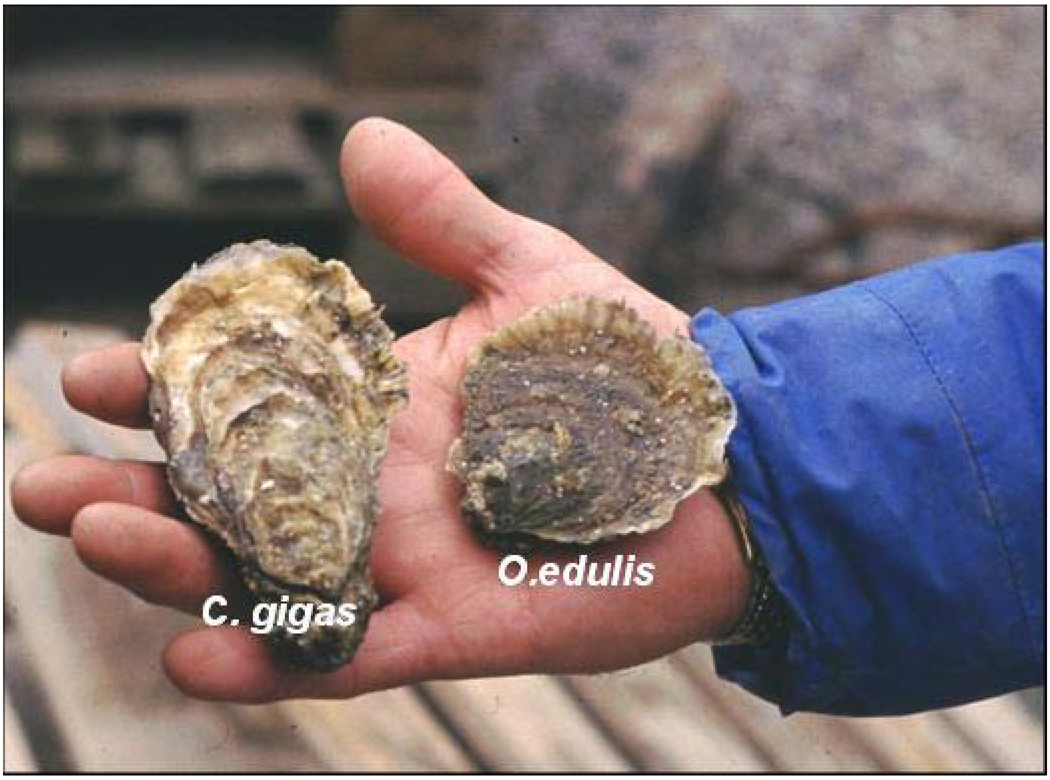

Figure 3. Oyster species cultivated in Strangford Lough - *Crassostrea gigas* and *Ostrea edulis*.

*4.1.1 Native oysters (*Ostrea edulis*)*

The European flat oyster is the only indigenous species of true oyster found around the British Isles (Yonge, 1966). *Ostrea edulis* exhibits a wide geographical distribution, ranging along the north-east Atlantic shoreline from Scandinavia to the northeast coast of Africa and throughout the Mediterranean as far as the Black Sea (Alvarez and Zapata, 1989).

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).

Ostrea edulis is dioecious and has been defined as an alternate, continuous hermaphrodite (Korringa, 1952). 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 annually 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, Yonge 1966). 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 1964). 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). When the larvae are fully developed they settle on to the surface of suitable material (cultch); this is often another oyster shell but may be many other substances. Flat oysters are reported to exceed 12 years of age and to reach sizes of 15 x 15.4 cm. Flat oysters exhibit slower growth rates than *Crassostrea* and reach market size within 5 – 6 years

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 the 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. Dilution of sperm results in incomplete fertilisation of females and wastage of reproductive effort (Galtsoff *et al*., 1930).

In addition to overfishing, oyster stocks are threatened by disease, particularly the flat oyster disease (Bonamiasis) caused by infection with the protozoan parasite *Bonamia ostreae* (Pichot *et al*., 1979, cited in Spencer, 1990). 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).

In Strangford Lough, the traditional native oyster fishery collapsed around 1903, possibly as a result of overfishing. The decline of natural oyster beds, such as those in Strangford Lough and elsewhere in Europe, 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.

4.1.2 Cultivation of Ostrea edulis *in Strangford Lough*

Native oysters processed through Cuan Oysters include those produced both locally and elsewhere [largely from Lough Foyle] (Table 2).

Table 2. *Ostrea edulis* processed in Strangford Lough (data from Fisheries Division). [Commercial in confidence]

Year	**Production (kg)**	**Value (£)**
1999	76,900	291,947
2000	56,550	214,890
2001	19,890	87,577
2002	25,035	102,800

The start of attempts to re-establish *Ostrea edulis* in Strangford Lough dates back to observation of oyster spat at various sites in the north of the Lough in the early 1990s; the spat were most probably derived from spawning commercial stocks of native oysters held in high densities on mats in the low intertidal (Figure 4). These observations resulted in trials, led by Strangford Lough Shellfishermen's Cooperative, to initiate extensive culture and a sustainable fishery for native oysters in the Lough. Shell cultch, native oyster seed and broodstock were placed on three licensed sites during 1998 under section 14 permits. The sites are situated in the northern region of the Lough (Figure 1d), an area known historically for oysters. In parallel with commercial trials, Kennedy (1999) investigated oyster distribution, larval production and spatfall. Kennedy (1999) noted significant larval flux from the part of the Lough with commercial oyster beds, supporting the idea that most spatfall could be attributed to this source. Sites surveyed by Kennedy in 1998 were re-surveyed by Smyth in 2003 and 2004 and point to significant oyster settlement over the last four to five years and widespread, unregulated harvesting which has resulted in the first significant harvest of native oysters from Strangford Lough for over 100 years (Appendix 3).

The Strangford Lough Shellfishermen's Co-op Ltd continues to work collaboratively with C-Mar on the restoration of native oysters in Strangford Lough.

Figure 4. Mats stocked with native oysters in Strangford Lough. Inset – detail.

*4.1. 3 Pacific oysters (*Crassostrea gigas*)*

Crassostrea gigas 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. *C. gigas* is perhaps the hardiest of all commercial oyster species having adapted to waters in many parts of the world and suffering much less than other species from predation and disease. The natural range of Pacific oysters includes Japan, parts of China and the Korean Peninsula.

The sexes are separate, but as the oyster ages it may change sex with females being more numerous when conditions are favourable. In contrast to *Ostrea edulis*, *Crassostrea gigas* has no brooding phase. 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^{o}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.

4.1.4 Cultivation of Crassosrea gigas

Crassostrea gigas was brought to Britain by MAFF in 1965. The species was trialled in Strangford Lough by DANI in 1970 (see Section 8.1 above) and in various sites in the Republic by BIM in 1973. Since then production has expanded steadily (Spencer 1990). All Pacific oysters grown in Ireland come from hatchery produced seed, they respond well to basic husbandry (Heath, pers.com.). *Crassostrea gigas* is both faster growing (reaches market size in 3 – 4 years), shows greater tolerance to disease and is tolerant of a wider range of conditions than the native or flat oyster (*Ostrea edulis*).

Crassostrea gigas seed can be purchased at a variety of sizes, small (G7) seed may be placed in nursery trays until it reaches a suitable size to be placed in bags (pouches) on trestles for on-growing. Seed taken at a larger size may be placed directly into the bags but as seed size increases so does the price. Legislation exists to control sources and destinations of seed, refer to section under Fish Health status in the legislation table (Appendix 1).

Pacific oysters are commonly grown in the intertidal zone in bags (poches), 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 5). Each trestle will hold 5 - 6 oyster bags, which are held on by rubber bands and / or hooks. When cultured off the bottom, oysters are protected from predators and tend to grow faster. Oysters grown in bags that are regularly turned are more evenly shaped and less bent and twisted than traditional bottom culture. If submerged for their full life-span oysters tend to have more fragile shells than those which have been 'hardened' by exposure to the air at major tides.

4.15. Cultivation of Crassostrea gigas *in Strangford Lough*

In 1977 there were 3 active commercial growers in Strangford Lough (Figure 1a) and currently there are 2 sites growing Pacific oysters (Figure 1d).

Figure 5. Pacific oyster, *Crassostrea gigas* grown on trestles.

Production data are only available for 1999-2002 and are fairly consistent over this period (Table 3).

Table 3. Figures for *Crassostrea gigas* grown or processed in Strangford Lough (data from Fisheries Division). [Commercial in confidence]

Year	Production (kg)	Value (£)
1999	291,000	589,664
2000	292,300	591,928
2001	284,500	612,546
2002	272,500	601,596

*4.2 The Great Scallop (***Pecten maximus***)*

For details of biology see commercial fishing section (WP3). Spawning cycles show interannual variability in Strangford Lough with either protracted or bimodal patterns of spawning between July and August (McDonough 1998).

4.2.1 Cultivation of Pecten maximus

Scallops are grown either on the seabed or by suspended cultivation. In bottom cultivation, the scallops are introduced onto the site at 45-55 mm 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 then it is attached directly to a vertical line suspended from a raft or long 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).

4.2.2. Cultivation of Pecten maximus *in Strangford Lough*

Sub-aqua cultivation of *P. maximus*, using scallop seed imported from Mulroy Bay, has been conducted on a small scale at two sites in Strangford Lough since the 1980s (Table 1); no production figures are available.

Investigations by C-Mar (Heath 1995) and McDonough (1998) into the potential for collection of local scallop spat for growout in the Lough revealed that settlement of *Pecten maximus* spat, which peaked in July (maximum densities = 14 per spat collector bag) was not commercially viable (minimum recommended 100 per spat collector bag [Wieland & Paul, 1983]) although higher densities of *Aequipecten opercularis* spat (maximum densities = 190 per spat collector bag) were obtained at this time.

In intermediate growth trials, growth rates were higher in the northern part of the Lough (McDonough 1998). Comparative studies of different cultivation equipment found that growth in lantern nets was commercially viable but survival was poor whereas the opposite was true for North-West Plastic trays. McDonough (1998) concluded that excessive fouling of both scallops and gear, poor survival and insufficient indigenous seed would limit the development of suspended cultivation of *P. maximus* in Strangford Lough.

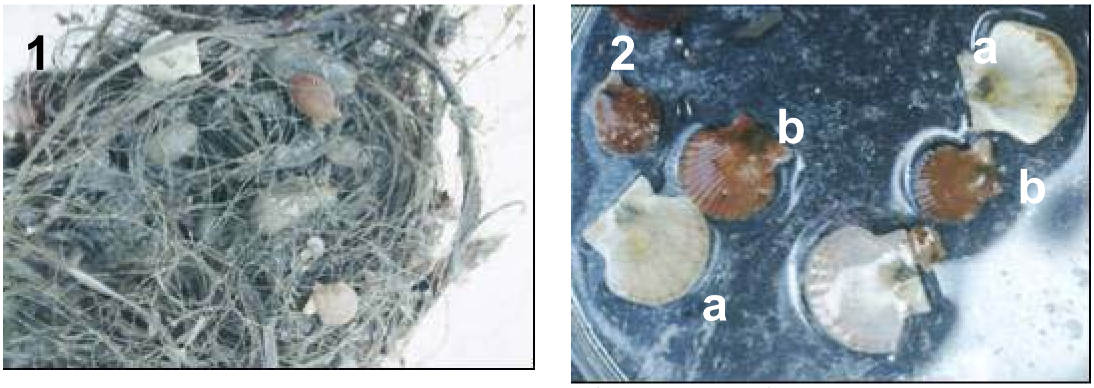

Figure 6. Recently settled scallops 1) on monofilament spat collectors deployed in Strangford Lough. 2) after removal from collectors: a) *Pecten maximus*, b) *Aequipecten opercularis*.

More recently, 30,000 seed (56mm), also from Mulroy Bay, were relaid in an area of approximately 5,000m^2 in Scotts Hole as part of a scallop re-seeding exercise around the coast of Northern Ireland undertaken by Northern Ireland Scallop Fishermen's Coop (NISFCo) in collaboration with North West Shellfish and C-Mar. A main aim of the exercise was to increase spawning stock biomass in the relaid sites. In this trial, scallops recessed quickly in Strangford Lough after relaying and showed good growth and survival (>70% after 5 months) (Heath, 1999).

4.3 Blue mussel (Mytilus edulis)

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). Mussels are filter feeders and can be found in both intertidal and sublittoral habitats.

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 from 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, (see Bannister (1998) for more detail). 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-dependent 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).

Throughout their entire lifecycle, mussels are susceptible to predatory pressure from starfish, crabs and birds.

4.3.1 Cultivation of Mytilus edulis*.*

Suspended mussel culture systems involve the collection and wrapping of seed mussels on ropes or similar material, which are hung from rafts or floats. 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, and is unlikely to occur in Strangford Lough (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.com.*).

4.3.2 Cultivation of Mytilus edulis *in Strangford Lough*

There are 2 commercially active sites that have been growing *Mytilus edulis* in Strangford Lough since the 1980s (Table 1); the method of cultivation involves sub-surface suspended culture. In addition, surface suspended culture systems including, since 2003, the Smart-Farm System (Figure 7) were introduced between 1998 and 2003 (Table 1). However, only 4 out of 9 are biologically active; none are in commercial production. No production figures are available.

Figure 7. Smart farm system (Strangford Lough, December 2003) for ongrowing blue mussel (*Mytilus edulis*).

4 Discussion

The impacts of aquaculture on the ecosystem have been reviewed my Moore & Service (2001). Major impacts depend on the stage of cultivation and the methods used. Stages in aquaculture production include: seed collection, intermediate culture, growout and harvesting. Different stages may have impacts on the benthos, the genetic integrity of local populations, ecosystem processes including the water column and may cause visual impacts. In Strangford Lough all commercial aquaculture involves the production of bivalves including *Crassostrea gigas*, *Ostrea edulis*, *Pecten maximus* and *Mytilus edulis*, although trials for the commercial production of dulse (*Palmaria palmata*) have been going on for over 5 years. In general, apart from the production and processing of oysters and the sub-surface culture of scallops and mussels, most aquaculture in the Lough has developed recently (Table 1) and appears to have low production levels, though data are lacking or incomplete for most species. Culture of *Crassostrea gigas*, *Ostrea edulis*, *Pecten maximus* involves import of seed produced elsewhere and is subject to import Fish/Shellfish Movement controls (Appendix 2). Mussel aquaculture in Strangford Lough involves suspended cultivation based on spat collected on spat collectors deployed in the Lough which does not involve dredging or seed importation.

Cultivation of bivalves is dependent on clean water and primary production, the major biological limitation which determines carrying capacity (see Moore & Service, 2001 and references cited therein). The scope for expansion in Strangford Lough should focus on oysters, and in particular *Ostrea edulis* as this species is listed in the UK biodiversity action plan (Gardner & Elliott 2001), since suspended cultivation of *Mytilus edulis* is limited by site availability (Moore & Service 2001). Bottom cultivation of scallops also has potential and should be the subject of further review.

Key recommendations of the Shellfish Management Plan for Northern Ireland (Moore & Service 2001) include relevant management approaches (SR1-SR6), development strategies (SR7, SR8) proposals to develop carrying capacity models for shellfish producing areas (SR9) and the need for cooperation of stakeholders (SR10). DARD is about to undertake research to develop carrying capacity models for the major loughs in Northern Ireland, including Strangford Lough. In addition, it is increasingly and more widely recognised that the development of sustainable aquaculture 'requires the involvement and cooperation of government, academia, the private sector, investors, communities and the public at large' (Devoe & Hodges, 2002).

5 Conclusions

A major issue raised by the present review is the very limited or lack of data on the production of key species by aquaculture in Strangford Lough. In addition, it is difficult to separate quantities of oysters produced in the Lough from those processed through the Lough. Such information will be essential for the development of carrying capacity models for Strangford Lough which is in the interests of both commercial producers and the regulatory authorities. Strangford Lough has the potential, through aquaculture, to make a valuable contribution to the economy of Northern Ireland and there is need to develop a strategy, based on the Shellfish Aquaculture Management Plan (Moore & Service 2001) for the development of sustainable aquaculture in the Lough.

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7 Appendix 1. Development of licensed aquaculture sites in Strangford Lough 1970 – present: Full-scale maps

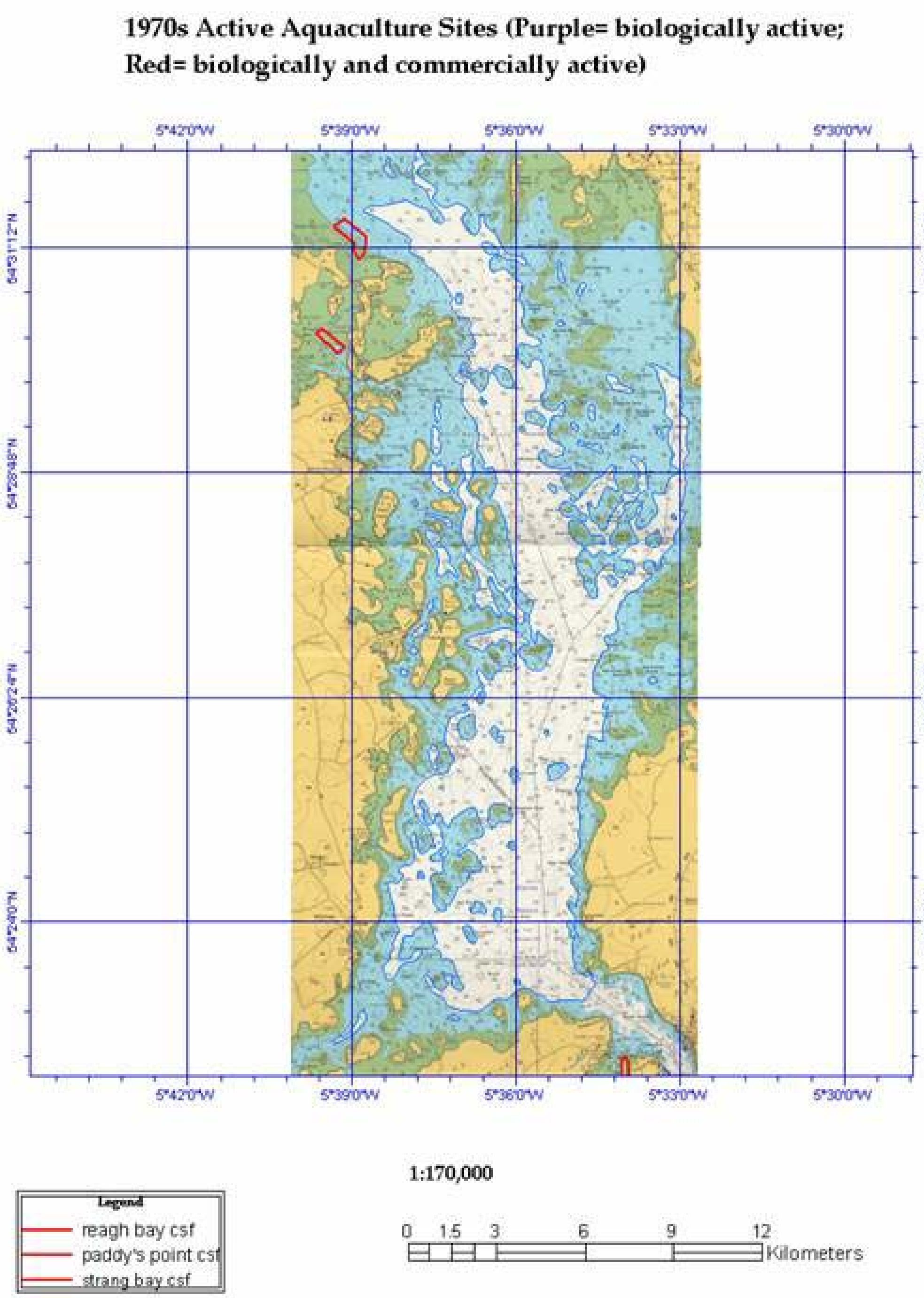

Figure 1a. Map showing active aquaculture sites in Strangford Lough in the 1970's.

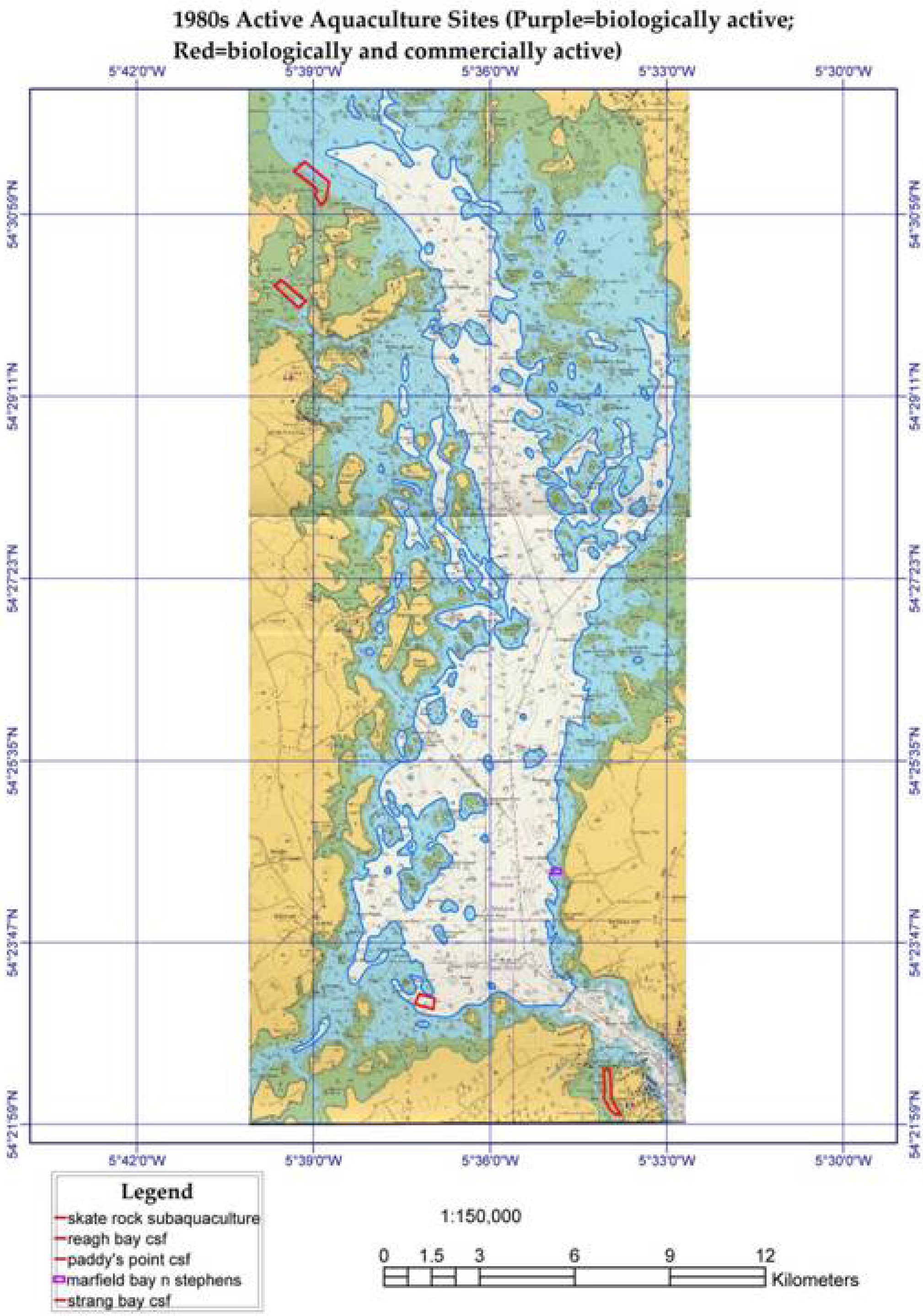

Figure 1b. Map showing active aquaculture sites in Strangford Lough in the 1980's.

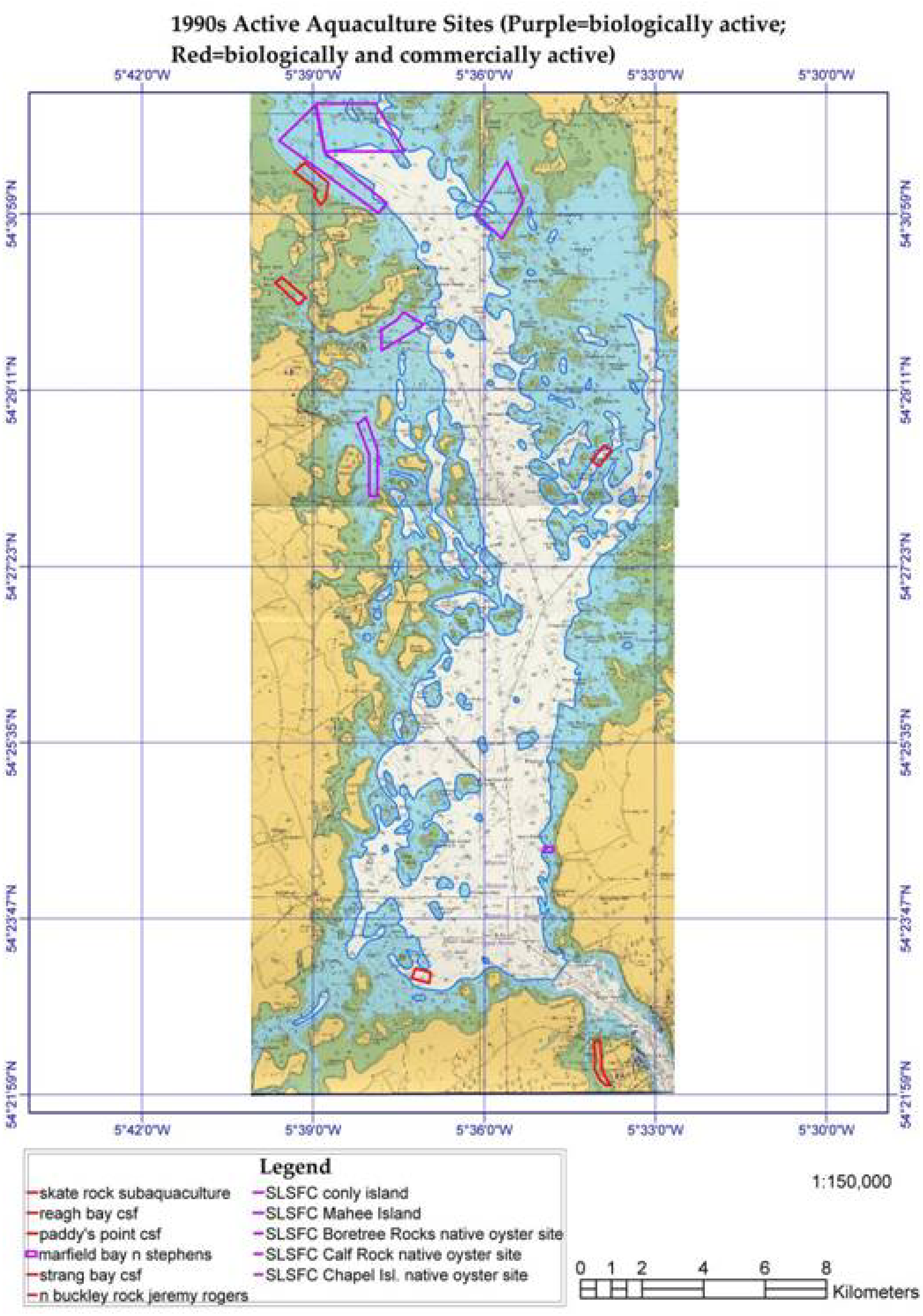

Figure 1c. Map showing active aquaculture sites in Strangford Lough in the 1990's.

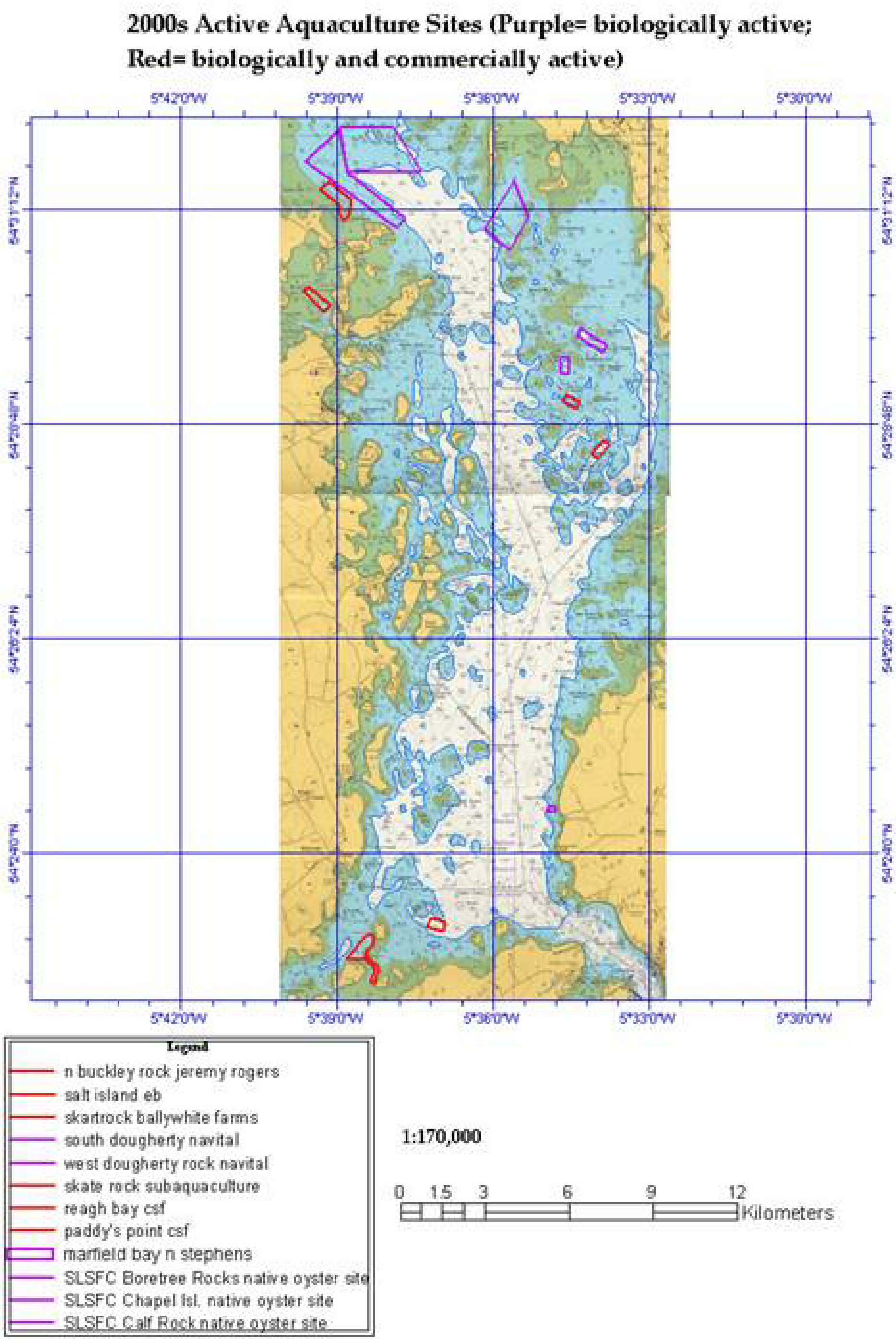

Figure 1d. Map showing active aquaculture sites in Strangford Lough in the 2000's.

8 Appendix 2. Guidelines to shellfish aquaculture legislation in Northern Ireland.

[Table of legislation from the Shellfish Aquaculture Management Plan for Northern Ireland (Moore & Service, 200)].

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,11 B,11C 131 to 137 137A
Ownership of Stock		Fisheries Act (Northern Ireland) 1966	131 to 137
Water Quality Public Health	Category A,B,C and Biotoxins & Contaminants Biotoxin closure	Council Directive 91/492/EEC, The Shellfish Hygiene Directive 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 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 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 Destruction and removal of diseased fish	Fish Health Regulations (Northern Ireland) 1998 Council Directive 91/67/EEC Fisheries Act (Northern Ireland) 1966 (as amended) Import permits Molluscan Shellfish (Control of Deposits) Order (Northern Ireland) 1972 Risk of infection (Oysters) Order (Northern Ireland) 1973 Prohibition of Introduction of Fish Order (Northern Ireland) 1979 Diseases of Fish (Control) Regulations (Northern Ireland) 1996	 13 and 14 Dis-applied in EU
Mussels	Seed	Mussels (Prohibition of Fishing) Regulations (Northern Ireland) 1999	
Razor Shells	Dundrum Bay Minimum size	Razor Shells (Prohibition of Fishing) Regulations (Northern Ireland) 1998 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	

*9 Appendix 3. Recent changes in intertidal populations of native oysters (*Ostrea edulis*) in Strangford Lough*

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1 Introduction

Growth trials undertaken during the 1970's produced favourable results for both *Crassostrea gigas* and *Ostrea edulis*. This formed the basis of today's very successful oyster-culture operations in Strangford Lough.

The UK Biodiversity Action Plan- lists *Ostrea edulis* as a species that should be maintained and expanded (Gardner & Elliott, 2001).

In 1998 an EU funded development project to re-establish a sustainable native oyster fishery in the Lough was started by fishermen (SLSF Co-op). As a result, 75 tonnes of cultch was laid to provide a suitable setting substrate for oyster larvae in licensed areas and these were seeded with brood-stock oysters and an estimated 250,000 oyster spat between 1998 and 1999.

Survey work started in 2002 into the current status of the *Ostrea edulis* population of Strangford Lough; this involved of a census of oysters at intertidal lough-shore and island sites, sub-tidal sites, spat collection and plankton sampling over a tidal cycle.

Results from the surveys of intertidal and island sites are presented here.

2 Results

The total number of intertidal *O. edulis* for 2002-2004 in the northern, mid-eastern and western divisions of the Lough were estimated for direct comparison with estimates by Kennedy & Roberts for 1998 using a population formula adapted from Gunderson[1] (1993). Proportionally weighted correction factors were applied to the regional divisions of the Lough to account for the amount of suitable oyster substratum present.

During the recent surveys, live oysters were found at 19 out of 40 intertidal sites (Table 1). The major features of the comparative surveys are: the high numbers of oysters found in the north sector in all surveys, the increase by two orders of magnitude in oyster numbers between 1998 and 2002 to a peak of over 1 million oysters in 2003 and a marked decline thereafter (Table 2). The decline in numbers is also evident in intertidal lough-shore and island sites (Figure 1).

$$P=\sum_{I=1}^{h}\left(\frac{R_i\,.F}{a}\right)\bar{C}_i$$

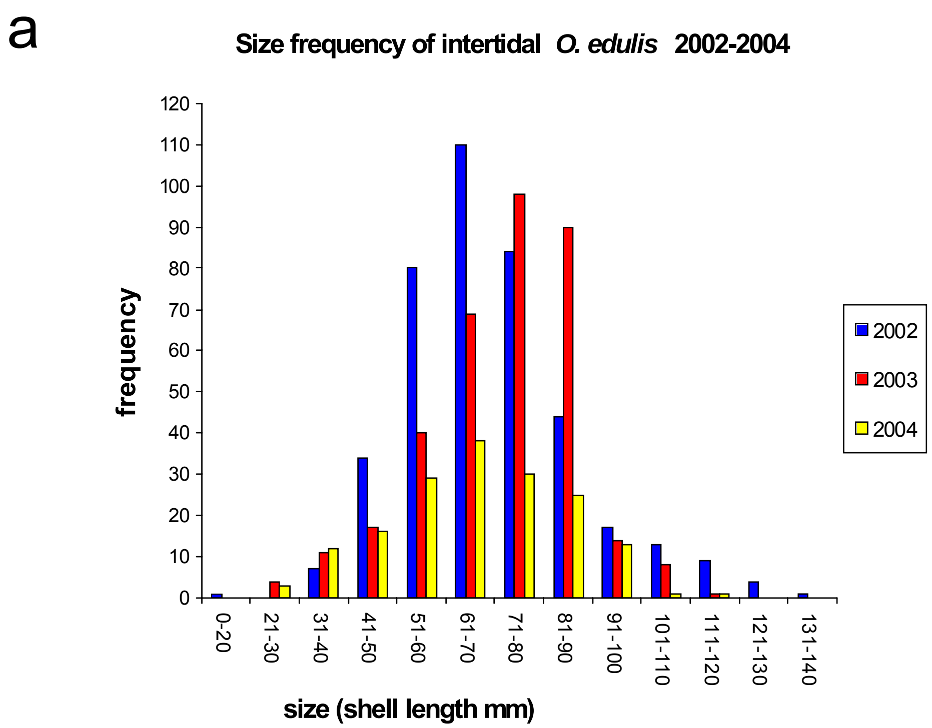
Where; P= Total population resident in full survey area.
Ri= Area of region I in m2 .
a= Area sampled within a single sampling unit.
F= Correction factor estimating substrate types.
$\bar{C}_i$= Mean number of oysters observed per sampling unit in the region based i on n samples.
h= Number of regions composing the survey.

Table 1 List of sites surveyed for *Ostrea edulis* by R Kennedy (RK) and present survey (DS) *Oysters present

Sites	**RK 1998-1999**	**DS 2002-2004**
Intertidal	Newtownards sailing club*	Newtownards sailing club*
	Cunningburn Milltown*	Cunningburn Milltown*
	Chapel Point*	Chapel Point*
	West Rock	West Rock
	Comber Estuary	Comber Estuary
	Paddies Point*	Paddies Point*
	Reagh Bay*	Reagh Bay
	Mahee Point*	Mahee Point
	Sketrick Shore*	Sketrick Shore
	Ringhaddy	Ringhaddy
		Ballyreagh*
		Greyabbey*
		Herring Bay*
		Kircubbin*
		Mount Stewart*
		Nicky's Point*
		Horse Island*
		Ballyhenry*
		Marlfield
		DS 2002-2004
		Granagh Bay
		Barr Hall
		Island Hill
		Castle Espie
		White Rock
		Simmy Island
		Killyleagh
		Castle Island
		Castleward Bay
		Chapel Island N*
		Chapel Island S*
Sites		DS 2002-2004
Intertidal Island sites		Sheelahs Island*
		Bird Island*
		Sand Rock*
		North Buckey Rock*
		Womens Rock
		Whitebank Pladdy
		Dougherty Rock*
		Boretree Rock

Table 2. Population estimates for intertidal oyster in different parts of Strangford Lough before (1998) and after (2002-2004) restoration.

	Kennedy & Roberts (1999)	Present surveys			
	1998	10-12/2002	8-11/2003	01/2004	02/2004
North	101,818	1,017,489	1,242,116	964,622	749,894
West	8,157	2,810	1,240	550	No data (550)
East	0	652	238	143	No data (143)
Total ($x10^3$)	11	1021	1244	965	751



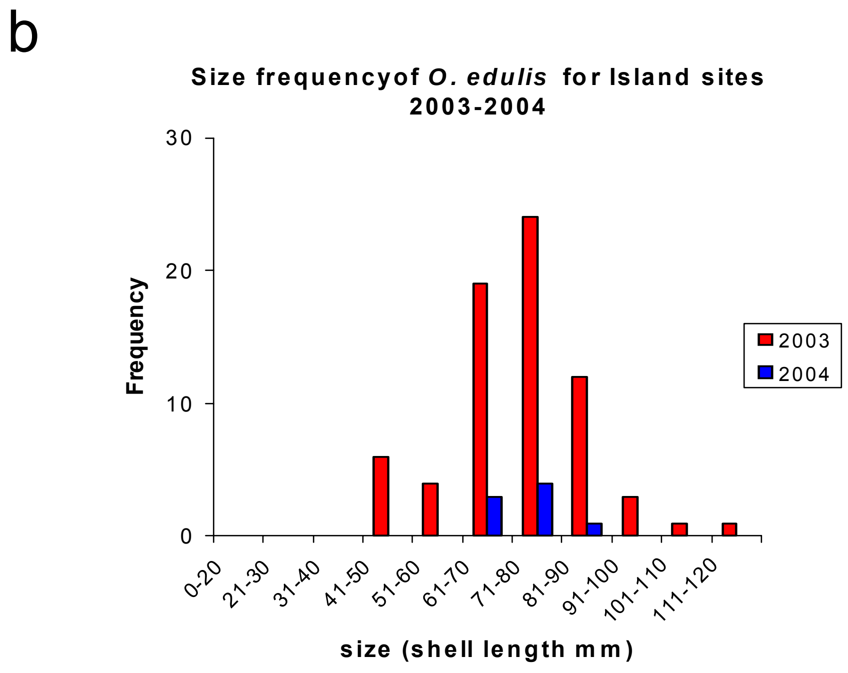


Figure1. Size frequency distributions of oyster population samples from a) intertidal lough-shore and b) island sites in Strangford Lough between 2002 and 2004

3 Discussion

The densities and range of the native oysters in Strangford Lough clearly increased between 1998 and 2003. This increase in oyster standing stocks in Strangford Lough can probably be attributed to a combination of oversummering of commercial oysters and the restoration programme and is unlikely to be due to recruitment from wild stock as no dense wild stocks are known. The decline in stocks since 2003 can be attributed to unregulated harvesting over the period of study. During the survey period, teams of between 10-20 shellfish gatherers were regularly encountered working the shore at both lough-shore and island sites. *Ostrea edulis* is now absent from many of these sites where it was previously abundant. Natural mortality and predation can be disregarded as cause of population decrease as no paired oyster valves, which would remain after natural mortality, were found at these sites. Intertidal harvesting has resulted in an estimated decrease of over 490,000 oysters since the end of 2003. Based on an estimated average weight of an oyster of 88g, this equates to 43.4 tonnes of harvested *O. edulis*.

Further consequences of unregulated harvesting includes a decrease in the spawning-stock biomass and therefore potential decreases in larval swarms and recruitment, disturbance of intertidal habitats within a candidate SAC, decrease in the oyster shell as a habitat (Korringa 1945 listed 68 sp. on *O. edulis*; Mistakidis 1951 listed 121 sp. on Essex oyster grounds) and a decrease in suitable cultch for larval settlement.

4 Summary and Conclusions

The Restoration Project resulted in the first significant harvests of *O. edulis* from Strangford Lough for over 100 years. Hand gathering is significant with an estimated 40% decrease in the total intertidal oyster population; many sites have been picked clean.

However the restoration of *Ostrea edulis* in Strangford Lough should be continued as the Lough has suitable regions where local circulation will promote larval retention (R Kennedy,1999).The restoration of *O. edulis* assemblages have the potential to increase biodiversity within Strangford Lough. The Lough is also fully saline providing protection against the parasite *Marteilia refrigens* and possesses large areas of good intertidal cultch coverage (*M. edulis*).

Strangford Lough possesses one of the few *Bonamia*-free *O. edulis* populations in Europe. The 1997-98 restoration project has already been successful with good settlement and growth being recorded. The UK Biodiversity Action Plan lists *Ostrea edulis* as a species that should be maintained and expanded and Strangford Lough has the potential to meet these requirements.

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